Diagnosis Faults of Electrical Transformer Using Fuzzy Logic

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Abstract - The power transformer is a crucial component in any power distribution or transmission network. The insulation system used in power transformers consists of paper and oil. As the temperature inside the transformer rises, the oil and paper begin to decompose, leading to gas changes that can weaken the dielectric strength of both materials. Dissolved Gas Analysis (DGA) is a powerful method that can identify faults such as overheating (pyrolysis), partial discharge (corona), and arcing in oil-filled equipment. This technique is highly effective for monitoring the condition of power transformers. In this paper, a fuzzy logic approach is proposed for detecting power transformer faults based on changes in gas ratios. The fuzzy logic model is designed to analyze dissolved gases in accordance with the International Electric Committee (IEC) standard, reducing the need for personal experience. The model is implemented using MATLAB/SIMULINK, and the simulation results demonstrate the reliability of the IEC standard method with fuzzy logic control.

Keywords –Power transformer, Fault detection, Dissolved gas analysis, IEC, Fuzzy logic, MATLAB/SIMULINK

I. INTRODUCTION

The electricity system commences with production, through which electrical power is generated in the power plant and then modified in the power station to high-tension electrical energy that is better suited for efficient long-range conveyance. High-Tension (HT) power cables in the transmission division of the electric power system proficiently carry electrical power over lengthy distances to the consumption sites. Converters are a fundamental component of any electrical system. When there is an overheating inside a converter, it will generate corresponding characteristic gas in the converter oil, so Dissolved Gas in oil Analysis (DGA) is the most commonly utilized method to diagnose power converter malfunctions.

Transformer is an important component of electricity transmission and distribution. For reliable electricity supply it is necessary to give considerable attention to the maintenance of transformers. To maximize the lifetime and efficiency of transformers, it is important to be aware of possible faults that may occur on the transformer. These faults can lead to the thermal degradation of the oil and paper insulation in the transformer. The composition and quantity of the gases generated depend on the types and severity of the faults, and regular monitoring and maintenance can make it possible to detect incipient flaws before damage occurs [1].

The power system network relies heavily on the transformer, which is a crucial piece of equipment. Any faults, whether they originate internally or externally, can result in significant damage to the transformer. Repairing any damage can be a challenging task, as it may involve various types of faults and require the expertise of trained personnel. Additionally, replacing the unit can be a costly endeavor. External faults can be managed through the protection scheme employed in the line. However, for internal faults, multiple techniques have been developed for protection. The selection of the appropriate protection technique depends on the type of fault, as well as the rating, size, and importance of the transformer. Internal faults in the transformer can be classified into two categories: electrical faults and mechanical faults. Early detection of faults is crucial for economic reasons, and preventive tests and diagnosis can be useful in predicting fault conditions [2].

II. ANALYSIS

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During regular operation of a transformer, gases such as Hydrogen (H2), methane (CH4), ethylene (C2H4), acetylene (C2H2), Ethane (C2H6) and others are emitted. In the event of an abnormal occurrence, such as a malfunction, specific gases are produced in larger quantities than during normal operation, causing an increase in their presence in the transformer oil. This increase in gas concentration leads to the saturation of the oil, rendering it incapable of dissolving any further gas. Consequently, the excess gas is released from the oil. The quantity of gas that can be dissolved in the oil is dependent on the temperature of the oil and the type of gas. The gases produced can be categorized into three groups: polarization, corona and arcing. These groups differ in the severity of the energy released during a malfunction, with arcing producing the largest amount of energy and corona producing the least. The types of transformer malfunctions are explained below.

A. Arcing

Arcing is the most severe of all faults processes. Large amount of hydrogen and acetylene are produced, with minor quantities of methane and ethylene. Arcing occurs in high current and high temperature conditions. Carbon dioxide and carbon monoxide may also be formed if the fault involves cellulose. In some instances, the oil may become carbonized.

B. Thermal heating

Decomposition products include ethylene and methane, together with smaller quantities of hydrogen and ethane. Traces of acetylene may be formed if the fault is severe or involves electrical contacts.

C. Corona

Corona is a low-energy electrical fault. Low-energy electrical discharges produce hydrogen and methane, with small quantities of ethane and ethylene. Comparable amounts of carbon monoxide and dioxide may result from discharge in cellulose.

D. Overheating Cellulose

Large quantities of carbon dioxide and carbon monoxide are evolved from overheated cellulose. Hydrogen-based gases, such as methane and ethylene, will be formed if the fault involved is an oil- impregnated structure [3].

- *Gases Detected*

  Usual gases produced by transformers insulated with mineral oil or cellulose (paper and pressboard) consist of Hydrogen (H2), Methane (CH4), Ethane (C2H6), Ethylene (C2H4), Acetylene (C2H2), Carbon Monoxide (CO), and Carbon Dioxide (CO2). Oxygen and nitrogen are also found in varying concentrations depending on the preservation method applied to the transformer. While propane, butane, and other gases may also be formed, they are not commonly used for diagnostic purposes. The concentrations of the different gases provide valuable information about the type and severity of the incipient-fault condition, as shown in Table 1 for fault interpretations based on dissolved gases [3].

- *International Electric Committee Standard*

For many years, the International Electric Committee IEC codes have been utilized in dissolved gas analysis to identify potential faults in transformers. Initially, the focus was on identifying specific gas components such as hydrogen and methane in the oil for the detection of discharges. Each ratio and its assigned limits codes are allocated based on the individual gases identified for each ratio, and the corresponding fault is characterized [4]. The IEC Standard 60599 is the most commonly used ratio method, which determines three ratios based on the gas ratios C2H2/ C2H4, CH4/ H2, and C2H4/ C2H6. The IEC method follows a coding rule and fault classification system. It monitors the concentration and gassing rates of key hydrocarbon gases, including H2, CH4, C2H6, C2H4, C2H2, CO, and CO2, expressed in ppm (parts per million) [1]. Considerable experience has been gained worldwide using the IEC codes in dissolved gas analysis for the diagnosis of incipient faults in transformers.

Table 1: Fault Interpretation from Dissolved Gases.

Gas	Normal ppm	Abnormal ppm	Interpretation
H_2	150	1000	Arcing corona
CH_4	25	80	Sparking
C_2H_6	10	35	Local overheating
C_2H_4	15	70	Severe overheating
C_2H_2	20	100	Arcing
CO	500	1000	Severe overloading
CO_2	10000	15000	Severe overloading
TDCG	720	2285	

The Total Dissolved Combustible Gas (TDCG) is the definition of the sum of the combustible gas concentrations as follows:

$$TDCG = H_2 + CH_4 + C_2H_6 + C_2H_4 + C_2H_2 + CO \qquad (1)$$

III. FUZZY LOGIC MODEL DESIGN

In this segment, a fuzzy logic model has been created to detect transformer faults by examining changes in gas ratios. The proposed system comprises of a single output and three input variables. The input variables of the model are $R1$ = CH4/ H2, $R2$ = C2H4/ C2H6, and $R3$ = C2H2/ C2H4, each of which is divided into three sets of membership functions (L: low, M: medium, H: high). The range of gas ratios from 0 to 4 is used with the Triangular membership function editor, as shown in Figures 1 – 3. The model's output variable is a single output that is divided into four sets of membership functions. The decision-making process is dependent on the fuzzification process, which determines the type of fault. This is shown in Table 2, which outlines asset management decisions based on the model output (F1: fault1, F2: fault2, F3: fault3, F4: fault4). The range of faults from 0 to 10 is used with the Triangular membership function, as shown in Figure 4.

Table 2: Asset Management Decision Based on Model Output

Fault	Rang	Fault diagnosis	Recommended decision
F_1	0 – 4	- No fault	- Continue normal operation
F_2	2 – 6	- Cellulosic / oil decomposition - Overheated cellulose and or oil - thermal fault 150 C-700 C	- Exercise extreme caution - Furan analysis is recommended - Check generation rate weekly - Reduce loading below 70% - Plan outage
F_3	4 – 8	-Corona in oil (Low intensity electrical discharge)	- Exercise extreme caution - Check generation rate weekly - Reduce loading below 60% - Plan outage
F_4	6 – 10	-Arcing in oil (High intensity electrical discharge)	-Exercise extreme caution -Check generation rate daily -Reduce loading below 50% -Consider removal from service

- *Membership function inputs and output*

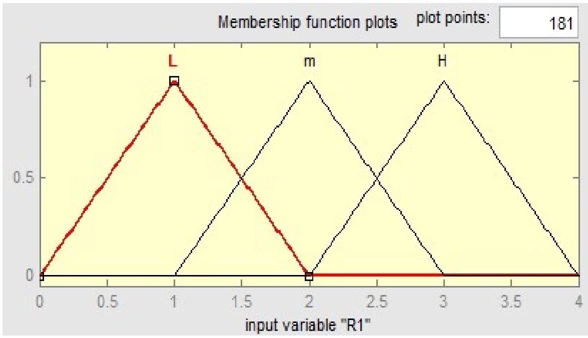

Figure 1: Input $R_1 = CH_4/H_2$

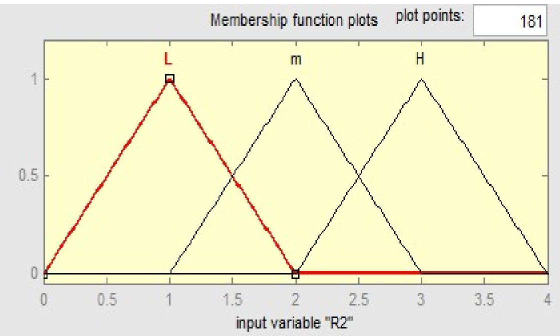

Figure 2: Input $R2 = C_2H_4/C_2H_6$

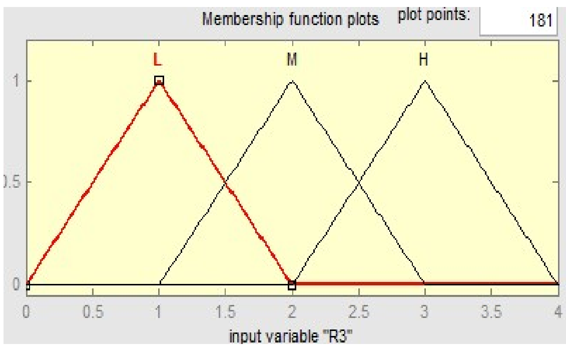

Figure 3: Input $R3 = C_2H_2/C_2H_4$

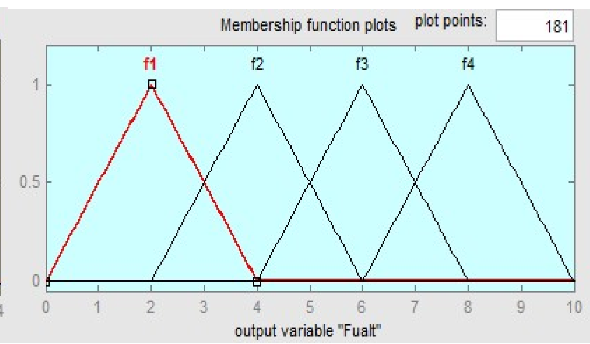

Figure 4: Output system

- *Fuzzy Rules*

The proposed system has three inputs it with 27 rules as shown in Table: 3and the rule editor shown in Figure 5.

Table 3: Fuzzy Rule System

R_1	R_2	R_3	Fault	R_1	R_2	R_3	Fault	R_1	R_2	R_3	Fault
L	L	L	F_1	M	L	L	F_2	H	L	L	F_3
L	L	M	F_1	M	L	M	F_2	H	L	M	F_3
L	L	H	F_1	M	L	H	F_2	H	L	H	F_3
L	M	L	F_1	M	M	L	F_2	H	M	L	F_4
L	M	M	F_1	M	M	M	F_2	H	M	M	F_4
L	M	H	F_1	M	M	H	F_2	H	M	H	F_4
L	H	L	F_1	M	H	L	F_2	H	H	L	F_4
L	H	M	F_1	M	H	M	F_2	H	H	M	F_4
L	H	H	F_1	M	H	H	F_2	H	H	H	F_4

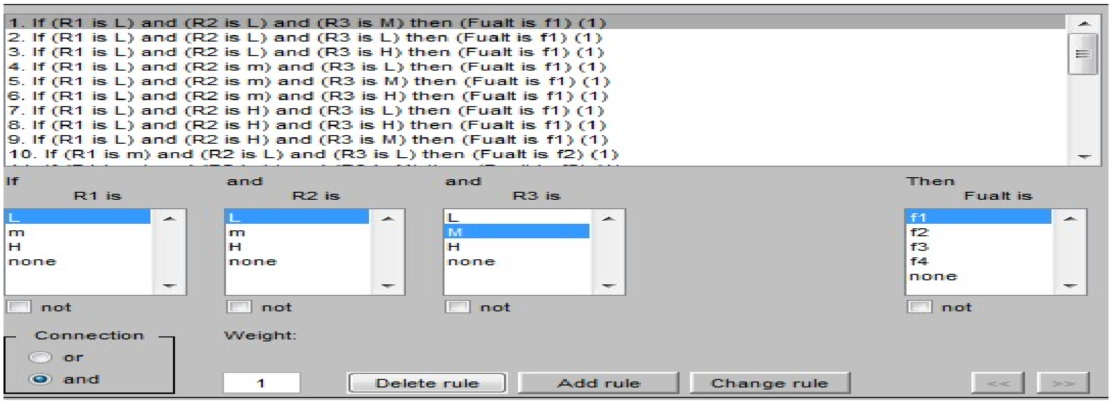

Figure 5: Rule editor

IV. SIMULATION RESULTS

This section the simulation results of a diagnostic faults of transformer by using design fuzzy logic controller with MATLAB/ SIMULINK as shown in Figure 6, the output system indicate as shown in Figure 7 and the output system fuzzy logic as shown in Figure 8.

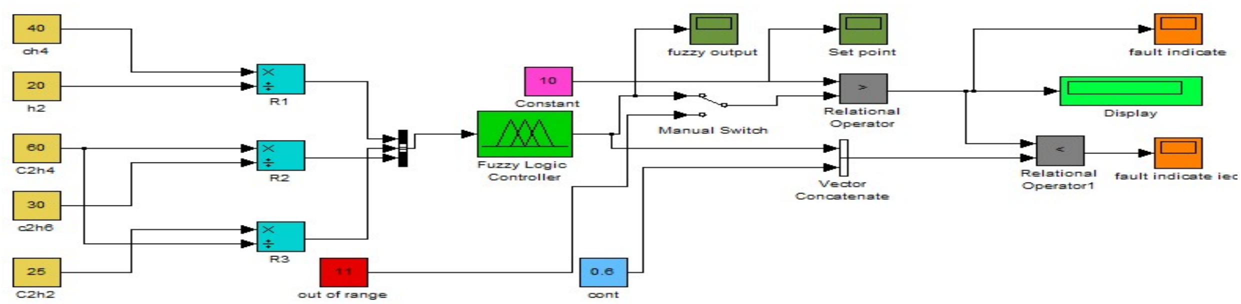

Figure 6: System simulation

V. DISCUSSION OF RESULTS

The primary objective of DGA is to identify faults at the earliest possible stage and to differentiate between various types of faults that may occur within the transformer, such as arcing, heating, and corona. The IEC diagnostic method, which is discussed in chapter three, possesses unique characteristics and benefits that aid in the detection of transformer faults. Table 3.2 displays the faults that are indicated, with F1 (0-4) indicating no faults and the system operating normally when the fault indicator is set to logic 1. When F2 (2-6) indicates cellulosic oil decomposition, overheated cellulose and/or oil, or thermal fault with a temperature range of 150C to 700C, the system is operating abnormally, and extreme caution should be exercised. Furan analysis is recommended, the generation rate should be checked weekly, loading should be reduced below 70%, and an outage should be planned. When F3 (4-8) indicates corona in oil and low-intensity electrical discharge, the system is operating abnormally, and extreme caution should be exercised. The generation rate should be checked weekly, loading should be reduced below 60%, and an outage should be planned. F4 (6-10) indicates electrical fault, arcing in oil, and high-intensity electrical discharge, and the system is operating abnormally. Extreme caution should be exercised, the generation rate should be checked daily, loading should be reduced below 50%, and removal from service should be considered. The output system range is from 0 to 10, with the set point being 10, as shown in Figure 9. If the fault indicator is set to logic 0, it means that the system is damaged or that the output is outside of the design range, as shown in Figure 10.

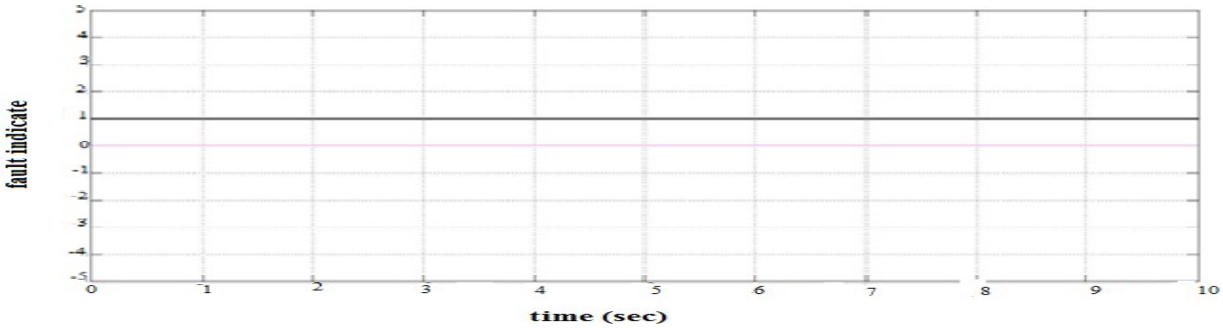

Figure 7: System output indicate

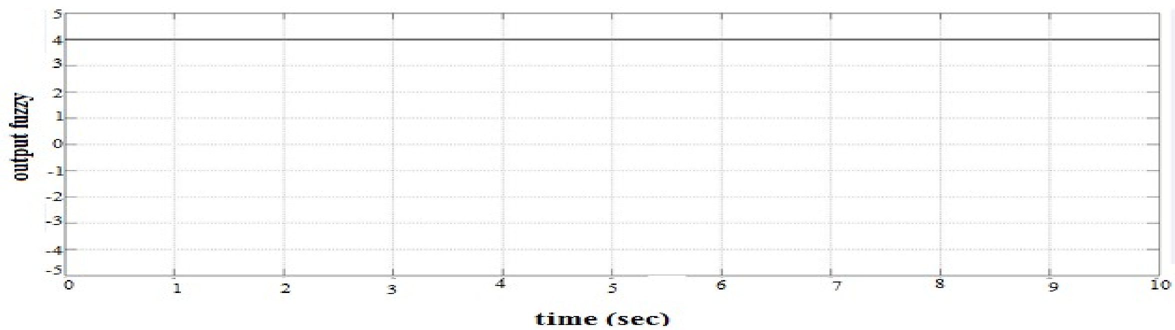

Figure 8: Output system of fuzzy logic

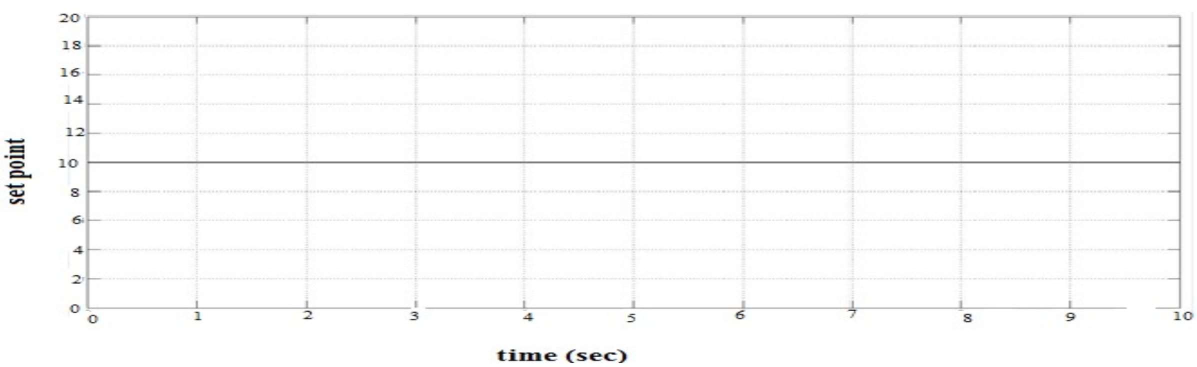

Figure 9: System output set point

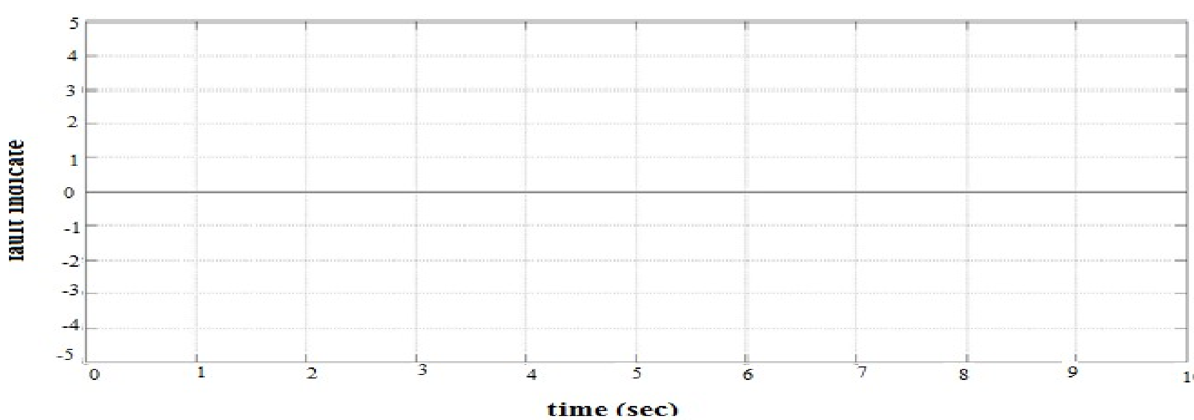

Figure 10: System damage

VI. CONCLUSION

This paper presents an examination of the dissolved gases present in transformers to detect faults, utilizing the IEC standard method which is based on three ratios. The MATLAB/Simulink software was employed to create the system, and it has successfully identified several faults in transformers. By utilizing the fuzzy diagnosis method, the system can provide more detailed information about the faults within a transformer, as well as enhanced information for maintenance engineers. The system's output fault indicator has two possible outcomes. The first outcome is when the fault indicator is F1, which indicates that the system is operating normally. The second outcome is when the fault indicator is F2, F3 or F4, indicating thermal faults, electrical faults, corona in oil, low intensity electrical discharge, arcing in oil or high intensity electrical discharge, respectively. In this case, the system is operating abnormally and requires attention. The second case is when the fault indicator is logic 0, indicating that the system is damaged.

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