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# An Implementation of Fuzzy Logic Technique for Prediction of the Power Transformer Faults

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***Abstract*****—**Power transformers are the most crucial part of power electrical system, distribution and transmission grid. This part is maintained using predictive or condition-based maintenance approach. The diagnosis of power transformer condition is performed based on Dissolved Gas Analysis (DGA). There are five main methods utilized for analyzing these gases. These methods are International Electrotechnical Commission (IEC) gas ratio, Key Gas, Roger gas ratio, Doernenburg, and Duval Triangle. Moreover, due to the importance of the transformers, there is a need for an accurate technique to diagnose and hence predict the transformer condition. The main objective of this technique is to avoid the transformer faults and hence to maintain the power electrical system, distribution and transmission grid. In this paper, the DGA was utilized based on the data collected from the transformer records available in the General Electricity Company of Libya (GECOL) which is located in Benghazi-Libya. The Fuzzy Logic (FL) technique was implemented as a diagnostic approach based on IEC gas ratio method. The FL technique gave better results and approved to be used as an accurate prediction technique for power transformer faults. Also, this technique is approved to be a quite interesting for the readers and the concern researchers in the area of FL mathematics and power transformer.

***Keywords*****—**Fuzzy logic, dissolved gas-in-oil analysis, DGA, prediction, power transformer.

## I. Introduction

TRANFORMER predictive maintenance techniques are designed to help determine the condition in-service equipment in order to predict when transformer maintenance should be performed. This maintenance is applied to transformer since transformer is one of the important parts of the electric power system. A transformer could be defined as an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. Moreover, the transformer can work as a step-up or step-down transformer based on feed direction. There are three types of transformer faults namely, mechanical faults, electrical faults and thermal faults. These three types of faults can detected by using DGA methods. There are five methods to diagnose power transformer incipient faults, these methods are IEC Ratio method, Doernenburg Ratio method, Key Gas method, Duval Triangular method and Rogers Ratio method.

In this paper, since IEC is widely used, it is utilized and FL model is developed for interpretation and diagnoses of transformer fault to reduce the dependency of personal experience to diagnose and predict the transformer faults.

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## II. Literature Review

One of the problems with the fault diagnosis of transformers based on dissolved gas is the inability to match the result of the different standards of fault diagnosis with real world standards. The results of the different standards were analyzed using FL and then compared with the empirical test. The proposed method was based on the standards and guidelines of the IEC, the Central Electric Generating Board (CEGB), and the American Society for Testing and Material (ASTM) and its main task was to assist the conventional gas ratio method. The comparison between the suggested method and existing methods indicates the capability of the suggested method in the on-line fault diagnosis of transformers. In addition, in some cases, the existing standards were not able to diagnose the fault. For these instances, the presented method had the potential of diagnosing the fault. FL method was suggested to diagnose the transformer faults. It was shown that the suggested method is capable in diagnosing the power transformer faults. This capability was validated by comparing the diagnosis given by the FL approach with the threes different standards diagnoses methods [1].

One of the most crucial methods to detect power transformer incipient faults is the DGA. IEC is one of the among three ratio widely used methods of the conventional DGA methods. However, this method has the disadvantage in its current form by falling of significant number of DGA codes outside the IEC ratio and inability of diagnoses of these codes. Eighteen additional new combinations were developed and added to the existing nine to avoid and solve this disadvantage. Moreover, five fuzzy ratio method was introduced for diagnose of multiple power transformer faults. This five ratio eliminates the diagnostic faults error resulted from the codes created by the crisp boundaries of 0,1 and 2 which are non-crisp fuzzy specifically under multiple power transformer diagnostic faults condition. The accuracy of these methods, in interpreting the power transformer condition, were tested by using 100 different cases [2].

Early diagnosis faults of power transformers which is an equipment part of the electric energy transmission and distribution system protects system and equipment. Power outages and financial loses are prevented thanks to diagnosis of transformers faults by ensuring continuity of efficient and high-quality working conditions [3].

DGA has ability to detect incipient faults of transformers. When any fault occurs in power transformers, some gases dissolved in transformer oil. These gases were interpreted the DGA systems. When DGA was carried out i-) Conventional Methods and ii-) Intelligents Systems were used. The conventional systems have limitations. Intelligent systems overcome limitations. A FL application was implemented to increase reliability of IEC Ratio, which was one of the DGA methods. The outputs showed that the intelligent system used was over the conventional method called IEC Ratio [3].

The electrical and thermal stresses are kinds of the stress taking place during the operation of power transformer. The power transformer operation is affected by its mineral gases. The DGA is a crucial method to detect the power transformer incipient faults. These gases are found by number of methods such as Key Gas method, Rogers Ratio method, IEC Ratio, and Duval triangle method. Also, the incipient power transformer faults could be detected using Artificial Neural Network (ANN) method [4]. Different methods are used to analyze the different types of the dissolved gases in insulating oil of the power transformer. Although the diagnose of the power transformer faults, based on the DGA, is an efficient and reliable method, in some cases, different types of faults could be indicated by each methods of the dissolved gas interpretation [4].

Condition monitoring of power transformers improves the security and reliability of an electrical power system. It protects the transformers from failures, and avoids huge revenue loss to utilities and customers. The fault diagnosis of transformers is carried out by concentrations of several dissolved gasses. An accurate fault diagnosis of transformers has been a critical problem for diagnostic experts of transformers [5].

A FL model was proposed to determine the transformer incipient faults. It incorporates the information obtained from DGA test. Further, the proposed model also incorporated conventional fault diagnosis methods viz. Duval Triangle, Doernenburg, Rogers, and IEC ratio code methods. The proposed FL models shorted out the problems occur in the conventional fault diagnosis methods of transformers [5].

Many asset managers dealing with power transformers need a reliable method to evaluate the incipient faults of the power transformer and make a decision on transformer insulation condition. Although, DGA is an extensively applied methodology to detect the power transformer incipient fault, it has the limitation of inability to quantify the severity of the transformer fault which is the main property in power transformer maintenance priority. To overcome this limitation, FL technique based on the use of energy of the fault formation of the released gases, which is a temperature dependent during power transformer faulting condition, was utilized. This method was implemented based on key gas method and validated based on DGA taken from different collected oil samples taken from different specification and transformers ages. The results showed good agreement and hence the decision making regarding the ranking of the maintenance activities was improved [6].

## III. Fuzzy Logic

FL allows intermediate value to be defined between conventional evaluations like yes/no, and black/white. A fuzzy set allows for the degree of membership of an item in a set to be any real number between 0 and 1. Its actual operation can be divided into three steps:

1. **Fuzzification**: actual inputs are fuzzified and fuzzy inputs are obtained.
2. **Fuzzy processing**: processing fuzzy inputs according to the rules set and producing fuzzy outputs.
3. **Defuzzification**: producing a crisp real value for a fuzzy output. Fig. 1, shows the fuzzy steps.

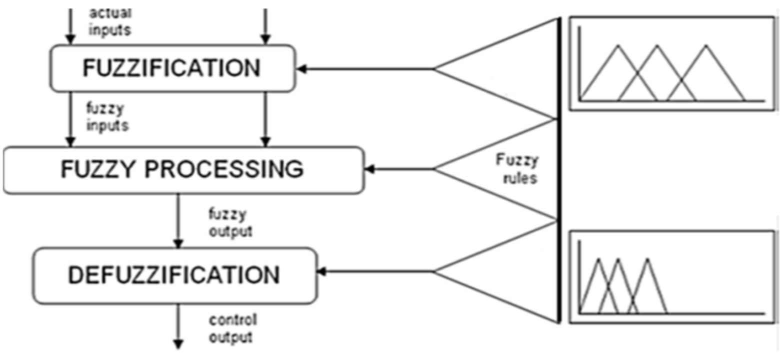


Fig. 1 FL steps

## IV. Implementation of FL, Results and Discussion

A 35 samples were taken from records of the transformer type: 220/30 kV Step-down at the General Electrical Company of Libya (GECOL), was analyzed and investigated to implement FL technique to predict the transformer faults. 28 samples were used for learning and seven samples were used for validation. The IEC Ratio method utilizes three gas ratios: $CH_4/H_2$, $C_2H_4/C_2H_6$ and $C_2H_2/C_2H_4$. Diagnosis of faults is accomplished via a simple coding scheme based on ranges of the ratios. Table I shows the fault types code in IEC method.

Fig. 2 shows IEC three Input parameters, namely $CH_4/H_2$, $C_2H_4/C_2H_6$ and $C_2H_2/C_2H_4$-output parameters namely the Fault type for FL control model.

Figs. 3-5 show the membership function for each of the three input parameters of the ICE method respectively divided into three linguistic variables namely Low (L), Medium(M) and High (H).

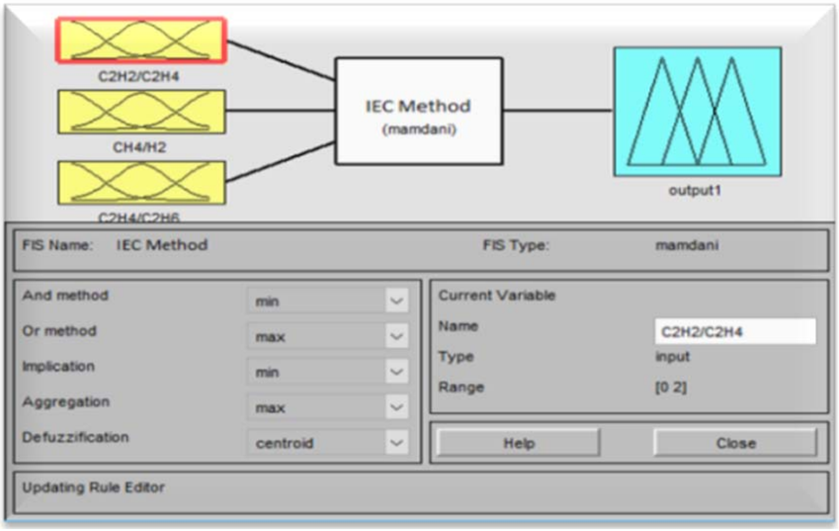


Fig. 2 IEC Input-output parameters for FL control model

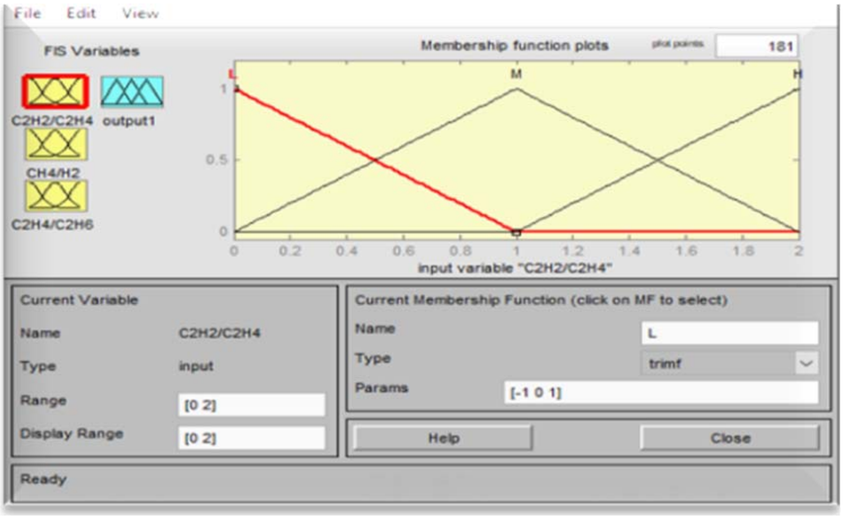


Fig. 3 Membership function for $C_2H_2/C_2H_4$

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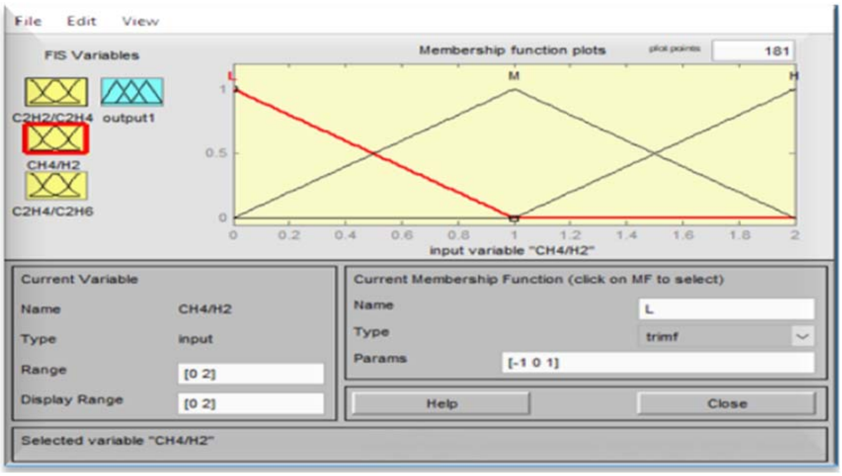


Fig. 4 Membership function for $CH_4/H_2$

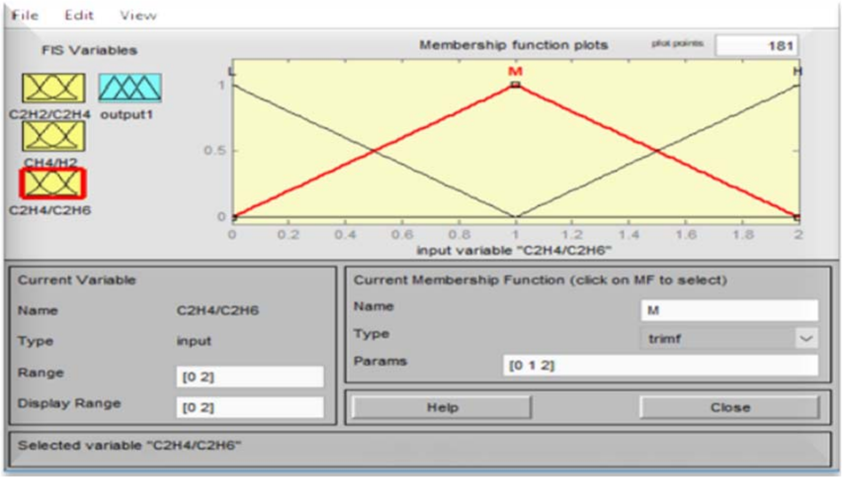


Fig. 5 Membership function for $C_2H_4/C_2H_6$

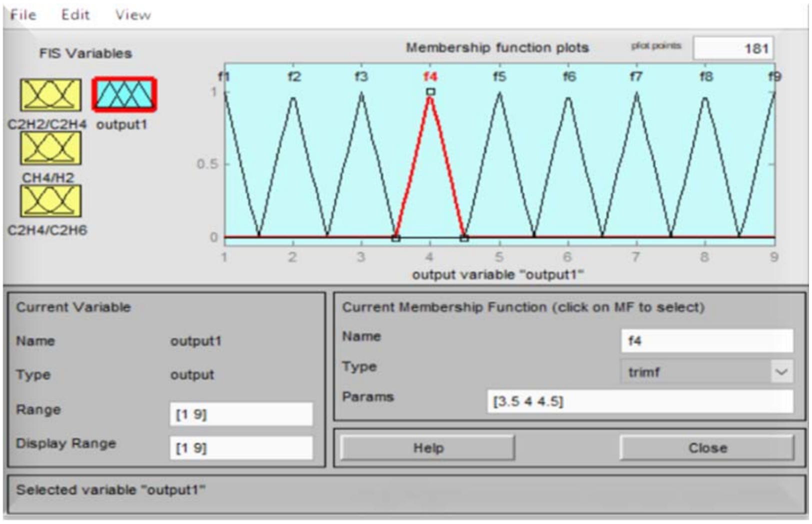


Fig. 6 Membership function for output IEC

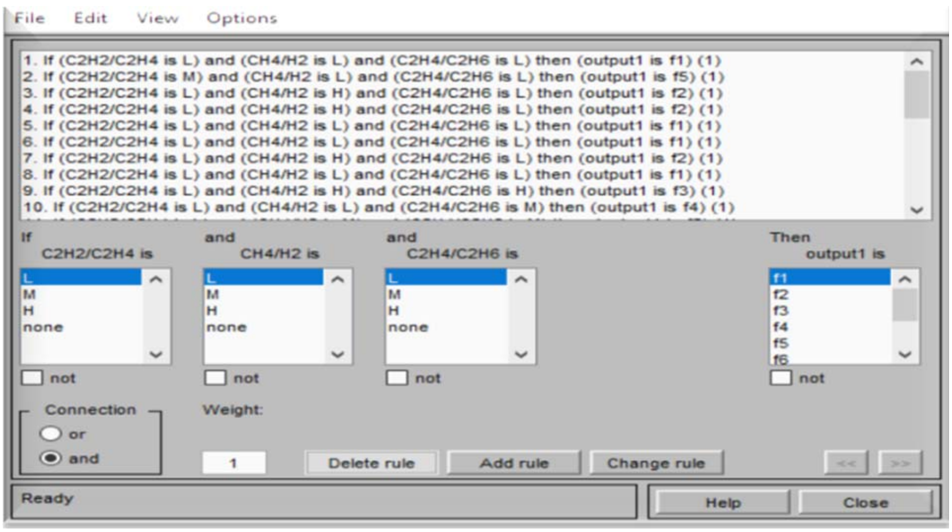


Fig. 7 Designed fuzzy rules

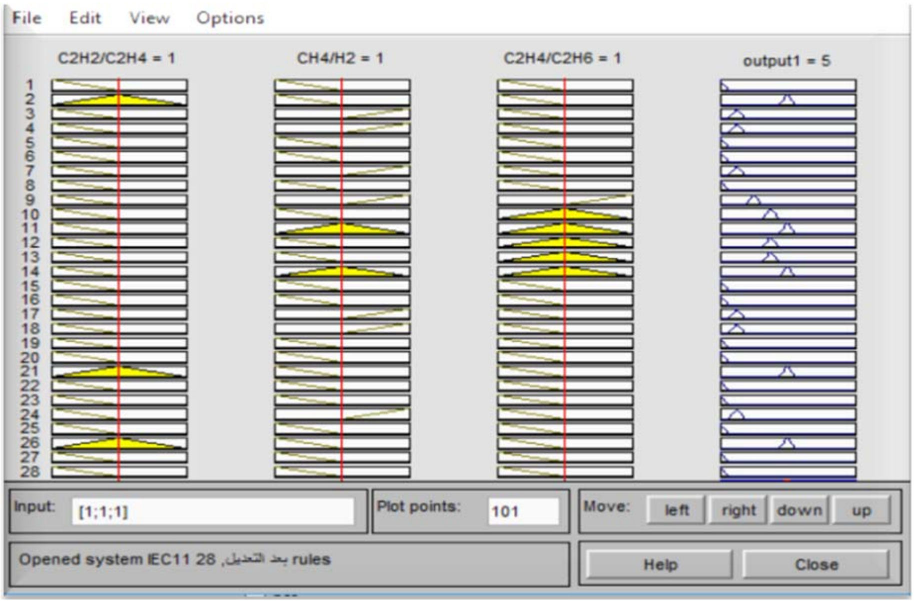


Fig. 8 Simulated fuzzy rules

TABLE I
THE IEC FAULT TYPES CODE

| Fault Type | Fault Type Code |
|---|---|
| Normal | F1 |
| *Thermal fault 150-300* | F2 |
| *Thermal fault >700* | F3 |
| *Thermal fault >150* | F4 |
| *Out off* | F5 |
| Partial discharge of low energy density | F6 |
| Arcing | F7 |
| *Thermal fault 300-700°C* | F8 |
| *Partial discharge of high energy density* | F9 |

Fig. 6 shows the membership function of the fault type output parameter of the ICE method divided into the nine types of the transformer fault types. Fig. 7 shows the designed fuzzy rules. The simulated FL stages are shown in Fig. 8.

The developed fuzzy model is utilized to diagnose and predict the power transformer faults. The 80% training 20% data validation approach is utilized to develop and validate the FL model.

The results of the 80% data were obtained and compared with the ICE method. Table III shows the compassion diagnoses. Table IV shows the 20% validation data. It is clear that there is good agreement between both diagnostic methods which means that the developed FL model, introduced to diagnose and predict the power transformer faults could be used efficiently and effectively.

## V. CONCLUSION

In order to maintain the power transformer effectively, it essential to evaluate its condition and predict its faults. In this paper, a FL model for fault diagnosis and condition evaluation of the power transforms, based on DGA and using IEC method, is designed and introduced. This FL model could be utilized effectively within the specified values of the analyzed gages.

TABLE III
THE COMPARISON BETWEEN IEC AND FL FAULTS

| C2H2/ C2H4 | C2H2/ C2H4 | C2H2/ C2H4 | IEC Fault | FL Fault |
|---|---|---|---|---|
| 0.78 | 0.66 | 0.01 | F1 | F1 |
| 0.5 | 0.5 | 0.2 | F5 | F5 |
| 0 | 7.5 | 0.63 | F2 | F2 |
| 0.05 | 3.75 | 0.42 | F2 | F2 |
| 0.01 | 0.4 | 0.56 | F1 | F1 |
| 0 | 0.5 | 0.2 | F1 | F1 |
| 0.066 | 2 | 0.75 | F2 | F2 |
| 0 | 0.93 | 0.46 | F1 | F1 |
| 0 | 5.52 | 4.96 | F3 | F3 |
| 0.004 | 0.14 | 2.38 | F4 | F4 |
| 0.0041 | 0.06 | .820 | F5 | F5 |
| 0.01 | 0.55 | 2.30 | F4 | F4 |
| 0 | 0.28 | 1.88 | F4 | F4 |
| 0 | 0.043 | 1.62 | F5 | F5 |
| 0 | 1 | 0.47 | F1 | F1 |
| 0 | 0.55 | 0.71 | F1 | F1 |
| 0 | 1.83 | 0.455 | F2 | F2 |
| 0 | 2 | 0.67 | F2 | F2 |
| 0 | 2 | 0 | F2 | F2 |
| 0 | 0 | 0 | F1 | F1 |
| 0 | 0 | 0 | F1 | F1 |
| 1 | 0 | 0 | F5 | F5 |
| 0 | 0 | 0 | F1 | F1 |
| 0 | 0 | 0 | F1 | F1 |
| 0 | 2 | 0 | F2 | F2 |
| 0 | 0 | 0 | F1 | F1 |
| 1 | 0 | 0 | F5 | F5 |
| 0 | 0 | 0 | F1 | F1 |

TABLE IV
THE COMPARISON BETWEEN IEC AND FL FAULTS

| C2H2/ C2H4 | C2H2/ C2H4 | C2H2/ C2H4 | IEC Fault | FL Fault |
|---|---|---|---|---|
| 0 | 0.14 | 1.39 | F4 | F4 |
| 0 | 17 | 4.20 | F3 | F3 |
| 0 | 0.22 | 0.92 | F1 | F1 |
| 0.03 | 0.75 | 4.33 | F5 | F5 |
| 0 | 7.28 | 0.67 | F2 | F2 |
| 0.02 | 3.37 | 0.42 | F2 | F2 |
| 0.03 | 0.29 | 0.56 | F1 | F1 |

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