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A new fuzzy logic approach to identify power transformer criticality using dissolved gas-in-oil analysis

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ABSTRACT

Dissolved gas analysis (DGA) of transformer oil is one of the most effective power transformer condition monitoring tools. There are many interpretation techniques for DGA results however all current techniques rely on personnel experience more than analytical formulation. As a result, the current techniques do not necessarily lead to the same conclusion for the same oil sample. A significant number of DGA results fall outside the proposed codes of the ratio-based interpretation techniques and cannot be diagnosed using these methods. Moreover, ratio methods fail to diagnose multiple fault conditions due to the mixing up of produced gases. To overcome these limitations, this paper introduces a new fuzzy logic approach that aids in standardizing DGA interpretation and identifies transformer critical ranking based on DGA data. The approach relies on incorporating all traditional DGA interpretation techniques (Roger, Doerenburg, IEC, key gas and Duval triangle methods) into one expert model. In this context, DGA results of 338 oil samples of pre-known fault conditions that were collected from different transformers of different rating and different life span are used to establish the model. Traditional DGA interpretation techniques are used first to analyze the DGA results to evaluate the consistency and accuracy of each method in identifying various faults. Results of this analysis were then used to develop the proposed fuzzy logic model. The model is validated using another set of DGA data that were collected form previously published papers.

Introduction

POWER transformer represents a critical link in any transmission or distribution network. To improve the reliability of the equipment and to avoid any catastrophic failure, effective monitoring and diagnostic techniques must be adopted. Transformer dielectric oil and paper insulation are considered as key sources to detect incipient and fast developing faults, insulation trending and generally reflects the health condition of the transformer [1]. There are several of chemical and electrical diagnostic techniques currently used by various utilities to examine the health condition of power transformers [2]. Among of these methods, dissolved gas in oil analysis (DGA) is widely used to detect power transformer incipient faults. DGA could also be facilitated to reflect the transformer failure rank. Due to electrical and thermal stresses that operating transformer exhibits, oil and paper decomposition occurs [3]. Gases produced due to oil decomposition are hydrogen (H_2), methane (CH_4), acetylene (C_2H_2), ethylene (C_2H_4) and ethane (C_2H_6). On the other hand paper decomposition produces carbon monoxide (CO) and carbon dioxide (CO_2) [4]. Various internal faults within a power transformer evolve particular amount of characteristic gases that can be used to determine the type and severity of fault. However, the analysis is not always straight forward as there may be more than one fault present at the same time. Partial discharge activity produces H_2 and CH_4 while arcing generates all gases including traceable amount of C_2H_2 [3]. DGA can be used to determine the amount and type of gases in transformer oil and hence aiding in determining the transformer failure rank [5,6]. There are many DGA interpretation techniques such as key gas method [7], Roger ratio method [8,9] and Duval triangle method [10] that have been reported in the literatures.

All of these methods rely on personnel experience more than mathematical formulation and they do not necessarily lead to the same conclusion for the same oil sample. Precise DGA interpretation is yet a challenge in the power transformer condition monitoring research area and there is no globally accepted technique for DGA interpretation.

Availability of DGA data history has recently motivated researchers to develop a standard approaches for DGA interpretation based on mathematical and artificial intelligent (AI)

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techniques [11–20]. The application of AI in the interpretation of DGA data are mainly to overcome the drawbacks arise from the application of ratio methods that include failure to identify fault types in case of multiple fault conditions and the invalid code that some DGA results may result in. A recent study [21] shows that various DGA interpretation techniques are not consistent and they may lead to different interpretation for the same oil sample. To verify this finding, consistency and accuracy analyses are performed on 338 DGA results of transformer oil samples of pre-known fault type that were collected from various transformers of different rating, life span and operating conditions. Results of consistency and accuracy analyses are then used to develop a fuzzy logic model that incorporates the key features of several well established interpretation methods such as Roger, Doerenburg, IEC ratio methods along with key gas and Duval triangle methods to assess the criticality ranking of a power transformer based on its DGA data. The key contribution of this paper lies in the novel intelligent asset management and diagnostic model it presents to assure a reliable and consistent decision on the health condition of the transformer based on its DGA data.

Dga interpretation techniques

There are many DGA interpretation techniques currently used by various utilities. Among these techniques the Roger, Doerenburg, IEC, key gas and Duval triangle are the most popular and widely used methods. These methods are well established in the literature and they are briefly elaborated below to highlight the limitation of each technique.

Roger's ratio method which is based on earlier work by Doerenburg, uses four-key gas ratios [22]. On the other hand, the IEC ratio method uses three-key gas ratios [23]. Ratio methods are only valid if there is a significant amount of the gas used in the ratio otherwise the method will not be able to identify the type of fault and will lead to invalid code. Therefore, ratio methods can be used to identify the type of fault more than detecting it.

The key gas method is set forth in IEEE standard (C57.104-1991) that was revised in 2008 [7,22] for transformer oil DGA interpretation. This method uses combination of individual gases and total combustible gas concentration (TCGC) to classify risks within a transformer. However, this guide is not widely accepted as an effective tool to evaluate the health condition of in-oil immersed transformers as it is considered very conservative and a transformer may operate safely even though its DGA analysis indicates condition 4 (imminent risk) as far as gas evolution rate is not constantly increasing [3].

Duval and De Pablo mentioned that good number of DGA results fall outside ratio-based techniques and cannot be diagnosed using these methods. Duval proposed a triangle for transformer fault diagnosis based on DGA results [10]. However as Duval triangle does not encompass an area for normal DGA results, this method can only be used to identify the fault type in case of faulty transformer and therefore, no indication of incipient fault can be obtained [23].

Fuzzy logic models

In this section, fuzzy logic models are developed to aid in standardizing the overall decision of various DGA interpretation techniques. Each fuzzy logic model is developed in accordance to fuzzy inference flow chart shown in Fig. 1.

Input variables to the model are the 7-key gases in parts per million (ppm). The output of each model is divided into 3 sets of membership functions comprising thermal (overheating in oil

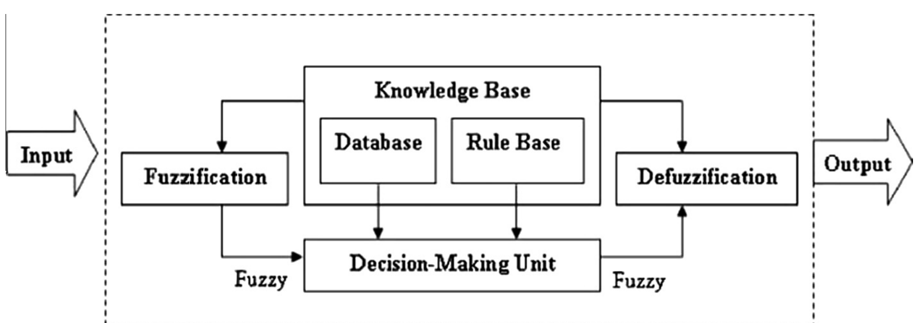

Fig. 1. Fuzzy logic model flow chart.

Table 1
Fault types identified by various dga interpretation techniques.

Method	F1 thermal fault (Oil, Cellulose)	F2 electrical fault (Corona)	F3 electrical fault (Arcing)
Roger	– Thermal fault <150 °C – Thermal fault 150–300 °C – Thermal fault 300–700 °C – Thermal fault >700 °C	– Low energy electrical discharge	– High energy electrical discharge
IEC	– Thermal fault <150 °C – Thermal fault 150–300 °C – Thermal fault 300–700 °C – Thermal fault >700 °C	– Low energy electrical discharge	– High energy electrical discharge
Doeren.	– Thermal decomposition	– Low energy electrical discharge	– High energy electrical discharge
Duval	– Thermal fault <300 °C – Thermal fault 300–700 °C – Thermal fault >700 °C	– Low energy electrical discharge	– High energy electrical discharge
Key gas	– Over heated oil and/or cellulose	– Low energy electrical discharge	– High energy electrical discharge
Principal gas [7]	CO/CO_2 (cellulose) and C_2H_4 (oil)	H_2	C_2H_2