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Review Paper

Faults diagnosis and assessment of transformer insulation oil quality: intelligent methods based on dissolved gas analysis a-review

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Abstract

The search for determining accurate faults and assessing the oil quality of high voltage electrical power transformers for life-long maintenance is ever-demanding. The durability of transformers function is significantly decided by the excellence of its insulation which deteriorates over time due to temperature fluctuations and moisture contents. The accurate diagnoses of faults in early stages and the efficient assessment of oil quality using an intelligent program is the key challenges in protecting transformers from potential failures occur during operation to avoid economic losses. The dissolved gases analysis in oil is a reliable method in the diagnosis of faults and assessing the quality of insulating oil in transformers. Recently, application of artificial intelligence (AI) has included fuzzy logic, expert system (EPS), and artificial neural network (ANN), Expert system and fuzzy logic can take DGA standards. This paper represents the review most of the methods used to diagnose faults and assessment of insulating oil for transformers through the dissolved gases analysis DGA.

Keywords: *Dissolved Gas Analysis; Fault Diagnosis; Assessing Insulating Oil; Traditional and Intelligent Methods.*

1. Introduction

The quest of finding accurate fault diagnostics and assessing the oil quality of electrical power transformer for life-long safeguard is never-ending. The longevity of transformers function is critically decided by the quality of its insulation. Generally, this insulation deteriorates over a time span with temperature, moisture and oxygen. The judgment of faults and the assessment of oil quality is one of the most important sources in protecting transformers from potential failures occur during operation. The quality of oil decides the working efficiency of the transformer. The high-voltage (HV) transformers are exceptionally expensive and the damage in insulation system often causes high economic loss (Wang et al. 2000) [1]. In the past, several methodologies are adopted for the diagnosis of faults in the transformer oil to assess the oil quality and different smart standards are developed with the approved specifications including IEEE standard C57-104 (Committee et al. 2009) and IEC standard 60599 (Prix & Code 1999) [2]. Despite many efforts the efficient and precise determination of the nature of faults and subsequent rectification mechanism for superior performance is far from being understood. The oils in electrical transformers have dual function such as insulation and cooling. They are characterized by good insulation and cooling properties in the coils under severely high change in the temperature for long period operation where faults emerge. Gases generated in the oil are hydrocarbon due to high electrical pressure, temperature and harsh environmental conditions (Muhamad et al. 2007) [3]. These gases have strong negative impact on the functioning of the transformer oil. Therefore, the process of diagnosing faults and assessing the oil quality are indispensable to support the protection program by identifying preventive maintenance schedules for transformers (Thang et al. 2003) [4]. There are many ways to detect faults and assess quality of insulating oil in electrical transformers based on the analysis of gases dissolved in the oil, including traditional methods rely at hand calculations such as ratios derived from the effect of the gases generated to give clear data for these ratios, including ways of using smart technologies such as artificial neural networks and fuzzy logic and genetic algorithm that is where these methods rely on data from the analysis of gases dissolved in the oil. This development improved the process of detecting faults in transformers(Chromatography 2004). In this paper has been some methods used in the diagnosis of faults and assessing of quality transformer oil through of DGA various methods used traditional and intelligent, such as artificial neural networks and fuzzy logic and view of modern techniques to help in the diagnosis of faults in an accurate and by error Low and determine the best methods used to diagnose faults and assessing of quality transformer oil [5].

2. DGA methods

Recently, several interpretative techniques such as IEC 60599 Standard ratio codes, IEEE Standard, Roger and Dorenburg ratio codes, Key gas method, CIGRE guidelines, MSZ-09-00.0352 National Standard ratio codes and graphical method like Duval triangle are developed to predict the emergence of faults and determine their types. All these methods of fault diagnosis are based on celebrated DGA scheme (Saha, 2003) [6] .

2.1. Key gas method

Decomposition of gases in the oil and paper insulation of transformers caused by faults depends on the temperature. Various faults produce certain gases and the proportion of some gases are found to indicate fault types such as over-heated oil and cellulose, corona in oil and arching in oil (Sabina Karlsson, 2007) [7] .

2.2. Ratio methods

The ratio methods are the most widely used technique. Typically, three or four ratios are used for sufficient accuracy. For instance, the initial Roger's ratio method uses four ratios such as CH4/H2, C2H6/CH4, C2H4/C2H6 and C2H2/C2H4 to diagnose the incipient fault conditions and the normal condition. This method extract information from the Halstead's thermal equilibrium and Dornenburg ratios along with those from faulted units (Hmood et al., 2012) [8] .

2.3. MSZ-09-00.0352 national standard method

Considerable differences in opinion exist for what is considered a "normal transformer" with acceptable concentrations of gases. In this standard four-levels of criteria are developed to determine the risks of the transformers. These criteria assist to determine whether a transformer is functioning normally. Especially, when there is no previous dissolved gas history or the transformers are in operation for many years. The criterion uses total concentration of all combustible gases for the type of Generator Step-Up (GSU) Transformers and Grid Transformers separately show in Table 1. The transformer is considered to be "normal" when the total dissolved combustible gases (TDCG) are below or within threshold levels and at the same time if any individual combustible gas does not exceed the specified limits. An additional investigation is needed whenever there is any deviation from this normalcy (Bhalla et al. 2010) [9].

Table 1: Concentration Limit of Dissolved Gas [9]

Dissolved gas	Concentrations limit (ppm)	
	GSU Transformer	Grid Transformer
Hydrogen (H2)	200	160
Methane (CH4)	100	60
Ethane (C2H6)	60	60
Ethylene (C2H4)	60	60
Acetylene(C2H2)	4	4
Carbon monoxide (CO)	700	360
Carbon-dioxide (CO2)	10000	

3. Traditional methods based on DGA

In the past, methods are adopted based on dissolved gases analysis (DGA) for the diagnosis of faults using TDCG. The samples are obtained from the transformer oil and the generated gas concentrations are recorded. However, all these traditional methods do not use any intelligent software program to perform the calculations in the faults diagnoses. All these approaches focused on the process of diagnosing faults through the analysis of transformer oil only and do not address the issues related to the quality assessment of the oil (Deherwal & Singh 2012) [10]. Most reports are on the calculation of the dissolved gases in the transformer oil some are on the prediction of errors. In a recent study, twenty samples of transformer oil are exposed to electric arc process to generate the gases and a non-linear increment in the individual gas concentration is achieved using TCG method. The calculations are manually performed without using intelligent computer codes and further analysis is carried out. This method is not only inaccurate but also inefficient in terms of time. This study addressed results on only faults diagnosis are without assessing the quality of the transformer oil (Engineering & Jl 2006) [11]. The Duval triangle method for DGA fault interpretations in power transformer is simpler because it uses only three gases. This method consume less time, software implementation on computer is based on many high level languages (not intelligent), easy to use and highly economic. Because this approach only deal with three gases and neglects other values of dissolved gases, its reliance on data from the sampling and analysis of the oil has low accuracy. The main drawback of this study is that it only diagnoses the faults not assess the quality of transformer oil (Chromatography 2004). A computer program is developed by combining four DGA interpretation techniques to determine the fault condition of a transformer which gives more credence and accurate results to the predictability (Suleiman 2012) [12]. The four DGA techniques employ Rogers's ratio, IEC Basic ratio, Duval Triangle and Key Gas methods which are easy to use because the program performs multiple tasks in single run. However, it does not possess any intelligent component and uses the external results for analysis. The program only diagnoses faults and does not assess the oil quality.

Methods are also developed by Alghamdi using visual style windows where the algorithms are based on basic software (Alghamdi 2012) [13]. A graphic user interface (GUI) is displayed on the monitor that requires input data from the user and the software processes the input for all the four DGA assessment methods. The achieved results are realistic and accurate. The software in the absence of any intelligent features is easy to use and economic, but the nursing analysis of samples has to be performed in an external laboratory. In addition, the method focuses on the fault diagnosis only. However, the DGA based Duval triangle method draws a normalization of three gases (CH4, C2H4, C2H2) coordinate system so that the data point are located in the area in exchange for the type of error. The generated data are then compared with IEC 60599 specification. This method neglects the gases such as H2 and C2H6, and uses two high-impact processes to effectively predict the faults. Also used to diagnose faults only, and did not used to assess the quality of transformer oil (Duval & Dukarm 2005) [14]. This method is somewhat accurate because it is detected the locations of all the faults even if the ratio of the generated gas concentration is low. Recently, Akbari developed a computer program using Java code that depends on the manual calculations and the samples are again analyzed in external laboratories. This study focused only on the faults diagnosis and not assessed the oil quality (Akbari et al., 2008) [15]. Following all earlier four methods, a computer program based on DGA is designed to calculate the ratios of dissolved gases in the transformer oil. The results are interpreted via the information constant obtained from any oil sample in power transformer. This is to confirm the reliability of the power and authority to ensure access. Asiah et al emphasized the need of an effective management of power transformers and not using intelligent software and analyzing samples in external laboratories to diagnose faults (Asiah et al. 2012) [16]. The management operations of electrical transformers with a statement to clarify all these activities separately are documented by Abu-Elanien & Salama. During this study, comprehensive illustrations of the transformer asset management activities are provided. The importance of each activity at the side of the most recent researches wiped out the area is highlighted. This study represents the process of assessing the methods used in the detection and diagnosis of faults in electrical transformers without assessing the quality of oils in transformers (Abu-Elanien & Salama 2010) [17].

Mathematical model is used by Abu-Elanien to identify the process of the nomination of oil used in transformers in anticipation of a failure. This model eases the users with a tool to design the buffer size on the premise of their tolerance of failure rate of the transformers. Mathematical model is conjointly been developed to calculate the probability by varying the service frequency. This model helps in the process of preventive maintenance to ensure the quality of transformer oil in anticipation of failures. The advanced mathematics is used by Chatterjee et al in their program which is capable of assessing the quality of the oil only and unable to diagnose faults nature in transformers (Chatterjee et al. 2012) [18]. This method used a questionnaire to a group of Iranian- electrical transformers manufacturer and obtained the results from two types of methods based on DGA. Survey over three hundred transformers in Iranian industries are carried out and completely different oil limitations with additional gas chromatography results based on DGA are analyzed. Investigations on assessing the quality of the oil in the transformer based on the chemical properties of the oil, the polymerization process and the analysis of dissolved gases during the service are made to determine the quality of oil but not fault are demonstrated by (Moradi et al. 2008) [19]. The estimation of total combustible gases (TCG) based on the DGA is made by Suwanasri et al to determine the failure rate of transformers as a precautionary measure for the safety of the nappy transferred from aging (Suwanasri et al. 2008) [20] . The transformer conditions are principally evaluated by the technique of Key Gas and verified by the Ratios and TCG method. This report is based on the traditional methods for the DGA in the transformer oil to diagnose of the faults only. Modern of diagnostic techniques to detect the level of moisture in the insulation directly through polarization measurement are implemented. Most of the up-to-date stress level status in transformers is directed to techniques relating to the quantification of moisture content of insulation indirectly by measuring RV limitations. The polarization method of Saha measures the proportion of aging in oil through the moisture content for diagnosing the oil quality in transformers (Saha, 2003) .The foremost challenge is still within the correct interpretation of the reappearance in voltage results.

4. Intelligent methods based on DGA

DGA based intelligent approaches exploit the fuzzy logic to assess the oil quality in HV transformers (Ijser, 2012) [21] .The program relies on the TCG method to calculate the rate of degradation of the oil in the transformer during the service and the possible manipulation for retrieval. They are superior in terms of assessing the transformer oil quality only. Intelligent method can deal with the early diagnosis of faults in transformers through DGA. A database expert system with fuzzy logic is adopted in the process for faults diagnosis in the conjectured machine. This method is good in the diagnostic but the high error rate is involved in distinguishing the type faults in the process of similar symptoms. Németh et al. employed a kind of expert system to diagnose the types and location of faults in the transformer oil (Németh et al. 2010) [22].

The Bayesian network and set theory combined procedure is used to test 200 samples taken from the transformer oil. The Bayesian network calculation depends on three process including variable elimination algorithm, spread clique tree and fuzzy logic. Recently, Xie demonstrated that the chromatographic analysis of the oil clearly estimated the concentration of generated hydrocarbon gases as much as 80% (Xie et al. 2013) [23]. This rate is commensurate with the excessive heat error via the degradation characteristics of the transformer oil. The dominant factors responsible for causing the faults in the transformer oil is identified by conducting a test on four working transformer of 50 to 150 MVA with voltage category of 400/220KV. A relation is established among necessary characteristics of transformer oil such as 1FT-NN, wet-1FT and BDV-wet. It is verified that the deterioration in the oil results from several factors including the breakdown voltage, high temperatures and overloading. Kumar et al. in their work assessed the quality of the oil and without faults diagnoses (Kumar et al. 2013) [24]. Applying ANN to automation Seifeddine et al. developed a novel technique for deciding nature of faults in power transformers by choosing the foremost acceptable traditional DGA. The projected combination ratios and graphical representation technique using the ANN is used for classifying power transformers faults. Although the method intelligent in detecting the faults but incapable of assessing insulating oil quality in transformers (Seifeddine et al. 2012) [25]. Malik et al proposed a method by integrating conventional methods for DGA with artificial intelligence (AI). The merits and de-merits of assorted typical and non-conventional DGA methods used by various researchers to associate degreed utilities for searching out the condition of the cellulose material inside an in-service transformer are demonstrated. Their intelligent expert system provides an effective solution to the issue in deciding and predicting the occurrence of faults in HV transformer oil (Malik, et al. 2012) [26]. Qaedi & Seyedtabaii considered the methods of SVM, KNN and ANN together for fault classification. It is further demonstrated that the number of patterns of error are uneven and inadequate one. Using artificial intelligence in ANN and introducing more input from the bootstrapping a remarkable improvement in the performance is observed. This method is to cut short the process of diagnosing faults through the insulating oil for transformers only where the quality assessment still remains uncertain (Qaedi & Seyedtabaii 2012) [27]. Meanwhile, a new scheme called ANFIS based on DGA is introduced by Hooshmand et al to determine the type and location of the faults concurrently and results are compared with other methods. It used associated nursing adaptation of new or fuzzy inference system supported by DGA. The ANFIS is initially “trained” in accordance with IEC 599 to acquire fault determination ability. The new technique could only diagnose faults and not assessed the oil quality (Hooshmand et al. 2012) [28]. Relying on the DGA in transformer oil, Velasquez-Contreras et al implemented an intelligent system to predict the occurrence of a failure in the electrical transformers. A sturdy anomaly detection module using prediction models supported by AI techniques is developed for high oil temperature monitoring. Interestingly, the expertise obtained from the implementation of a part the modules of GAMMEU using real data has incontestable. This form of Smart Systems is recommended as an expert system for detecting faults in electrical transformers before a failure occurs (Velasquez-Contreras et al. 2011) [29] .

All the proposed intelligent systems for faults diagnoses in transformers intimately depend on the mixing of ANN with fuzzy logic. A transformer using adaptive Neuron-Fuzzy inference System (ANFIS) is created. Detection of the fault types in the early stages with few key gases is convenient for on-line gas-in-oil observation systems. Akgundogdu et al affirmed that DGA may be a very efficient tool for the observation of transformers failures. Their work is confined to faults diagnoses only (Akgundogdu et al. 2008) [30]. The ANN based on the algorithms within the training of the network suggested by Hao and Caixin is used in the detection process of faults that occurs in the worst adapters. The projected AINC algorithm is tested on several real fault samples and the results are compared with those of IEC ratio codes and ANN. It is found that the proposed approach has outstanding diagnosing accuracy where multiple inchoate faults can often be classified effectively (Hao & Cai-xin 2007) [31].

Expert system designed by Muhamad et al is used to detect a failure in the electrical transformers. Two types of oil in immersed and dry form are administered in intelligent fuzzy logic based on DGA data. The fuzzy logic in such expert system is capable of assessing all the knowledge to diagnose and predict types of faults in different transformers. The window connecting the user with the system is developed by exploiting lab view where the user is able to choose, observe and diagnose the condition of oil inside the transformer (Muhamad & Ali 2005) [32]. The expert system efficiently diagnoses types of faults in electrical transformers in dry and oil-immersed one. According to Sarma et al, the detection of incipient faults in oil immersed transformers can be made by examining the gases dissolved in oil. They developed an efficient scheme based on original Buchholz relay application to detect incipient faults. Thus, the importance of ANN approach in beating the drawback of other methods cannot be overemphasized. The results on faults classification obtained through ANN are highly reliable (Sarma & Kalyani 2004) [33]. The model of Dukarm based on total deterioration of combustible gases (TDCG) and DGA for the transformer oil introduced ANN in the detection of faults. It is asserted that if the TDCG generation rate exceeds ten ppm/day then the faults bound to occur. Too many numeric input variables are needed for such prediction. To avoid the complexity in diagnostic neural networks may be used in combination with fuzzy logic for implementation (Dukarm, 1993) [34].

5. Summary of literature review

Reviewed literatures are classified into two categories. Firstly, the studies on traditional methods for diagnosing the faults and assessing the oil quality in transformer oil as listed show in Table 2. Secondly, the investigations based on intelligent methods to diagnose faults and assess the oil quality of transformer are summarized show in Table 3. In is important to note that both category is relied on the DGA methods for determining the dissolved ratios of gases by testing oil samples in external laboratories.

Table 2: Using Traditional Methods

Type of Method	Approach	Process	Features	Authors Name	Year
Traditional Methods	Using a computer program	Allows for faults diagnoses only	All take the ratios of gases by sending oil samples to external laboratories	Suleiman	2012
				Alghamdi	2012
				Asiah et al	2012
				Singh & Bandyopadhay	2010
				Akbari et al	2008
	Using manual calculations	Allows for faults diagnoses only		Bhaskar	2012
				Deherwal & Singh	2012
				Abu-Elanien & Salama	2010
				Ciulavu & Helerea	2008
				Suwanasri et al	2008
	Using a computer program	Allows for faults diagnoses only		Engineering & JI	2006
				Duval & Dukarm	2005
	Using manual calculations	Assess the quality of oil only		Chatterjee et al	2012
				Moradi et al	2008
				Saha	2003

Table 3: Using Intelligent Methods

Type of method	Approach at work	Process	Features	The author's name	Year
Intelligent methods	Using fuzzy system	Allows for faults diagnoses only	All take the ratios of gases by sending oil samples to external laboratories	Xie et al	2013
	Fuzzy expert system			Nemeth et al	2012
Intelligent methods	AI expert system	Allows for faults diagnoses only		Malik, Singh et al	2012
	Using ANN			Seifeddine et al	2012
				Qaedi & Seyedtabaii	2012
Intelligent methods	FLNN expert system	Allows for faults diagnoses only		Hooshmand et al	2012
	AI expert system			Velasqez-contreras et al	2011
	Using ANN			Meng et al	2010
	AI expert system			Prosr et al	2010
Intelligent methods	Fuzzy &NN	Allows for faults diagnoses only		Akgundogdu et al	2008
	Using ANN			Hao & Cai-Xin	2007
	Fuzzy expert system			Muhamad & Ali	2005
	Using ANN			Sarma & Kalyani	2004
Intelligent methods	Fuzzy expert system	Allows for faults diagnoses only		Jota et al	1998
	Using fuzzy system			Dukarm	1993
Intelligent methods	Using ANN	Assess the quality of oil only		Malik, Jarla et al	2013
	Using fuzzy system			Ijser	2012

6. Future work of diagnosis and assess of quality transformer oil

A propose of future work will develop a new intelligent method (MATLAB program) using artificial neural networks based on dissolved gases analysis for precise diagnoses of faults and assessment of oil quality in high voltage transformers when in operation. Mobile sensors will be used for dissolved gas detection in the oil and Rogers's ratio method to develop the program for diagnosing faults and simultaneously assessing the oil quality. The artificial neural networks based software will be trained by a back propagation algorithm following IEC standard 60599 where sensor detected gas ration act as input. The trained algorithm will be capable of assessing the quality of oil via IEEE standard C57-104 (TCG). The appropriate treatments including single filtering and degassing, double filtering and degassing and reclamation will be employed without reusing the oil. The simulated results will be analyzed and compared with those used traditional methods based program. It is believed that our results on early fault diagnoses and oil quality assessment will be useful to assist maintenance teams to take precautionary measure to avoid failure of transformers and save from financial damage.

7. Conclusion

Undoubtedly, the electrical power transformers are usually the most critical and expensive component in power transmission and distribution systems. The failure rate of extra high-voltage (EHV) power transformers as much as 3% per year per device result in the loss of huge wealth. It is recognized that the failures are mainly due to serious insulation oil spills causing major disruption of supply. The studies of the traditional program and Intelligent Software that achieves the goals is put forward to determine the process that diagnoses faults and assess the oil quality in high voltages transform. Through the presentation of the studies noted that the process of diagnosing faults and assess of quality transformer oil depends on the proportions of the gases generated in the insulating oil for transformers where these gases are combustible and on this basis is trained artificial neural networks to determine the ratios and give the correct results. As well as when building a database and the rules of the fuzzy logic also depends on the values of these ratios to determine the type of faults can accurately. This paper was authored by focusing on recent developments in smart programming techniques and to shed light on the opportunities provided for the diagnosis of faults in the insulating oil of high voltage transformers. We hope that future studies included more than one way to diagnose faults and at the same time assesses the state of the oil and conducting prompt treatment for him.

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