Faculty of Electrical Engineering

IMPROVEMENT OF DISSOLVED GAS ANALYSIS INTERPRETATION BY COMBINING DUVAL TRIANGLE METHOD WITH MACHINE LEARNING TECHNIQUES

Ghaith Anmar Dheyaa

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Ghaith Anmar Dheyaa

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DECLARATION

I declare that this dissertation is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………….

Name : Ghaith Anmar Dheyaa.

Date : ………………………….

APPROVAL

I hereby declare that I have read this dissertation and in my opinion, this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

Signature : ……………..............................

Supervisor Name : Ir. Dr. Norazhar Bin Abu Bakar

Date : ……………………...................

DEDICATION

To my father

For earning an honest living for us and for supporting and encouraging me to believe

In myself

To my mother

A strong and gentle soul who taught me to trust in Allah, believe in hard work and that

So much could be done with little

To my brother and sister

I am really grateful to my family

The reason of what I become today

Thanks for your great support and continuous care.

ABSTRACT

Power transformer is one of the main components in any power transmission and distribution network. Transformers have complicated winding structures and are subjected to electrical, thermal and mechanical stresses. During the last few years, there has been a trend of continuous increasing of transformer failures. It is therefore vital to diagnose the incipient faults for safety and reliability of an electrical network. Thus, these transformers are needed to be routinely maintained. Due to the large number of transformers with different manufactures and capacities, routine maintenance and diagnosis of such transformers are difficult since different transformers exhibit different characteristics and problems. By means of dissolved gas analysis (DGA), it is possible to distinguish faults such as partial discharge (corona), overheating (pyrolysis) and arcing in oil-filled equipment. Dissolved gas analysis is one of the most effective tools for power transformer condition monitoring. There are several interpretation techniques for DGA results including Key Gas, Doernenburg, IEC Ratio, Roger's Ratio and Duval Triangle. However, DGA interpretation is still a challenge issue as most of the techniques are relying on personnel experience more than standard mathematical formulation. As a result, various interpretation techniques do not necessarily lead to the same conclusion for the same oil sample. Furthermore, significant number of DGA results fall outside the proposed codes of the current based-ratio interpretation techniques and cannot be diagnosed by these methods. Moreover, ratio methods fail to diagnose multiple fault conditions due to the mixing up of produced gases. To overcome these limitations, this thesis proposes a new Artificial Intelligence (AI) approach to reduce dependency on expert personnel and to aid in standardizing DGA interpretation techniques. The approach relies on incorporating the Duval triangle method (DTM) with two machine learning classifiers named decision tree (DT) and random forest (RF), which the final interpretation will apply the voting combination method to get the final prediction of the incipient fault inside the power transformer. DGA results of oil samples where the real fault already known that were collected from different published papers were used to train and test the classifiers. The results demonstrate that combining the conventional method with artificial intelligence based on DGA interpretation methods gives reliable diagnosis of the incipient fault in the power transformer.

ABSTRAK

Alatubah kuasa adalah salah satu komponen utama dalam mana-mana rangkaian penghantaran atau pengagihan kuasa. Alatubah mempunyai struktur lilitan yang rumit dan tertakluk kepada tekanan elektrik, terma dan mekanikal. Dalam beberapa tahun kebelakangan ini, terdapat trend peningkatan berterusan kegagalan alatubah. Justeruitu amat penting untuk diagnosis kesilapan awal bagi keselamatan dan kebolehpercayaan rangkaian elektrik. Oleh itu,alatubah ini perlu diselenggara secara berlcala.memandeiuglcen sebahagiain besar alatubah brbeza kapasiti dan pembrat, diagnosis dan penyelenggaraan rutin ke atas alatubahtersebut, adalah sucker disebabkan. Alatubah yang berbeza mempamerkan ciri dan masalah yang berbeza. Dengan menggunakan analisis gas terlarut (DGA), ia mungkin boleh membezakan kerosakan seperti pelepasan sebahagian (corona), pemanasan lampau (pyrolysis) dan arkaan dalam pelbagai peralatan yang dipenuhi minyak. Analisis gas terlarut adalah salah satu alat yang paling berkesan untuk pemantauan keadaan pengubah kuasa. Terdapat banyak teknik tafsiran tradisional untuk keputusan DGA termasuk Key Gas, Doernenburg, IEC Nisbah, Roger's Ratio dan Duval Triangle. Walau bagaimanapun, tafsiran DGA masih merupakan isu yang mencabar kerana semua teknik yang ada bergantung pada pengalaman seseorang lebih daripada perumusan piawaian matematik. Akibatnya, pelbagai teknik penafsiran tidak semestinya membawa kepada kesimpulan yang sama bagi sampel minyak yang sama. Tambahan pula, sejumlah besar keputusan DGA berada di luar kod cadangan teknik penafsiran nisbah berasaskan semasa dan tidak boleh didiagnosis oleh kaedah ini. Selain itu, kaedah nisbah gagal untuk mendiagnosis pelbagai keadaan kerosakan akibat pencampuran gas yang dihasilkan. Untuk mengatasi kelemanan ini, tesis ini memperkenalkan pendekatan Kecerdasan Buatan yang baru bagi mengurangkan kebergantungan kepada kakitangan pakar dan untuk membantu menyeragamkan teknik tafsiran DGA. Pendekatan ini bergantung pada cara menggabungkan kaedah segitiga Duval dengan pengelas yang bernama pepohon keputusan dan 'random forest' dan ianya bergantung kepada kaedah gabungan suara bagi mendapatkan ramalan akhir kesilapan yang baru di dalam alatubah kuasa. Keputusan DGA sampel minyak yang telah diketahui kesalahan sebenar dikutip dari kertas yang diterbit berlainan dan digunakan untuk melatih dan menguji pengelas.

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LIST OF ABBREVIATIONS

CM	Condition Monitoring
CBM	Condition Based Maintenance
DGA	Dissolved Gas Analysis
AI	Artificial Intelligence
KGM	Key Gas Method
RVM	Recovery Voltage Measurement
PDC	Polarization and Depolarization Current
FDR	Frequency Dielectric Response
DTM	Duval Triangle Method
ANF	Adaptive Neuro Fuzzy inference system
ANN	Artificial Neural Networks
SVM	Support Vector Machine
PSO	Particle Swarm Optimization
ML	Machine Learning
DT	Decision Tree
RF	Random Forest

CHAPTER 1

INTRODUCTION

1.1 Background

Power transformers are among the most important equipment in the power system network. Their reliability directly affects the safety of the power operations. Fault-free operation of large power transformers is essential to sustain electricity supply. Transformer failures are often catastrophic, and usually cause irreversible internal damage (JJ, 2002). Transformer unexpected failures cost can reach $15 million, in addition to utility reputation. These massive costs give serious reason for electrical power utilities to maintain the reliability of the power transformer within its life cycle. Early detection of faults can reduce repair costs by 75 percent, prevent loss of revenue up to 60, percent and yearly cost savings equal to 2 percent of the cost of a new transformer-i.e., approximately $40,000 to $80,000- can be achieved by efficient monitoring of the state of oil (Y. Han, 2003). Many sorts of faults can be predicted before it become failures and outages. Therefore, accurate evaluation of power transformer conditions is critical. Various condition-monitoring techniques of power transformer have been developed to enhance the reliability of operation and to improve power supply quality services to the customers. Some of the techniques are winding vibration analysis, thermal analysis and dissolved gas analysis (Moravej, 2005). Insulation system within a power transformer consists of oil and paper. Due to the high operating temperature inside the power transformer, oil and paper degrade and release several gases inside the oil, which will decrease the dielectric strength of oil and paper. Therefore, it is very essential to measure the amount of these gases in transformer oil to identify incipient faults within the power transformer (C. Homagk, 2008). Dissolved gas in-oil analysis DGA is one of the most effective tools for power transformer condition monitoring (Duval, 1989). DGA is a sensitive and reliable technique for the detection of incipient fault condition within oil-immersed transformers, Through DGA technique the presence of certain key gases can be monitored and quantified. From the DGA test results, an appropriate actions can be taken, either carry out preventive maintenance or repairs the transformer. The analysis of transformer oils not only gives information about the oil, but also affords the detection of other possible problems, such as contact arcing, ageing insulating paper and other possible faults. Due to the need for continuous demand of electricity, transformers will continuously operate except when faults occur in or during maintenance. Hence, the companies usually spend a lot of money for the maintenance of the transformers to ensure that they are in good operating condition. Researchers around the world always try to find new diagnostic methods for detecting and predicting the condition of the power transformers (Boss P, 2000).

1.2 Transformer Condition Monitoring

Condition monitoring embraces the benefit of reducing the maintenance cost, minimize the probability of destructive failures, quality of supply, mitigation in the severity of any loss incurred, eliminating further repair activities, identification of the root causes of losses and knowledge of the transformer operating life. These benefits enable business decision to be taken either on plant revamping or on equipment replacement (Lezhen, 2002). During operation, the transformers are exposed to various stresses, like electrical, thermal, mechanical and environmental. These stresses further pave the way occurrence of some internal faults in transformers with irreversible evolution, hence, reducing their operating life. Taking into consideration that majority of the transformers have been in service more than two decades. Thus, it becomes imperative to fit the transformers with monitoring and diagnosing system. All units undergo through routine tests based on parodic scheme for screening to diagnose initial failure condition (M. Wang, 2002). Recently an advanced maintenance policy called condition based maintenance (CBM). The basis of CBM is the knowledge of health condition obtained from equipment. The knowledge is further utilized by the data analysis and diagnostic techniques to predict the remaining life of equipment or loss rate. Subsequently, the decision are made related to equipment maintenance by optimizing their reliability index, either the equipment requires preventive maintenance, or the equipment must be repaired. This scheme has been widely acknowledged in the area of maintenance. The initial CBM decision depends on the threshold values. When the monitored value exceeds the threshold or the trend occurs to change, the maintenance decision should be timely decided according to pre—set threshold value devices (A. Setayeshmehr, 2004). The maintenance policy is easy and simple, however for a system with multiple state variables tested it is difficult to reflect the combined effect on variety of factors. Therefore, the key of CBM decision making is to establish a precise and reasonable functional relation between their health levels and their condition parameters.

1.3 The Gas Formation

The transformer liquid consists of different hydrocarbon atomic groups like CH_3, CH_2 and CH. The molecular bond which is used to link the molecular group together, such as C-H and C-C bonds, will be broken when exposed to stress for long period. Newly formed of unstable radical or ionic fragments will merge with either hydrogen (H-H), methane (CH_3-H), ethane (CH_3-CH_3), ethylene (CH_2=CH_2), acetylene (CH≡CH), CO (C≡O) or CO_2 (O=C=O) to form another gas molecules, hence, will exhibit different types and amounts of fault gases depends on the severity and category of the transformer fault (Duval, 2001) . Arcing, low energy sparking, partial discharge and overheating are common faults that could happen in the oil-filled transformers. Once faults occurs, the insulation liquid will be decomposed and then a certain amount of combustible and non-combustible faulty gases will be formed. There are 7 types of fault gases that could be generated after the transformer faults; such as hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon dioxide (CO_2) and carbon monoxide (CO) (M. Jovalekic, 2011) . Due to the different amounts of energy required to break different kinds of molecular bonds, types and amount of fault gas generation are varies and depend upon the magnitude of the fault energy. As result there exists a relationship between the fault type and fault gas generation, which can be used to interpret the DGA results. Figure 1.1 shows the diagram of the indicator gases related to each fault type (Sukhbir Singh, 2010) .

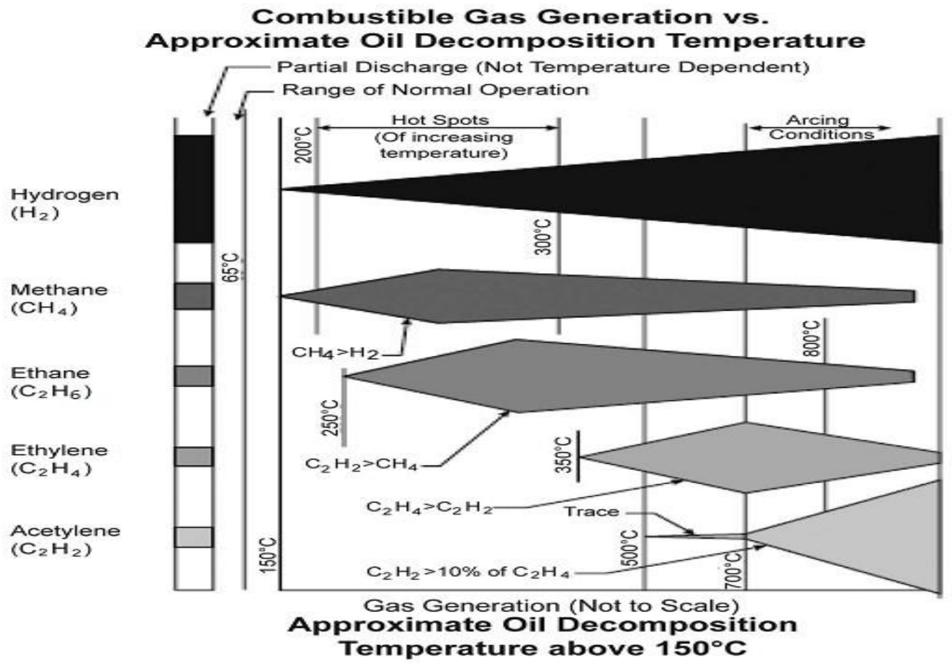

Figure 1.1 Diagram of indicator gases and faulty type and severity (Sukhbir Singh, 2010) .

For example, C_2H_2 and C_2H_4 which have C≡C bond and C=C bond require a higher energy to be formed compared to CH_4 and C_2H_6 . In other words, the generation of C_2H_2 and stands C_2H_4 contributes to the significant faults for oil-filled transformers such as electrical arcing and some hotspot of very high temperatures. As a result, these two types of the fault gases have higher weighing factors in the industry scoring system of transformer operation condition assessment. Even a small amount of C_2H_2 would raise concerns of utility companies who own and operate the transformers (L. V. Badicu, 2012) .

1.4 Problem Statement

Previous methodologies used before for analyzing the dissolved gas in power transformer oil have generally been insufficient. IEEE STD C57.104 stated, "Many techniques for detection and the measurement of gases have been established. However, it must be recognized that analysis of these gases and interpretation of their significance is at this time not a science, but an art subject to variability". Further, "the result of American Society for Testing and Materials (ASTM) indicates that the analytical procedures for gas analysis are difficult, have poor precision, and can be wildly inaccurate, especially between laboratories utilities should be aware that although the physical causes for gas generation have a firm technical basis, interpretation of that information in term of the certain cause or causes is not a specific science" (Ghalkhani, 2002). Several DGA interpretation techniques have been implemented so far, several individual DGA users have also implemented their own graphical software. However, all these methods depend on empirical and not scientific formulation, combining DGA diagnostics may decrease the possibility of misinterpretation and embrace accuracy. It is proven that new methods for analyzing the DGA results are required. Scientifically, sustainable techniques can improve the ability to predict the possible electrical failures, maintenance requirements, and important replacement, assist to determine the need for extra spare transformer, reduce personal reliability risks and reduce the costs (Ghalkhani, 2012). There are couple interpretative techniques based on DGA to diagnose the nature of transformers damage, such as the IEC ratio codes, Rogers's and

Dornenburg's methods, which were developed from important investigations on gases evolved from each faults. Although, existing DGA interpretation technique is widely known in the industry, in some cases, the traditional methods fail to diagnosis. This usually occurs for those transformers, which have more than one sort of fault. Actually, the traditional diagnostic methods (key gas methods) depend on the ratio of gases formed from an individual fault or from multiple faults but with one of dominant nature in a transformer. When gases from multiple fault in a transformer are obtained, the relation between different gases gets too complicated and might not match the codes are pre-defined. For instance, the IEC codes are defined from specific gas ratios. When the gas ratio rise across the defined boundaries, the code is changed suddenly between 0, 1 and 0.2 In fact, the gas ratio limit may not be clear. Therefore, among various sorts of faults, the code should not change extremely across the limits (Su, 2016). Duval triangle method (DTM) is another traditional method in DGA. Based on some published studies, DTM gives the most accurate and consistent diagnoses than any other conventional method exist at this time (Golarz, 2016).Although this method is easily performed, but due to careless implementation, DTM can obtain false diagnoses since there is no region inside the triangle is designated for normal condition. Therefore it always provides diagnoses of fault even in the normal ageing condition when there is no faults. This can be rephrased as a shortcoming because it reduces the accuracy (Huo-Ching Sun, 2012). These conventional methods do not involve any mathematical formulation and the interpretation is based on experimental method, which may change based on experience of the user, results in unreliable analysis (Fathiah Zakaria, 2012). As result, there is still a vital need to increase the prediction accuracy. Hence, this project is motivated by two elements; first is to provide early prediction of fault which can enable precautionary measures to be performed in reducing the risk of transformer explosion. Second, to attempt the best performance by introducing new fault diagnosis approach which is able to interpret diagnostic result more accurately, hence reduce the cost and provide better quality services.

1.5 Research Objective

The main objectives of this research are:

1. To develop a Hybrid model, which combines Duval Triangle Method with two machine-learning classifiers, decision tree and, random forest
2. To evaluate and compare the performance of the proposed method in term of the accuracy.

1.6 Scope of Research

The dissolved gas analysis technique is concerned to determine the incipient electrical and thermal faults in the power transformer in order to suit the maintenance demands and, sustainable replacement. It also can help to determine the need for additional spare transformer, and reduce reliability risks.This is research focusing on improving the accuracy of diagnosing and prediction the incipient fault in the power transformer oil by using machine learning classifiers based on the conventional method Duval triangle. This technique combines between conventional method with artificial intelligence method to get reliable and accurate final prediction. The machine learning classifiers have been implemented by using Java code program, while the Excel program was used to process the data and do some calculations in this study.

1.7 Thesis Organization

The thesis is organized as follows:

Chapter 1: This chapter presents the brief introduction of this project including problem statement, objectives and scope.

Chapter 2: This chapter presents the background of the research study and review the related works on DGA technique in power transformer oil. A comprehensive review on power transformer and DGA conventional methods.

Chapter 3: This chapter reviews the methodology of the optimisation technique that are proposed to predict the incipient faults in the transformer. Also, the tools and data which are utilised in the experiment.

Chapter 4: This chapter demonstrates the results of DGA for test cases of Duval tringle method and machine learning classifiers. A total of 62 test cases were obtained from published papers and all of the outcomes and comparisons are discussed in this chapter.

Chapter 5: This chapter reviews the conclusions and the achievements of the study accomplished in this research, suggests future works on further improvement to cover the work limitations.