MONITORING THE PROGRESSION OF DIBENZYL DISULPHIDE PRESENCE IN TRANSFORMER INSULATING OIL AT DIFFERENT AGEING TEMPERATURE VIA THIN FILM SACRIFICIAL COPPER STRIPS SENSOR

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A report submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "MONITORING THE PROGRESSION OF DIBENZYL DISULPHIDE PRESENCE IN TRANSFORMER INSULATING OIL AT DIFFERENT AGEING TEMPERATURE VIA THIN FILM SACRIFICIAL COPPER STRIPS SENSOR"is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : AHMAD ZAMANI BIN MAT ZIN BOESTAMI

Date : 4/7/2021

APPROVAL

I hereby declare that I have checked this report entitled "MONITORING THE PROGRESSION OF DIBENZYL DISULPHIDE PRESENCE IN TRANSFORMER INSULATING OIL AT DIFFERENT AGEING TEMPERATURE VIA THIN FILM SACRIFICIAL COPPER STRIPS SENSOR" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

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Signature : ....

Supervisor Name : Ts. Dr. Mohd Shahril Bin Ahmad Khiar

Date : 05/07/2021

DEDICATIONS

My loving mother and father, Mat Zin Boestami bin Jaya and Siti Salmah binti Saidun, as well as my other family members, extend their heartfelt support and love to me and my family. I also dedicate my work to my friends, who have taught me a considerable measure of additional data and have shared their thoughts with me in order to complete my study project. Dr Mohd Shahril Bin Ahmad Khiar, my acknowledged supervisor, is to be thanked for all of his patience, compassion, encouragement, and tolerance in making this all possible, and ultimately worthwhile..

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May God shower the above cited personalities with success and good health in their life.

ABSTRACT

The presence of dibenzyl disulfide (DBDS) in the mineral oil is commonly used as an antioxidant to prevent the formation of oxygen in the insulating oils. However, if the operating temperature of the transformer exceed 100 °C, the chemical bond of DBDS may be breaks and caused a formation of corrosive by-product (i.e., mercaptans). The presence of corrosive by-products in transformer insulating oils may result in the production of semi-conductive copper sulphide, which may be found in both the insulating oils and on the surface of the insulating paper, depending on the circumstances. A low resistance route between the paper-wrapped copper windings is created as a result of this occurrence, which results in a short circuit defect between the turns of the winding. Previous research revealed that thin film sacrificial coppers sensors is an excellent technique to overcome the aforementioned issue. However, the capability of this sensor in detecting the presence of corrosive by-products due to the breakdown of DBDS at various temperature conditions is still vague. In order to solve this problem, an alternate technique is presented in this research, which makes use of the interpolation and extrapolation methods implemented via the MATLAB programme. The findings of this study showed that this method is capable of predicting the existence of corrosive by-products resulting from the breakdown of DBDS at a certain temperature throughout the course of its operation.

ABSTRAK

Kehadiran dibenzyl disulfide (DBDS) dalam minyak mineral biasanya digunakan sebagai antioksidan untuk mencegah pembentukan oksigen dalam minyak penebat. Walau bagaimanapun, jika suhu operasi transformer melebihi 100 ° C, ikatan kimia DBDS mungkin pecah dan menyebabkan pembentukan produk sampingan yang menghakis (iaitu, mercaptan). Kehadiran produk sampingan yang menghakis dalam minyak penebat pengubah boleh mengakibatkan pengeluaran sulfida tembaga separa konduktif, yang mungkin terdapat pada minyak penebat dan di permukaan kertas penebat, bergantung pada keadaan. Laluan rintangan rendah antara belitan tembaga yang dibalut kertas dibuat sebagai hasil dari kejadian ini, yang mengakibatkan kecacatan litar pintas antara putaran belitan. Penyelidikan sebelumnya menunjukkan bahawa sensor penipisan filem nipis adalah teknik yang sangat baik untuk mengatasi masalah yang disebutkan di atas. Walau bagaimanapun, kemampuan sensor ini dalam mengesan kehadiran produk sampingan yang menghakis akibat kerosakan DBDS pada pelbagai keadaan suhu masih samar-samar. Untuk menyelesaikan masalah ini, teknik alternatif dikemukakan dalam penyelidikan ini, yang menggunakan kaedah interpolasi dan ekstrapolasi yang dilaksanakan melalui program MATLAB. Hasil dapatan kajian ini menunjukkan bahawa kaedah ini mampu meramalkan adanya produk sampingan yang menghakis akibat kerosakan DBDS pada suhu tertentu sepanjang pengoperasiannya

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BiBZ	-	Bibenzyl
BS EN	-	British standard
°C	-	Degree Celsius
CCD	-	Covered conductor deposition
CIGRE	-	International Council on Large Electric Systems (in French: *Conseil International des Grands Réseaux Électriques*)
DBDS	-	Dibenzyl disulphide
DBS	-	Dibenzyl sulphide
DGA	-	Dissolved gas analysis
DIN	-	German Institute for Standardization (in German: *Deutsches Institut für Normung*)
EDX	-	Energy dispersive X-ray spectroscopy
FDS	-	Frequency domain spectroscopy
IEC	-	International Electrotechnical Commission
mm^2	-	Square millimetres
SEM	-	Scanning electron microscopy
wt %	-	Weight percent
µm	-	Micrometre(s)
ME	-	Mathematical equation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Insulation system is the heart of power transformer that is used to insulate many critical elements (i.e. tap changers, circuit breakers, bushings, and transformers) [1]. Figure 1.1 depicts the components of an oil-filled power transformer, which is comprised of two primary insulations, cellulose-based solid insulation and insulating oil, as shown in the diagram. The pressboard (insulator) between the windings and the core yoke, as well as between the leads and the ground, provides the most significant insulation. For minor insulation, it refers to the insulator (Kraft paper) at the inter-disc and inter-turn windings.

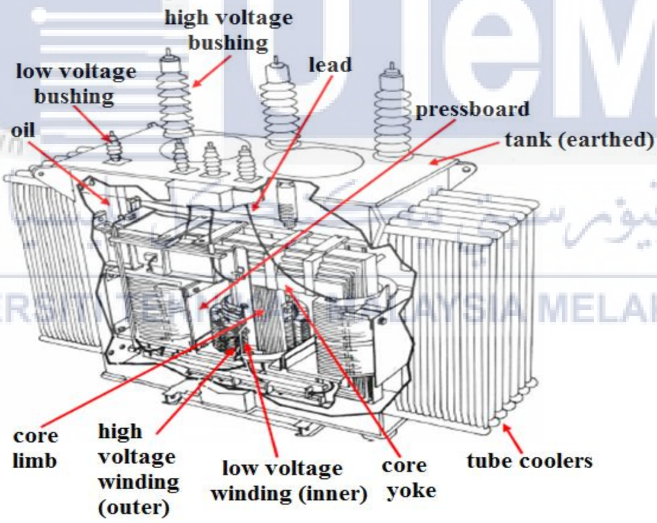

Figure 1.1: Components of an oil-filled power transformer [2]

The state of the insulator in transformers may be used to predict their life expectancy [3]. When it comes to the health of a power transformer, the quality of the oil and the insulating paper are important considerations [4]. As a result, condition monitoring is critical to preventing the deterioration of insulating oil and paper insulation, which is necessary to safeguard power transformers from failure.

There are two types of power transformer, which differ on their insulation type which are liquid-filled transformers and dry-type transformers. The insulating medium used in liquid-filled transformers is oil while dry-type transformers are either air or gas [5]. Liquid-filled transformers is commonly used in power transformers [2] because oil is more efficient to reduce temperature at hot spots in the coils as compared to either air or gas in dry-type transformers [1]. The drawback of using the oil as the insulation is that it is highly flammable thus, may cause an explosion [6]. It shall be noted that power transformer explosions can cause work accidents, environmental hazards (oil spillage), and sudden discontinuity of power supply that give a significant sufferer to utility companies and commercial businesses [7].

Insulating medium of oil and insulating paper in the oil-filled transformer carry two main functions; (1) creates an acceptable level of insulation, and (2) acts as coolant to extract heat from the winding [8]. The malfunctioning of insulation system inside the transformer not only effect the insulating properties, it also effects the heats transfer properties of the oil itself which in turn reducing both performance and life expectancy of the transformer. In order to protect the stability of mineral oil and prevent from overheating to the transformers, some additives know as antioxidant is added. The common antioxidant used is Dibenzyl disulphide (DBDS) [9] because of its characteristic which is a good and stable antioxidant. However, the existence of DBDS in insulating oil may leads to sulphur corrosion problem.

1.2 Research Motivation and Problem Statement

According CIGRE technical report (Working Group A2.40) published in 2015, two main concern of power transformer failure stated are inter-turn failures and dielectric failures, which represent 64 % of power transformer failures (as shown in Figure 1.2) [10].

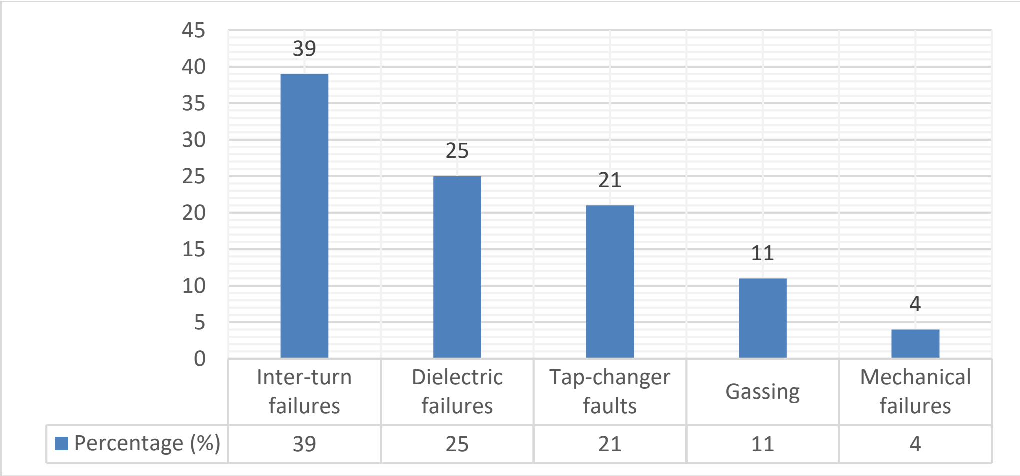

Figure 1.2: Types of transformer failures [10]

Figure 1.2 shows that 86 % of transformer failures are due to sulphur corrosion. Even though the percent are quite high, sulphur corrosion is considered as a minor technical issue in electrical utilities and still lack of in-depth studies because only a few failure cases have been reported [5]. Arvidsson et al. [11] stated in his report that sulphur corrosion already known at the end of the 1980s in Brazil and South Africa. However, the improvement of oil purification and the implementation of oil corrosive tests somewhat resolved this issue in the early 1990s [**12**],[**13**]. This issue resurfaced back at the beginning of the 21st century [**14**] and since then, the significantly increasing trend cases associated with the sulphur corrosion was reported [5]. Due to the lacking in studies related to sulphur corrosion, some of the major organisations such as CIGRE and Sea Marconi led to implement countermeasures to tackle this problem [[**15**],[**16**].

Corrosion sulphur in oil-filled transformer has been recognised as a global problem due to increasing trend of transformer failure cause by unwanted semiconductor deposition of copper sulphide (Cu_2S) [**17**] due to presence of DBDS. Therefore, it is crucial to monitor the presence of DBDS in insulating oils. On the other hand, any mitigation techniques are necessary to avoid any insulation failure.

The introduction of a new approach for monitoring sulphur corrosion in transformer oils, which makes use of thin film technology, has occurred recently in 2019. Using this method, which includes correlating the resistance of copper strip sensors with the concentration of corrosive sulphur compounds in transformer oils, it is possible to monitor the development of sulphur corrosion in transformer oils (i.e., DBDS and elemental sulphur). The temperature range utilised in this method, on the other hand, is the smallest possible. An alternate method is thus presented in this research in order to enhance the capacity of this sensor in detecting the corrosive by-products produced during the breakdown of DBDS across an extended temperature range. As a result, interpolation and extrapolation methods will be implemented via the use of MATLAB software.

1.3 Research Objectives

For the purpose of accomplishing this goal, the following three goals have been established:

1. To study the effect of temperature variations on the progression of corrosive by products due to the breakdown of DBDS via thin film sacrificial copper strips sensors.
2. To develop new algorithm for enhancing the capability of thin film sacrificial copper strips to detect the presence of corrosive by-products due to the breakdown of DBDS wide range of temperature conditions using interpolation and extrapolation method via MATLAB software.
3. To validate the results obtained from the developed algorithm with the results obtained using mathematical expressions...

1.4 Scope of Research

This study looks at the impact of DBDS at various ageing temperatures utilizing a thin film sacrificial copper strips sensor. This study's scopes are as follows:

a) Data on the change in resistance (ΔR) f thin film sacrificial copper strips is collected [18].

b) Using MATLAB software, create an innovative interpolation and extrapolation method.

c) Comparing the results of interpolation and extrapolation using MATLAB software to the outcomes of mathematical equations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter contains all of the review related to sulphur corrosion. Section 2.2 explains the review on monitoring of insulating oil. Then, Section 2.3 describes the overview of the mineral oils in order to clearly generate the ideas on the specification of mineral oil. General background and the effect of corrosive sulphur in are explained in Section 2.4 and Section 2.5, respectively. The last section presents the fundamental issues related with this investigation focusing about the identification and condition observing of corrosive sulphur.

2.2 Condition Monitoring of Insulating Oil

Insulating oil used for the oil-filled power transformer can be describe as a blood in a human body that carry a lot of valuable information, easy to access and able to identified the health of any power transformers. Therefore, monitoring for insulating oil is the something that very crucial to do to prevent any catastrophic that causes loss in money and importantly, the human life. The degradation of insulating paper mainly causes by the problem occurrence in the insulating oil itself.

There are two types of monitoring namely schedule-based monitoring and condition-based monitoring. Schedule-based monitoring or offline monitoring, the maintenance always does with specific time or date. However, the failure incidents may happen before the maintenance time. Therefore, condition-based monitoring is more favourable to predict the transformer failure as compared to the schedule-based monitoring. As a result, the industry places a greater emphasis on schedule-based to condition-based monitoring when it comes to power transformer maintenance. [19].

Nowadays, many researchers have been preferred to online condition monitoring in order to study and create their own innovation. When compared to offline condition monitoring, the benefits of this monitoring include that the instant information given can eliminate the need for an unneeded shutdown, which can save money, manpower, and time. Presently, the significant role as an online condition monitoring tool has hold by dissolved gas analysis (DGA) as equipment to detect any transformer faults [20], such as partial discharge, local overheating, and arcing based on the concentration of the gases. The specifics gases are methane, ethylene, ethane, carbon dioxide, oxygen, acetylene, hydrogen, carbon monoxide and nitrogen [20] that formed because of the chemical reaction of insulating paper and insulating oil.

Generally, the proper routine maintenance of power transformer expectedly functioning around 60 years [21]. However, according to the International Association of Engineering Insurers (Table **2.1**), the accounted of losses in cost (US Dollar) that in the range of 1997 and 2001 show total value of more than 286 million US dollars due to early power transformer failures. From Table 2.1, the insulation failure is the highest number of casses where the contribution factors are heat, acidity, moisture and oxidation. The life expectancy also reduces to around 40 years comparing with normal life expectancy due to this failure. Hence, a proper investigation technique is crucial to overcome this issue.

Table 2.1: Type of power transformer failures [23].

TYPE OF FAILURE	CONTRIBUTION FACTORS	NUMBER OF CASES	COST (US DOLLAR)
Insulation failure	Heat, moisture, oxidation, acidity	24	149,967,277
Design/material/ workmanship	Foreign object left in the tank, poor brazing (metal joining)	22	64,696,051
Oil contamination	Sludge	4	11,836,367
Overloading	Load exceed the capacity written on nameplate	5	8,568,768
Fire/explosion		3	8,045,771
Line surge	Line faults/flashovers	4	4,959,691
Improper maintenance/ operation	Accumulation of dirt in oil / corrosion	5	3,518,783
Flood	Man-made/natural caused flood	2	2,240,198
Loose connection	Improper bolt connection	6	2,186,725
Lightning	Lightning surge	3	657,935
Moisture	Pipe leak/roof leak/ leaking bushing or fitting	1	175,000
Unknown		15	29,776,245
Total		94	286,628,811

2.3 Overview of Mineral Oils: Types and Reasons

The similarities for all types of transformers insulating oil are for its purpose to serve as an electrical insulator and act as a coolant to ensure steady operational performance of high voltage equipment under normal operating state [3]. There are many types of insulating oil for example mineral oil, silicone-based oil, natural ester, and synthetic ester that give different benefits and disadvantage but still the same use purposes [3]. Since this research is focusing about the degradation of insulating paper due to DBDS, the discussion only talks about the mineral oil because of few reasons.

Mineral oil is one of the most usually utilized insulating liquid ordinarily to the huge power transformers around the world [22]. The comprehensiveness of utilization of mineral oil results from its numerous positive characteristics and its excellent acknowledgment throughout the long term [23]. Mineral oil is a dielectric liquid that derived from crude petroleum [24] and needs to undergo thoroughly a refinery process to get a wanted physicochemical property and to eliminate contaminations based on the requirement of specific application [3]. Mineral oil is a hydrocarbon fraction (Figure 2.1) mainly composed of four generic classes of organic compounds which are aromatics, paraffins, naphthene and olefines. The organic compounds must be an optimum mixture of four organic components to get optimum insulating property and stability at the same time [25].

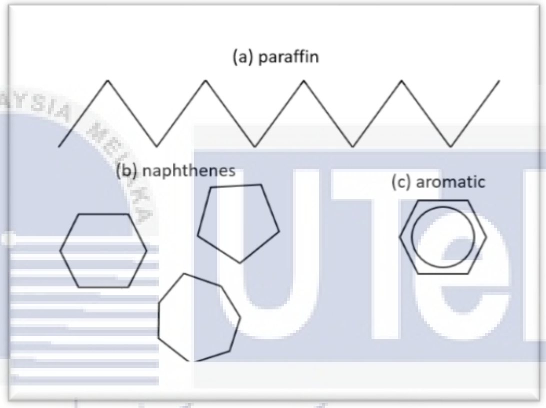

Figure 2.1: Three hydrocarbon compound mainly in mineral oil: (a) paraffin, (b) naphthene, and (c) aromatic [25]

The most commonly oil used in power transformers is hydrocarbon-based mineral oil. It is mainly composed of four generic classes of organic compounds, aromatics, paraffins, naphthene and olefines. Transformer oil gives a better insulation when aromatics, paraffins, naphthene and olefines are present at the right proportion. The optimum insulation transformer oil is required to have more of saturated paraffins then of aromatics, naphthene and olefines combinations [26]. The optimum stabilityare neceessary required more aromatics and naphthene compounds. To get both insulating property and stability at the same time, there must be an optimum mixture of four organic components. This can be gained by wisely purifying of crude oil.

The fundamental function for the insulating oil is it need to delivers exceptional heat dissipation. When the transformer is heavily loaded for a long time, local overheating of the transformer winding can occurred and might lead to catastrophic transformer failure. Due to this reason, naphthenic based mineral oil is the best selection due to its low kinematic viscosity [27] which enhanced the circulation flow speed for the heat to be released from the transformer. Furthermore, the naphthenic based mineral oil helps to dissolve any oil sludge created from those burdens [28]. The sludge created will block the cooling pipes and increasing the temperature, plus, scratching cellulose surfaces while circulation. Therefore, naphthenic based is recommended to extend the life expectancy of a power transformer.

High specific heat capacity and thermal conductivity, high electrical strength, high chemical stability, high level of flash point, low viscosity, low pour point, good impulse strength, and non-toxicity towards the surrounding environment are the characteristic needed for the good and reliable insulating oil. However, to achieved all these properties are impossible. Therefore, a well-adjusted compromise between the oil properties is vital.

Figure 2.2 and Figure 2.3 show the failure in the transformer related to the insulation failure due to high temperature in the windings [29]. The reasons for this failure is the poor cooling of the winding or configuration imperfection. The presence of copper sulphide on the copper channels and the Kraft paper tapes adjoining them become a potential place of overheating. Researchers found out that regularly copper sulphide deposits reveal at the hot spots of high temperature and strongly signifying that in these failure, corrosive sulphur are the vital contributing factor [29].