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REPORT

Sweep Frequency Response Analysis (SFRA) Results Interpretation using Cross Correlation Coefficient Method for Distribution Transformer

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SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA) RESULTS INTERPRETATION USING CROSS CORRELATION COEFFICIENT METHOD FOR DISTRIBUTION TRANSFORMER

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

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I declare that this report entitle "*Sweep Frequency Response Analysis (SFRA) Results Interpretation using Cross Correlation Coefficient Method for Distribution Transformer*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

Signature	:	……………………………………
Student name	:	……………………………………
Date	:	……………………………………

To my beloved mother and father

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ABSTRACT

The distribution transformers in Malaysia are very crucial parts of the power system grid. Therefore, asset management is a must in order to sustain the distribution transformer services. Recently, one of the advanced techniques of asset management in Tenaga Nasional Berhad (TNB) is Frequency Response Analysis (FRA). Its capability is compromised via monitoring winding displacement and other electrical faults. The FRA technique uses Sweep Frequency Response Analysis (SFRA) to measure and evaluate the condition of the transformer whether it is healthy or not. Previously, the interpretation of SFRA results is used based on worldwide research finding as a guideline. Recently in 2013, IEEE Std C57. 149 2012 (IEEE Guide for the Application and Interpretation of Frequency Response Analysis for Oil-Immersed Transformer) is established for interpreting SFRA measurement result data. From the IEEE Standard C57.149 2012, four frequency sub-band is discovered: Region 1 (20 Hz – 10 kHz), Region 2 (5 kHz – 100 kHz), Region 3 (50 kHz – 1 MHz) and Region 4 (> 1 MHz). Statistical technique is one technique used to analyze the data and the method to evaluate the condition of the transformer is done using Cross Correlation Coefficient (CCF) method. Ten transformers are used as the test's subject and the finding from the testing is two from the transformers is in unhealthy condition while others are not. The CCF value 90% and above evaluated as a healthy condition and below than 90% evaluated as unhealthy condition of transformer. PPU Seksyen 23 T2 and PPU Kelibang T2 are obviously indicated in unhealthy condition and other transformer still operates as usual.

ABSTRAK

Pengubah pengagihan di Malaysia adalah bahagian yang sangat penting bagi sistem grid kuasa. Olehitu, pengurusan aset adalah satu kemestian bagi mengekalkan perkhidmatan pengagihan pengubah. Kini, salah satu teknik pengurusan aset di Tenaga Nasional Berhad (TNB) ialah Analisis Sambutan Frekuensi (FRA). Keupayaanya terjejas melalui pemantauan penggulungan anjakan dan kesilapan elektrik lain. Teknik FRA menggunakan kaedah Analisis Sambutan Frekuensi Sapuan (SFRA) untuk mengukur dan menilai keadaan pengubah samaada ia sihat atau pun tidak. Sebelum ini, tafsiran bagi keputusan SFRA adalah berdasarkan penyelidikan seluruh duniasebagai panduan. Awal tahun 2013, IEEE Std C57.149 2012 (IEEE Panduan Untuk Aplikasi Dan Tafsiran Bagi Analisis Sambutan Frekuensi Untuk Minyak-Rendam Pengubah) ditubuhkan untuk mentaksir data dari Pengukuran SFRA. Daripada IEEE Std C57. 149 2012, empat frekuensi sub band di jumpai: Kawasan 1 (20 Hz – 10 kHz), Kawasan 2 (5 kHz – 100 kHz), Kawasan 3 (50 kHz – 1 MHz) and Kawasan 4 (> 1 MHz). Teknik statistik adalah salah satu teknik untuk menganalisis data dan kaedah untuk menilai keadaan pengubah ialah menggunakan kaedah Palang Kolerasi Pekali (CCF). Sepuluh pengubah digunakan untuk di uji dan hasil daripada ujian tersebut adalah dua daripada pengubah berada dalam keadaan tidak sihat dan yang lain masih lagi boleh beroperasi. Nilai CCF 90% dan keatas dinilai sebagai keadaan yang sihat dan bawah daripada 90% dinilai sebagai keadaan yang tidahk sihat bagi pengubah. PPU Seksyen 23 T2 dan PPU Kelibang T2 jelas menunjukkan keadaan yang tidak sihat dan pengubah lain masih lagi boleh beroperasi seperti biasa.

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CHAPTER 1

INTRODUCTION

This chapter will discuss about the research background, project motivation, problem statement, project objective, project scope and the expected result. This chapter will show the view of the research work.

1.1 Research Background

The continuous supply of power system network in transmission and distribution system depends on the reliability of power transformer [1]. Transformer is an important device in electrical power system especially in the distribution system and it produce large mechanical stress during in operation. The largest mechanical stress during operation is caused by winding and core [2]. The condition of the transformer must be maintained by using routine test or investigation because the power transformer is one of the most expensive devices in the electrical system [3]. Previously, the research makes the testing using the worldwide research finding as a guide. Now, IEEE standard appears in 2013 as a guide for Frequency Response Analysis (FRA) diagnosis.

Frequency Response Analysis (FRA) is a technique that often used for diagnostic of the mechanical and electrical fault of transformer. FRA use Sweep Frequency Response Analysis (SFRA) method to measure and analyze the condition of transformer to produce the response curve. The response curve is used to detect the condition of transformer by using graphical of curve or statistical techniques from curve data. The data from response curve could be analyzed by using statistical technique such as statistical indicator [1]. The Cross Correlation Coefficient (CCF) method is one of various tools and algorithms for analyzing FRA measurements. The data compressed and analyzed by using frequency sub band from response curve. The result from statistical techniques determine the transformer whether it is in healthy condition or not. The analysis is according to IEEE Std C57. 149 2012 as guidelines.

1.2 Project Motivation

The main goal and purpose of this research is about the maintenance and internal check of the transformer condition. The transformer is an important device in electrical power system especially in the distribution system. Transformer condition must be maintained in good condition. Electrical and mechanical stress can damage the transformer windings if there is no maintenance done to it in certain period. Once the transformer winding is damaged, whole transformer must be replaced with new transformer and the price of one transformer is very expensive [1]. This situation will increase the cost of development just because there is no maintenance done to the transformer.

Actually, transformer maintenance and condition check must be done as routines. Diagnostic technique is used to check the internal of the transformer winding. Sweep Frequency response Analysis (SFRA) is one of the methods to diagnose the condition of the transformer winding. The diagnosis result from SFRA must be analyzed by using statistical technique to detect and verify the condition of the transformer. Previously, the analysis of result depends on the worldwide research finding as a guide. In March 2013, new IEEE standard is established and the maintenance and internal check for this research is more accurate by using new IEEE standard.

1.3 Problem Statement

Previously, the research of interpretation of Sweep Frequency Response Analysis (SFRA) for TNB distribution transformer is based on worldwide research finding [4].The worldwide research finding that is used as a reference is Cigre Working Group A2/26, Chinese Standard DL911/2004 and IEEE Draft Guide PC57 149. The Chinese Standard DL911/2001 is only valid for China states but it is not suitable to be use din another country. For Cigre Working Group A2/26 and IEEE Draft Guide PC57 149, it did not confirm as a guide because it is only a draft from working group experiment. Beside that, TNB evaluates the transformer winding condition by using Omicron FRAnalyzer Software which the guide of the interpretation used was based on Chinese Standard DL911/2004 [5]. By that, the results of analyzed by engineer cannot be standardize.

In this research work, the new guide from IEEE standard: IEEE Std C57. 149 2012 was applied to evaluate the data from TNB distribution transformer. Because of the use of new IEEE standard, the manual verification is applied by using Cross Correlation Coefficient (CCF) method. By using the new IEEE standard, the transformer condition diagnostic could be more accurate and reliable.

1.4 Project Objectives

The project objectives of this project are:

1) To discover frequency sub band from the SFRA result according to IEEE Std C57.149 2012 (IEEE Guide for the Application and Interpretation of Frequency Response Analysis for Oil-Immersed Transformer).

2) To evaluate the transformer condition by using Cross Correlation Coefficient method from the SFRA result.

1.5 Project Scopes

The project scope involves the following:

1) SFRA measurement conducted on ten TNB distribution transformers with two transformers are already in defective condition and other in normal conditions.

2) Interpretation of SFRA measurement results of TNB distribution transformer according to IEEE Std C57.149 2012.

3) Omicron FRAnalyzer software is used to collect the SFRA result data.

4) Cross Correlation Coefficient (CCF) method was used to analyze the SFRA measurement result data using SPSS Statistical Software.

1.6 Expected Project Outcome

From this research work, the expected project outcome is SFRA measurement results data from ten TNB distribution transformers is extracted and rearrange in Microsoft Excel by frequency sub-band according to IEEE Std C57.149 2012 standard. The results in the frequency sub- band will be analyzed in Cross Correlation Coefficient (CCF) method as statistical technique. By using statistical technique, the condition of the transformer will be detected. After this research complete, it can be used in TNB distribution department for diagnosis and evaluation of transformer condition.

CHAPTER 2

LITERATURE REVIEW

This chapter will present the literature review to give the readers information and ideas in completing the research in the detecting failure of the transformer. In this chapter, it covers about the theory and basic principles, review of previous related work, software information and summary of frequency sub-band of this research.

2.1 Theory and Basic Principles

On this topic, it will discuss about the theory and basic principles of the project. In this topic, it will discuss about the fault diagnosis using sweep frequency response analysis (SFRA), frequency response analysis (FRA), failure in transformer and statistical technique: cross correlation coefficient (CCF) method.

2.1.1 Transformer Failure

Transformer is an important element in electrical power system. It is a device that transfer electrical energy from one circuit to another circuit through inductively couple conductor or coil [6]. The major construction of transformer is the primary and secondary winding. The primary winding is connected to the input voltage and the secondary winding is connected to output voltage which is to be stepped up or stepped down.

Figure 2.1 : Power transformer [6]

The power transformer has three types: unit transformer, substation transformer and distribution transformer. There are five classifications in power transformer. The classification of the power transformer is pole mounted transformer, house hold transformer, dry type distribution transformer, current transformer (CT), and power transformer (oil immersed) [6]. The power transformer is shown in the Figure 2.1.

The transformer failures can be defined by two situations: first, any forced outage due to transformer damage in service and second, any problem that requires removal of the transformer to a repair facility, or which requires extensive repair [7]. The main component of power transformer is winding, core, main tank, oil, cooling system, bushing and tap changer. This component can make the transformer stress to operate when faults occur. The Table 2.1 shows the percentage of the transformer failure with and without on load tap changer (OLTC).

Table 2.1 : Percentage of transformer failure [2]

Component	**With OLTC**	**With OLTC**
Tank	6%	17.4%
Tap Changer	40%	4.6%
Winding and core	35%	33%
Auxiliaries	5%	11%
Bushing and terminal	14%	33.3%

In Table 2.1, the transformer failure at winding and core is always occurs in both situations, with and without OLTC. Winding and core failure are categorized under mechanical problem. Winding deformations caused by mechanical and electrical faults. The effect of winding deformation is winding movement, hoop buckling, insulation damage, bending of conductors and collapse of the winding structure. The mechanical stress occurs during the transformer fault condition such as a short circuit. Axial and radial electromagnetic forces are induced from the interaction of the short circuit current with the leakage flux.

Axial winding deformations cause the winding stretched and then tighten [8]. The effect of axial winding deformation is axial bending of conductors. Figure 2.2 shows the illustration of the axial bending of the conductor. Radial winding deformation or hoop buckling caused of high over current faults [8]. It is stress on the inner winding which cause the conductor bend and on the outer winding which causes the conductor is tensile stress. Figure 2.3 shows the inner and outer winding cause by hoop buckling.

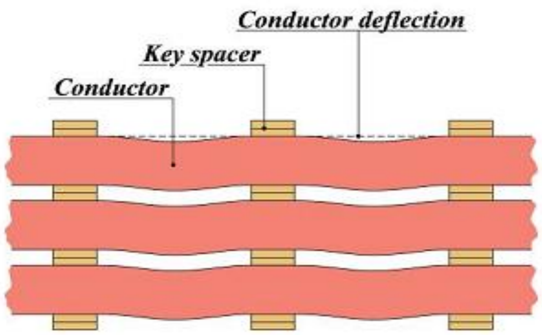

Figure 2.2 : Axial bending of conductor [9]

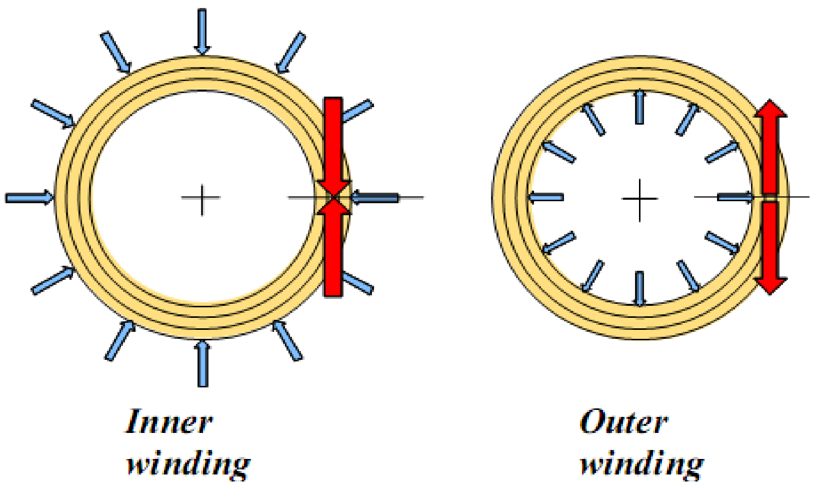

Figure 2.3 : Inner and outer winding cause by hoop buckling [9]

2.1.2 Transformer Fault Analysis

Any device in power system has life time, including transformer [9]. The transformer can be monitored using several methods depend on the problem in transformer as shown in Table 2.2.

Table 2.2 : Problem and diagnostic techniques [9]

Problem	**Diagnostic Techniques**
Mechanical	1. Excitation Current 2. Low-Voltage Impulse 3. Frequency Response Analysis (FRA) 4. Leakage Inductance Measurement 5. capacitance
Thermal	Gas and oil analysis 1. Gas Chromatography 2. Equivalent Hydrogen Method Oil paper deterioration 1. Liquid Chromatography 2. Furan Analysis Hot spot detection 1. Invasive Sensor 2. Infrared Thermograph
Dielectric	Oil analysis 1. Moisture, Electric Strength, resistivity 2. Turn ratio Pd measurement 1. Ultrasonic Method 2. Electrical Method 3. Power Factor Method 4. Dielectric Frequency Response

2.1.3 Frequency Response Analysis (FRA)

The condition of transformer must be maintained in healthy condition by using diagnostic. There are many methods which were created to diagnose the transformer condition such as dissolved gas analysis (DGA), partial discharge (PD) measurement or insulation oil dielectric measurement [10]. These methods were able to maintain the condition of transformer but some failure exist, such as transformer core damage or coil displacement and other mechanical damages. So, Frequency Response Analysis (FRA) was introduced to diagnose mechanical deformation in transformer. It is very capable and effectual in analyzing the mechanical failure because of injected frequency in winding of transformer.

FRA is a powerful technique used to diagnose the transformer condition because of its capability to sense the change of mechanical condition causes of electromagnetic force. This technique is done by measuring the FRA magnitude and then the measurement is show in wide range of frequency. The result is compared with trace comparison method such as baseline and previous data, sister unit results, or between phase (for this research using between phase comparison method) [8]. The example of test lead connection is shown in Figure 2.4.

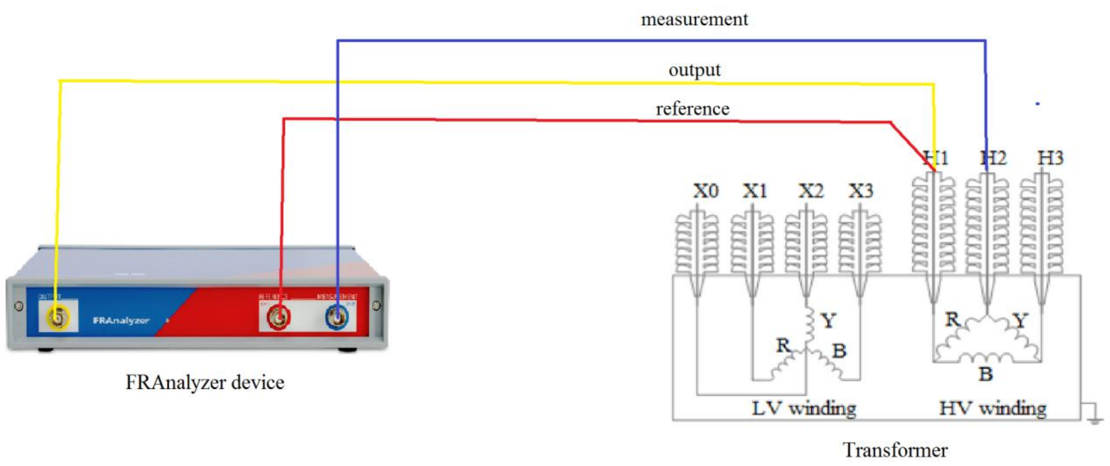

Figure 2.4 : Test lead connection [5]