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REPORT

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

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Date : ……………………………………….

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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2014

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.

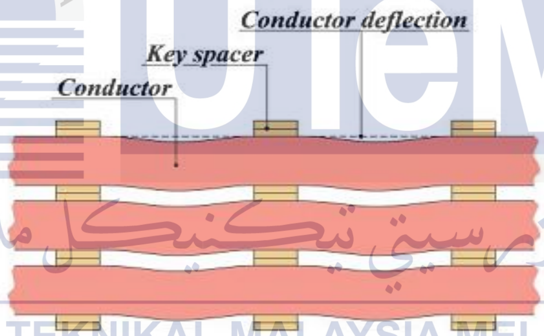


Figure 2.2 : Axial bending of conductor [9]

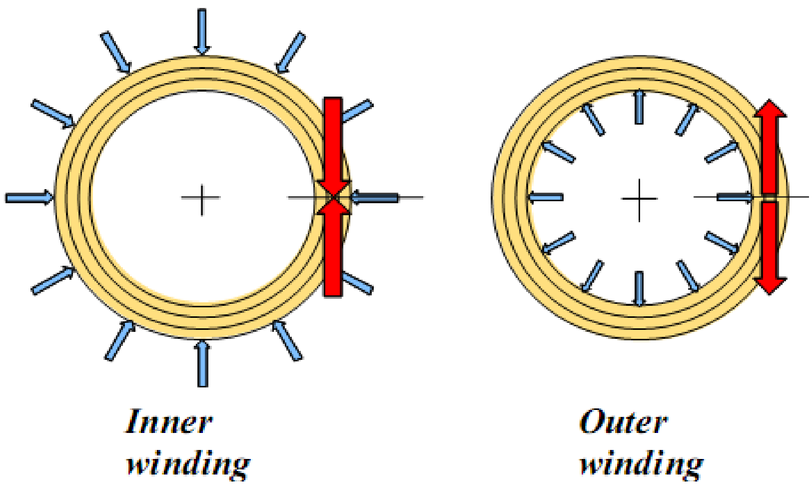


Figure 2.3 : Inner and outer winding cause by hoop buckling [9]

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	<u>Gas and oil analysis</u> 1. Gas Chromatography 2. Equivalent Hydrogen Method <u>Oil paper deterioration</u> 1. Liquid Chromatography 2. Furan Analysis <u>Hot spot detection</u> 1. Invasive Sensor 2. Infrared Thermograph
Dielectric	<u>Oil analysis</u> 1. Moisture, Electric Strength, resistivity 2. Turn ratio <u>Pd measurement</u> 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.

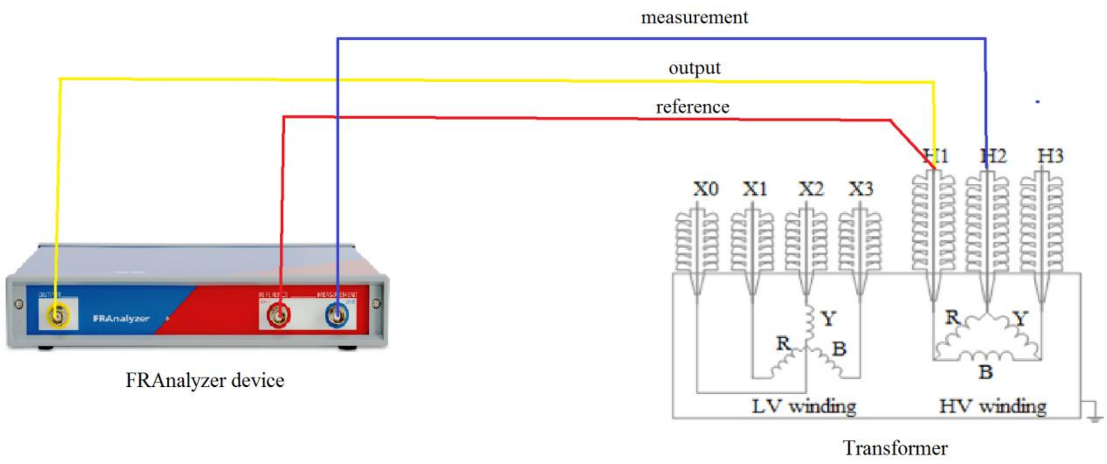


Figure 2.4 : Test lead connection [5]

Figure 2.4 shows an example of test lead connection of FRAnalyzer device connected to winding of the transformer. The “measure” point is connected to H2 terminal, “output” and “reference” point is connected with H1 terminal to get the trace of H1H2 (Red phase for HV winding of the transformer).

From the test lead connection shown in Figure 2.4, the FRA analyzer device is connected with computer to display the result of diagnostic. The result of diagnosis is shown in a graphical waveform as shown in Figure 2.5. The result of diagnosis was displayedin terms of magnitude (above) and phase (below) trace. The magnitude of trace is sub band frequency (Hz) ranging from 20Hz to 2MHz versus magnitude (dB). The phase of trace is frequency (Hz) versus phase (Θ) which is sub band frequency from 20 Hz to 2 MHz. The graph shown in Figure 2.5 can help to interpret the condition of transformer. The data from graph must be converting to data ratio by using formula (2.1) and using Cross Correlation Coefficient (CCF) method to analyze and indicate the condition of transformer.

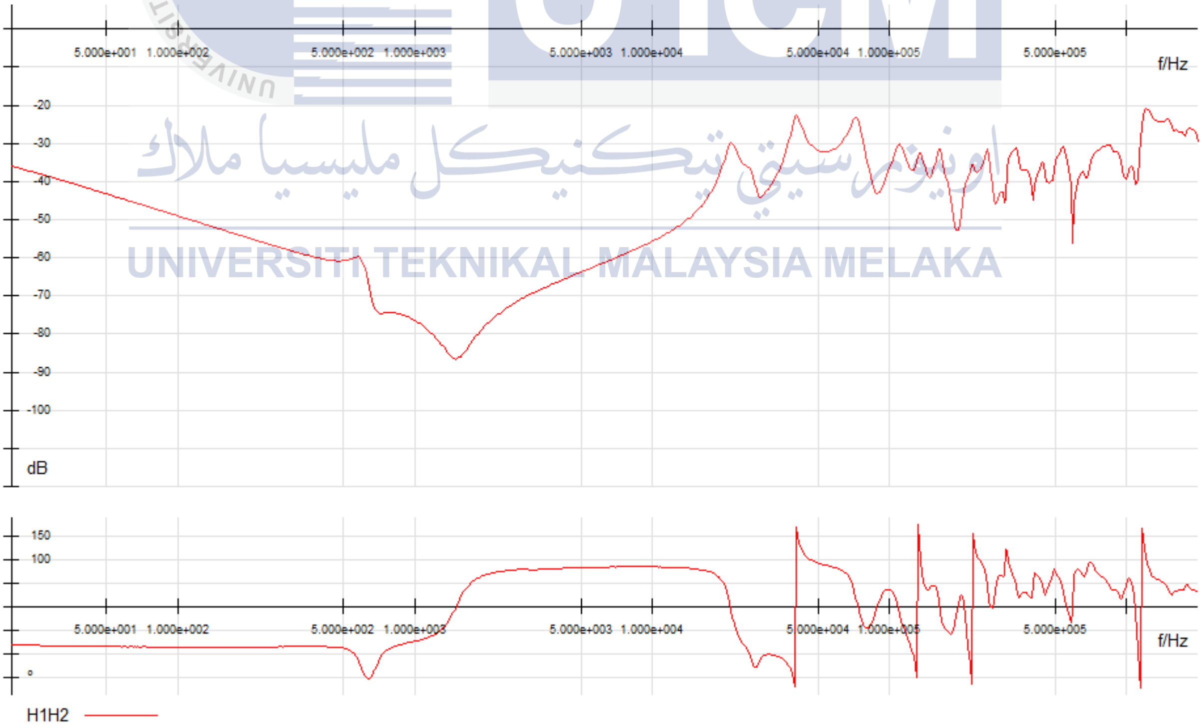


Figure 2.5 : The example graphical result of diagnostic [5]

The Figure 2.6 shows the example of comparison between phases. This example is related to transformer condition between Red and Blue phase. If the trace is not same pattern, thus the transformer has potential to defect. The frequency range of interest is between 20Hz to 2MHz. FRA technique is based on graphical analysis. By using this graphical, the transfer function can be obtained and the result of transfer function can be made using interpretation of frequency responses for detecting the failure of transformer according IEEE guidelines.

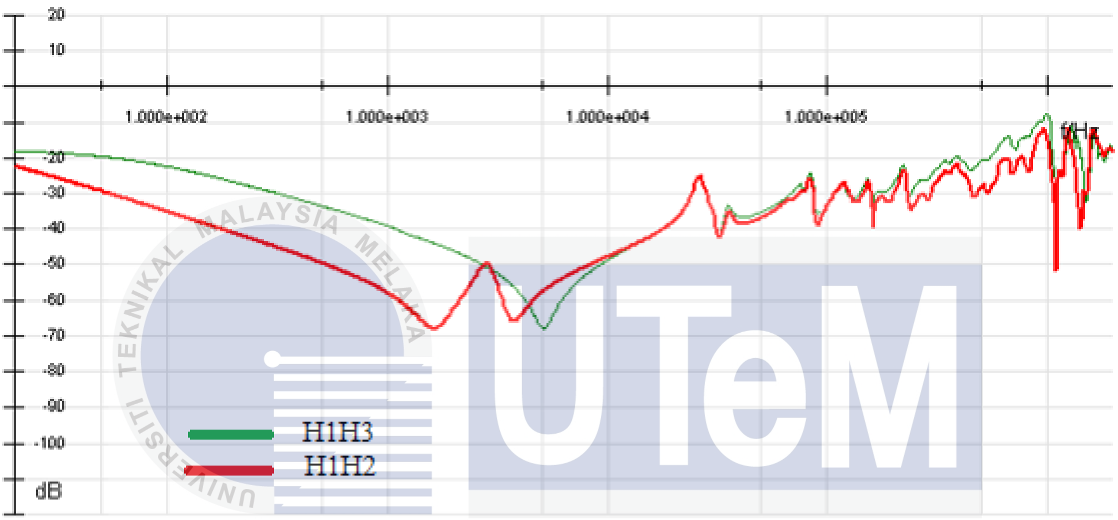


Figure 2.6 : Comparison between H1H2 phase and H1H3 phase [5]

The measurement types of FRA techniques is open circuit measurement, short circuit measurement, capacitive inter winding measurement and inductive inter winding measurement [8]. The measurement type for this research work is open circuit measurement. An open circuit measurement is made from one end of a winding to another with all other terminals floating [8]. It can be applied for both single phase and three phase transformer. Figure 2.7 shows the example of open circuit measurement for high voltage winding with other terminal floating.

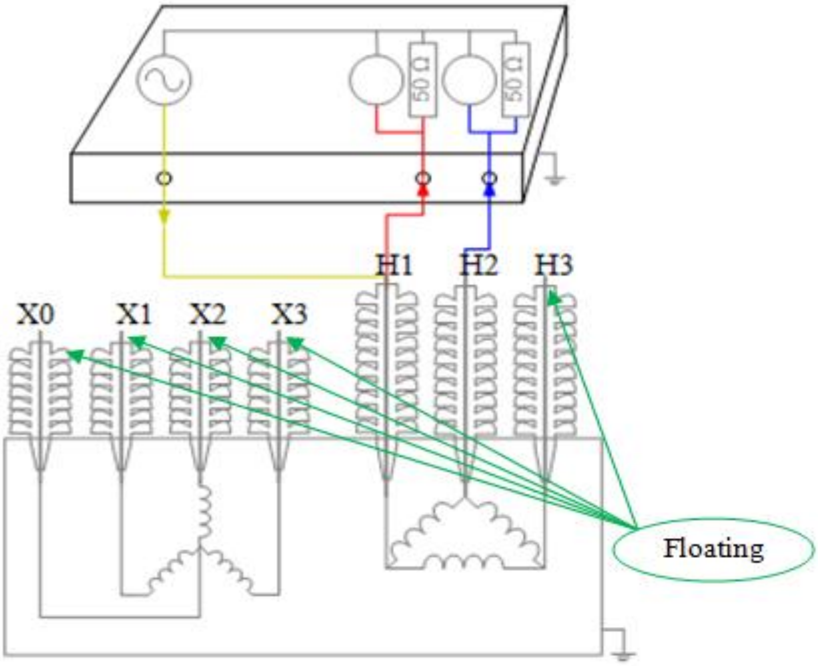


Figure 2.7 : Example of open circuit measurement [5]

For test connection, two winding transformer used; high voltage (HV) winding in delta connection and low voltage (LV) winding in star connection. The trace comparison is use phase to phase comparison of each HV and LV winding. This comparison is used because of an absence of pervious SFRA measurement fingerprints result and unavailability to get SFRA measurement results from the transformer sister unit. Table 2.3 and Figure 2.8 shows the test connection for two winding transformer using phase to phase comparison.

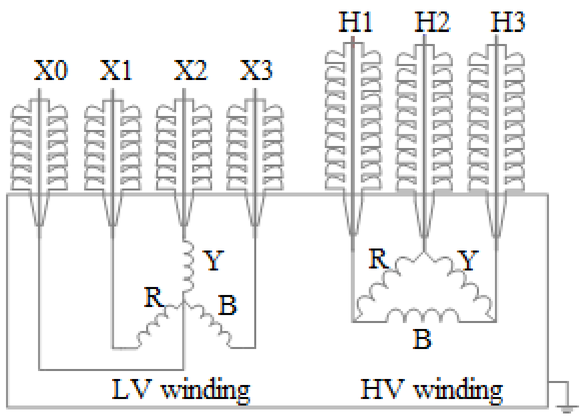


Figure 2.8 : Terminal for HV and LV winding [5]

Table 2.3 : Test connection using phase to phase comparison [8]

Dyn11 distribution transformer		
Winding	**Open Circuit Measurement**	
	Winding configuration	**Phase to phase comparison**
High Voltage winding Delta connection	H1H2 phase (red) H2H3 phase (yellow) H3H1 phase (blue)	H1H2 to H2H3 H1H2 to H3H1 H2H3 to H3H1
Low Voltage winding Star connection	x0x1 phase (red) x0x2 phase (yellow) x0x3 phase (blue)	x0x1 to x0x2 x0x1 to x0x3 x0x2 to x0x3

2.1.4 Sweep Frequency Response Analysis (SFRA)

The FRA has two different methods to detect the failure, sweep frequency response analysis (SFRA) and impulse frequency response analysis (IFRA). SFRA is an effective mechanical condition assessment technique for transformer compare with IFRA [11]. In SFRA method, the wide range of required frequency is generated via a sweep of individual sinusoidal signals injected into one terminal. The magnitude and phase of the transfer function can be obtained as shown in Figure 2.9.

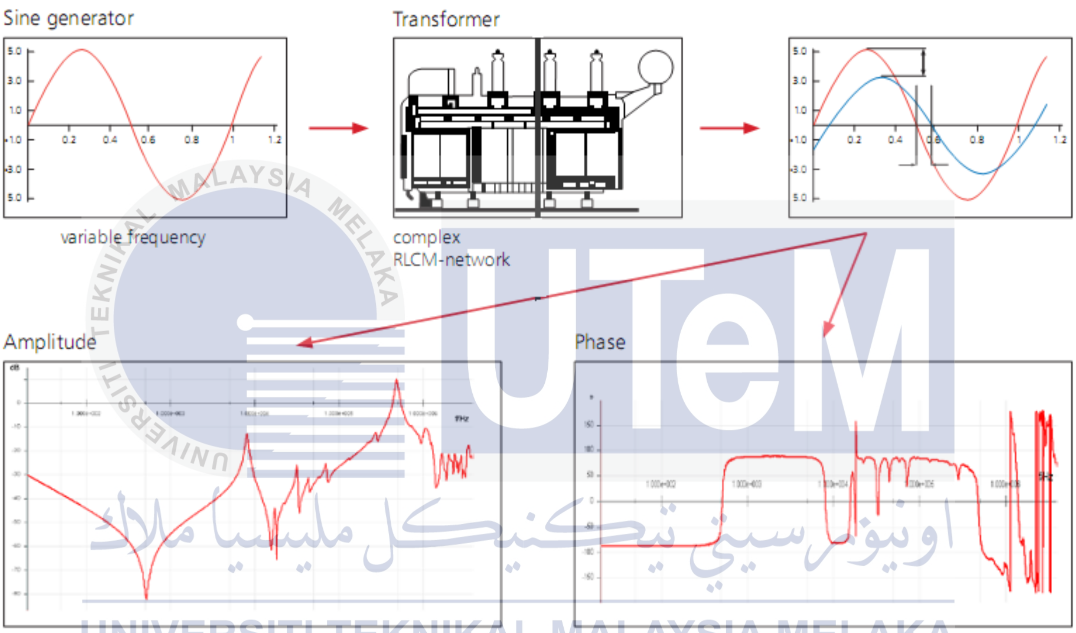


Figure 2.9 : Magnitude and phase transfer function of SFRA [21]

The sinusoidal excitation voltage (from FRAnalyzer device) injected with a continuously increasing frequency into one end of the transformer winding and measures the signal returning from the other end [21]. The injected of sinusoidal into winding produce signal return (other signal) at the other end winding. The comparison with sinusoidal signal and signal return produced unique frequency response [21]. From the comparison, amplitude and phase response will be display at computer.

The measuring range frequency is between 20Hz to 2MHz. The phase response is not used because it did not give more useful information [11]. Figure 2.10 shows the measurement voltage for SFRA result which V_{signal} is the injected sinusoidal signal, V_{in} the measured reference and V_{out} is the response signal. The 50 Ω is the impedance of the SFRA instrument and Z is the transformer impedance [12]. The transformer impedance, Z causes the difference between V_{in} and V_{out} .

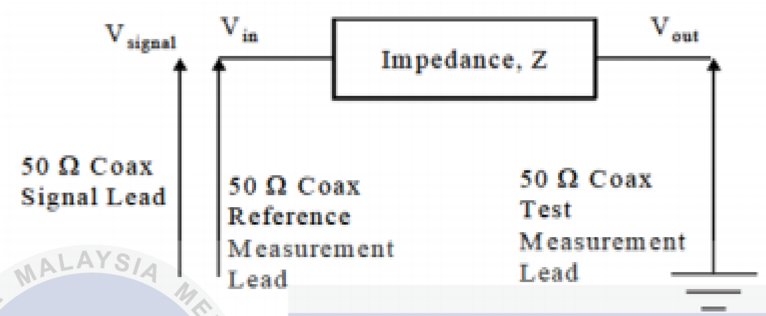


Figure 2.10 : Basic measurement for SFRA [13]

The equation in form magnitude response (dB) is shown in equation (2.1).

A (*f*) = 20 log (V1/V2), dB (2.1)

A = frequency in dB

V1 = source voltage (Vout)

V2 = measure voltage (Vin)

The equation in form phase response (Θ) is shown in equation (2.2).

Θ = < (V1/V2) (2.2)

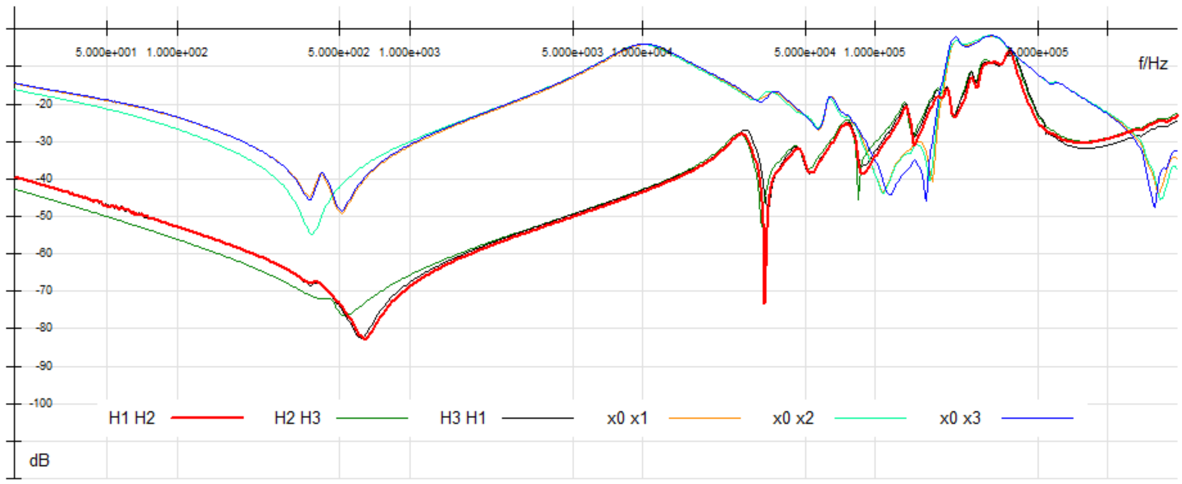


Figure 2.11 : Example of healthy trace transformer [5]

Figure 2.11 shows an example of healthy trace transformer. The trace shows the LV winding trace (x0x1, xox2, x0x3) and HV winding trace (H1H2, H2H3, H1H3). In LV winding trace, x0x1 and x0x3 is same place, but not same with x0x2. It is because, the three phase core magnetization in transformer. In HV winding trace, H1H2 and H3H1 is same place, but not same with H3H1 trace. In the case is also same with the LV winding which three phase core magnetization in transformer. For unhealthy transformer, the pattern of the traces for LV and HV winding is not the same and has different forms.

2.1.5 Frequency Sub-Band

According to IEEE Std C57. 149 2012, SFRA interpretation focusing on frequency range between 20 Hz to 2 MHz as shown in Figure 2.12 for healthy pattern. The results expose four different frequency regions to detect the failure in transformer: Region 1 between 20 Hz to 10 kHz, Region 2 between 5 kHz to 100 kHz, Region 3 between 50 kHz to 1 MHz and Region 4 is greater than 1 MHz. Each region has different elements potential defect such as radial winding deformation, axial winding deformation, overall bulk movement, core defect, contact resistance, winding turn to turn short circuit and open circuit winding. The frequency range and elements potential defected shown in Table 2.4.

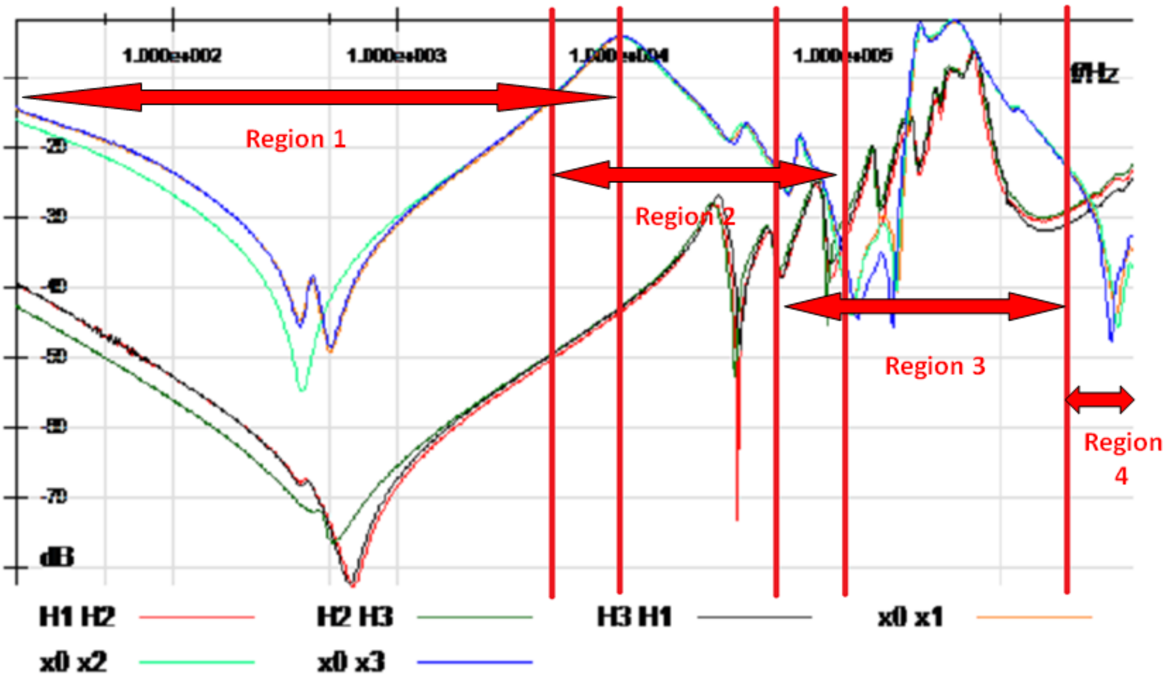


Figure 2.12 : Frequency analysis band [5]

Table 2.4 : Frequency sub-band [8]

Region	**Frequency range**	**Failure mode**
1	20 Hz – 10 kHz	Core defects, winding turn to turn short circuit
2	5 kHz – 100 kHz	Axial winding deformation, overall bulk winding, open circuit winding May be occur: radial winding deformation, core defects, contact resistance, winding turn to turn short circuit
3	50 kHz – 1 MHz	Radial winding deformation May be occur : axial winding deformation, overall bulk winding, contact resistance, winding turn to turn short circuit, open circuit
4	> 1 MHz	May be occur : contact resistance, winding turn to turn short circuit, open circuit winding

2.1.6 Statistical Analysis

Statistical technique is a method to analyze the SFRA measurement results data. The technique is Cross Correlation Coefficient (CCF) method. A correlation coefficient is a relationship between two sets of paired data. The basic formula for CCF is defined as:

$$CCF = \frac{\sum_{i=1}^{n} XY - [\frac{\sum_{i=1}^{n} X \sum_{i=1}^{n} Y}{n}]}{\sqrt{\left[\sum_{i=1}^{n} X^2 - [\frac{(\sum_{i=1}^{n} X)^2}{n}]\right]\left[\sum_{i=1}^{n} Y^2 - [\frac{(\sum_{i=1}^{n} Y)^2}{n}]\right]}} \tag{2.3}$$

Where;

X = First set data (variable 1)

Y = Second set data (variable 2)

n = Number of data

Correlation value has a range between +1 and -1. If the value CCF is equal to 0, the two traces will absolutely have no correlation. The goal for analysis is to get correlation value as close to 1 as possible [8]. CCF analyzed SFRA measurement results data when shows the value betweens 0 to 1 depend on the frequency sub-band which tells us about the physical health of the transformer. The CCF statistics are the one that quantify the relation between X axis (variable 1) and Y axis (variable 2).

The scatter plot could be produced from two variable of comparison to look the pattern and the strength from correlation coefficient of the data [14]. In general, the scatter plot is divided in three patterns: positive correlation (high values of X associated with high values of Y), negative correlation (high value of X associated with low values of Y), and no correlation (values of X are not at all predictive of value of Y). When the perfect positive correlation, the value is +1 and the perfect negative correlation, the value is -1 and the scatter plot is shown in Figure 2.13 and the Figure 2.14 shows the illustration of weak and strong correlation display using scatter plot.

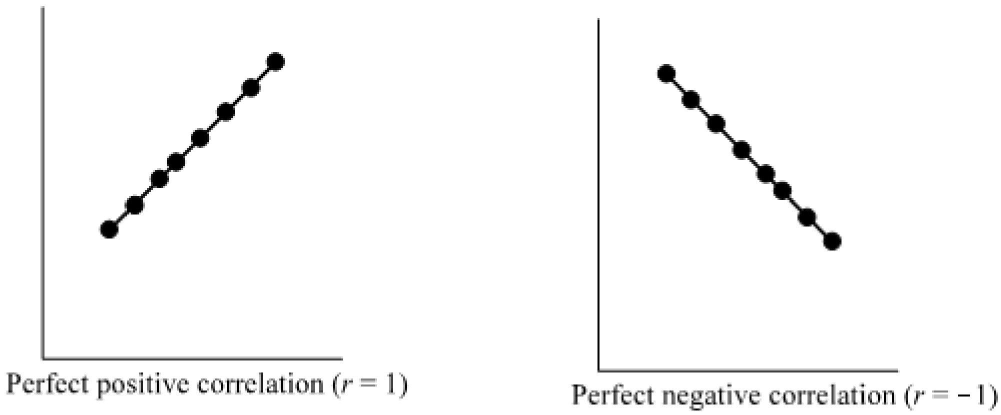


Figure 2.13 : Scatter plot for perfect positive and negative correlation [14]

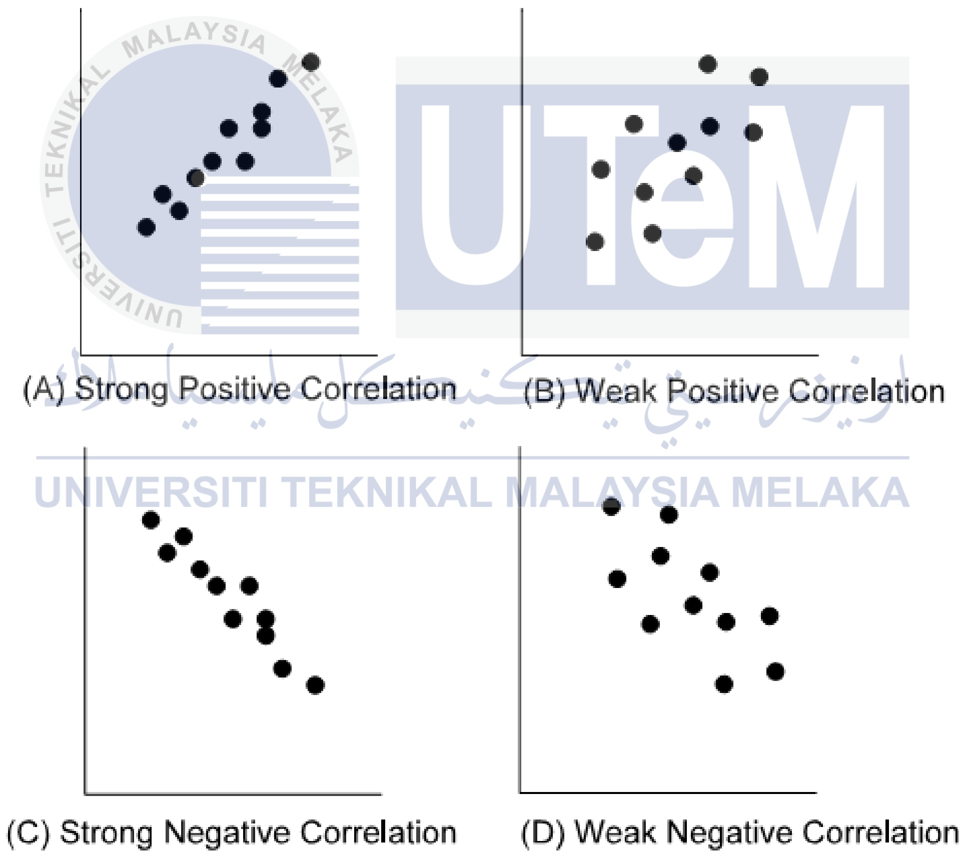


Figure 2.14 : The illustration of weak and strong correlation [14]

2.2 Review of Previous Related Works

Previously, the research of the interpretation of sweep frequency response analysis (SFRA) of transformer is used based on worldwide research finding as a guide. The previous research is used the worldwide research finding as standard such as Cigre Working Group A2/26, IEEE Draft Guide PC 57 149, and Chinese Standard DL911/2004 [15]. The Figure 2.15 shows the status of standardization used for FRA research.

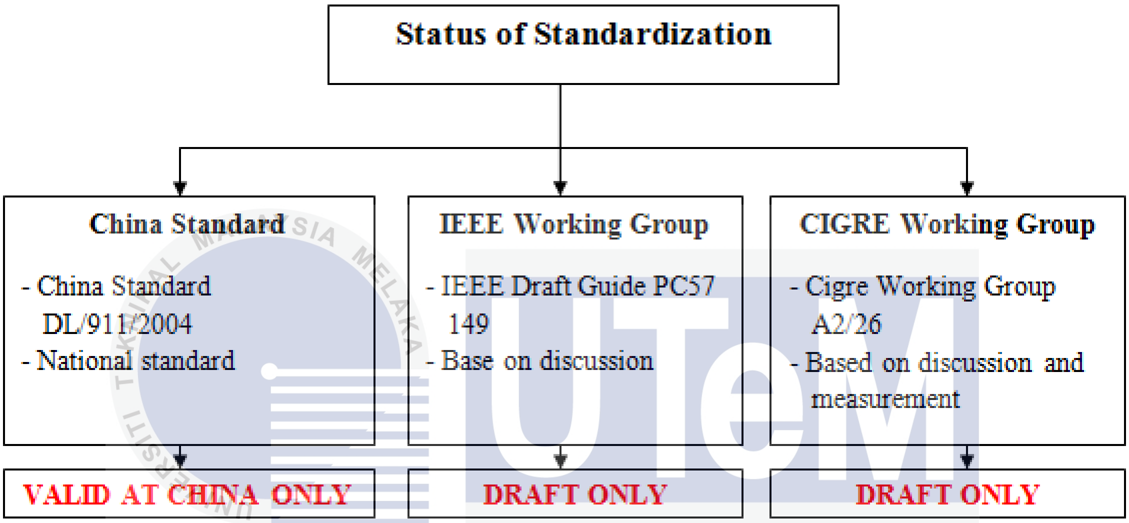


Figure 2.15 : Status of standardization use for FRA research [16]

i) Cigre Working Group A2/26

The Cigre Study Committee (SC) A2 decides in 2003 to establish a Working Group on the application of FRA to power Transformer [15]. Cigre Working Group A2/26 is exist in 2004 and produced the report with the title “Mechanical Condition Assessment of Transformer Winding using Frequency Response Analysis”. The report is covered about experiment comparison of measurement technique, second FRA workshop, Typical FRA responses, and modeling to support interpretation [17].

ii) Chinese Standard DL911/2004

The Chinese Standard DL911/2004 is the first standard in the world established in China and managed b the Technology Commission for Electric Power Industry & High Voltage Test Technology Standardization. This standard covers about the test principle, requirements for testing instruments, testing methods and the analysis of the results [15].

iii) IEEE Draft Guide PC 57 149

IEEE is established the FRA in 2002 and followed Working Group (WG) founded in 2004. The IEEE Draft Guide PC 57 149 is a guide for the application and interpretation of FRA oil immersed transformers. The different between other standard is IEEE recommend a three test system for source, reference and measurement [18].

Previously, the research is follows the worldwide or experience research finding as a guide to determine the frequency sub-band. Table 2.5 and Table 2.6 show the findings of the frequency sub-band. According to first paper [19], cross correlation coefficient (CCF) is used as a tool to analyze the SFRA traces for phase to phase comparison and sister unit comparison. For second paper [4], the CCF is used as an indicator to detect the condition of the transformer. The CCF supports with other statistical analysis, such as standard deviation (SD) and absolute sum of logarithm error (ASLE) to analyze the SFRA trace for phase to phase comparison.

Table 2.5 : Frequency sub-band sensitivity [19]

Region	Frequency sub-band	Failure Sensitivity
1	< 2kHz	Core deformation, open circuits, shorted turns and residual magnetism
2	2 kHz to 20 kHz	Bulk winding movement between windings and clamping structure
3	20 kHz to 400 kHz	Deformation within the main of tap winding
4	400 kHz to 1 MHz	Movement of the main and tap windings, ground impedance variations.

Table 2.6 : Frequency sub-band sensitivity [4]

Region	Frequency sub-band	Failure Sensitivity
1	< 10 kHz	Transformer core and magnetic circuit
2	5 kHz to 500 kHz	Radial movement between winding
3	> 400 kHz	Axial deformation

2.3 The Aid of Software

The aid of software is an important part in this project to analyze and verify the condition of the transformer. With the aid of software, have two types of software is used: Omicron FRAnalyzer and SPSS Statistical Software.

2.3.1 Omicron FRAnalyzer Software

The Omicron FRAnalyzer Software is specially designed to the requirements of the engineers analyzing the data. The test documentation of transformer testing recorded in this software as shown in Figure 2.16.

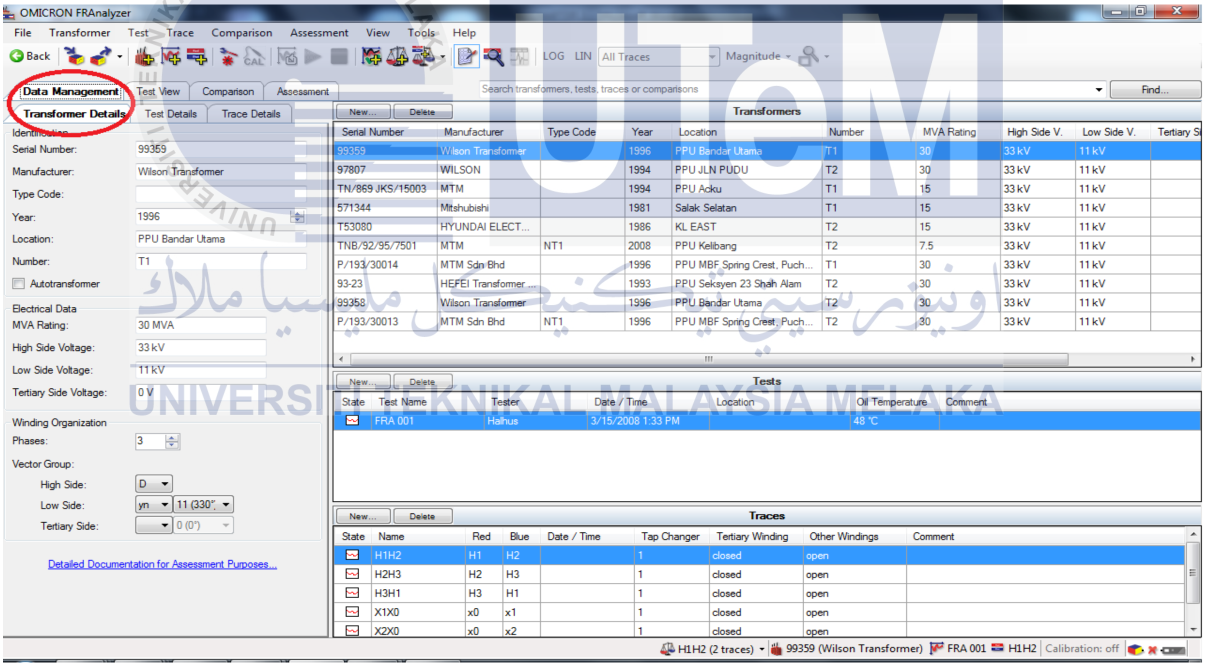


Figure 2.16 : Test documentation of transformer testing [5]

When the testing is done, the trace is an existing at test view as shown in Figure 2.17. The trace can be control or managed by using Tool bar as shown in Figure 2.18. It has the important method to analyze the trace such as import and export data, connection information, sweep setting, cursor table, and other.

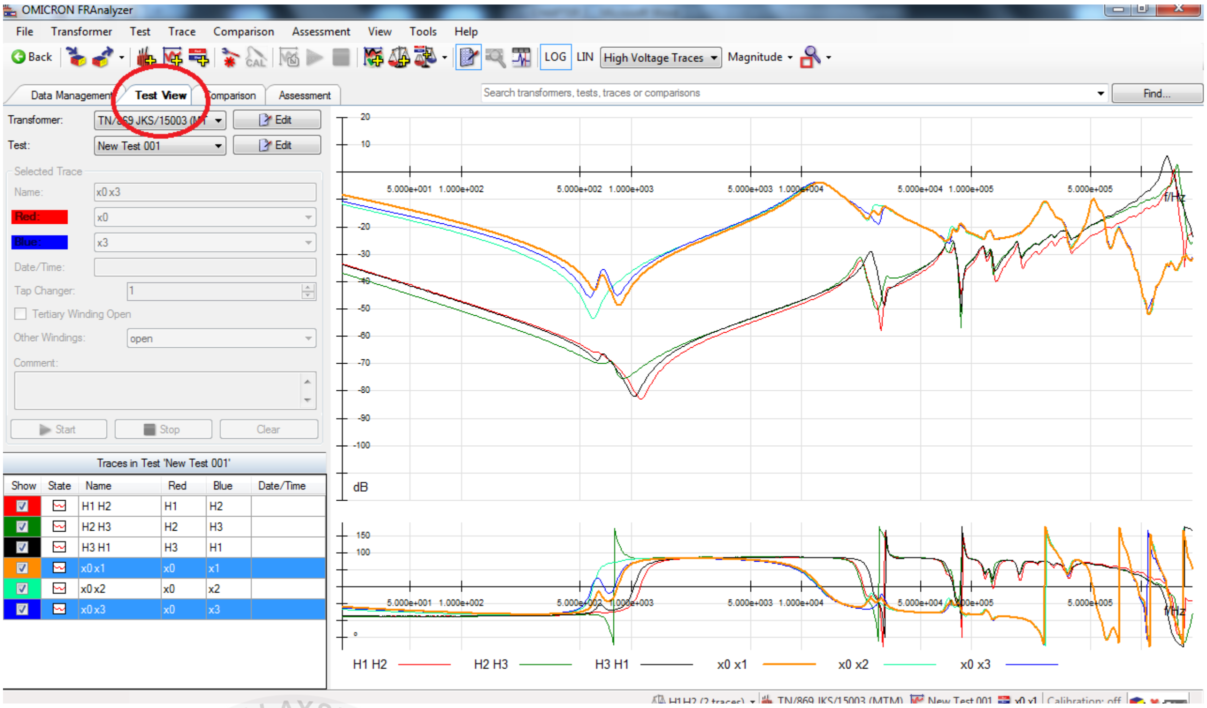


Figure 2.17 : Test view of transformer testing [5]

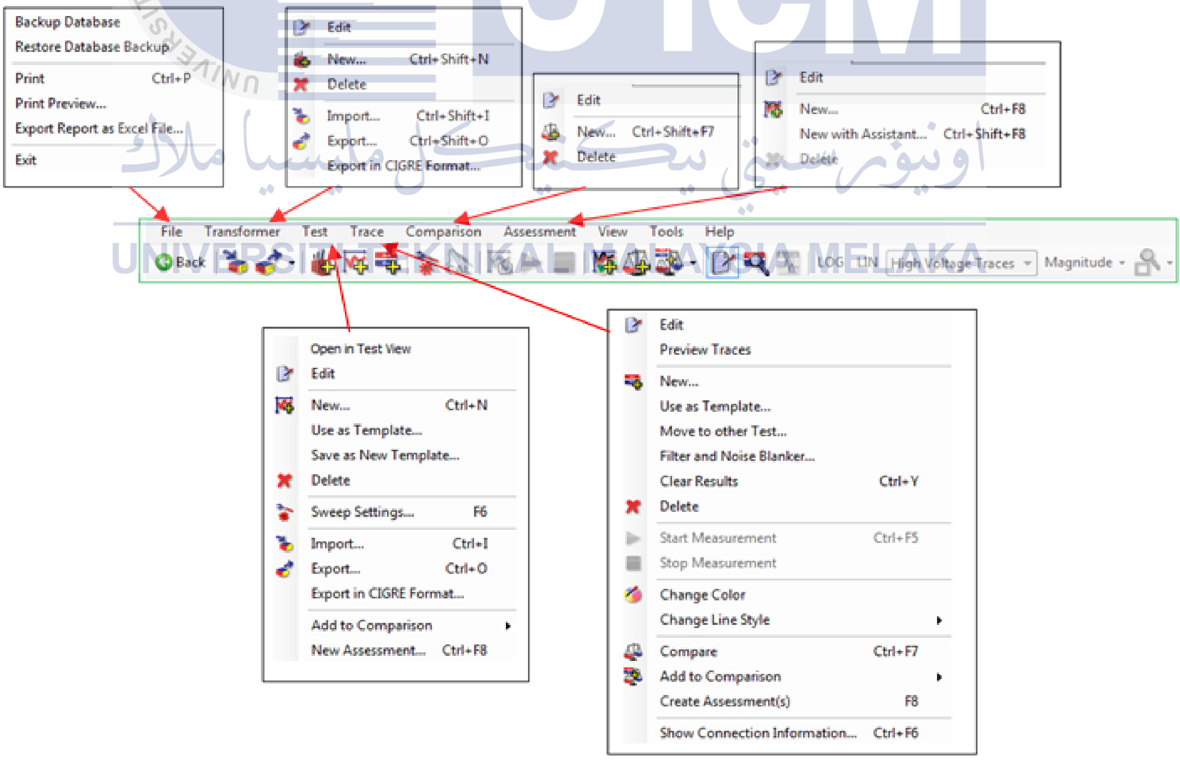


Figure 2.18 : Tool bar in Omicron FRAnalyzer Software [5]

2.3.2 SPSS Statistics Software

SPSS is stand for Statistical Package for the Social Sciences is a powerful, user-friendly software package for the manipulation and statistical analysis of data [2]. Figure 2.19 shows the SPSS statistics software version 17.0. This software is for manipulating, analyzing and presenting the data.

Figure 2.19 : SPSS Statistics Software version 17.0 [20]

The data editor consists of two windows: Data View and Variable View. Figure 2.20 and Figure 2.21 shows the Data View and Variable View in SPSS Statistics software. The function of Data View is allows the data to be entered and viewed. The data value can be entered in the Data View spreadsheet. For most analysis SPSS assumes that rows represent cases and columns variable [2].

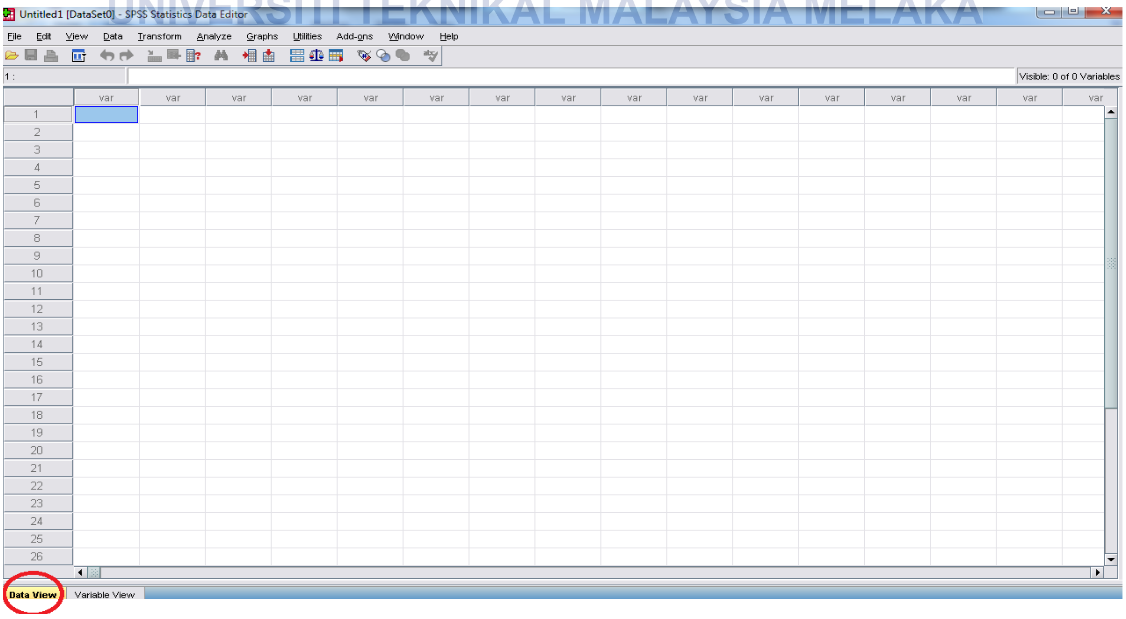


Figure 2.20 : Data View spreadsheet [20]

The function of Variable View is to define the variables. Each variable definition occupies a row of this spreadsheet. There are 10 characteristic to be specified under the columns of the Variable View: Name, Type, Width, Decimals, Label, Value, Missing, Columns, Align and Measure [2].

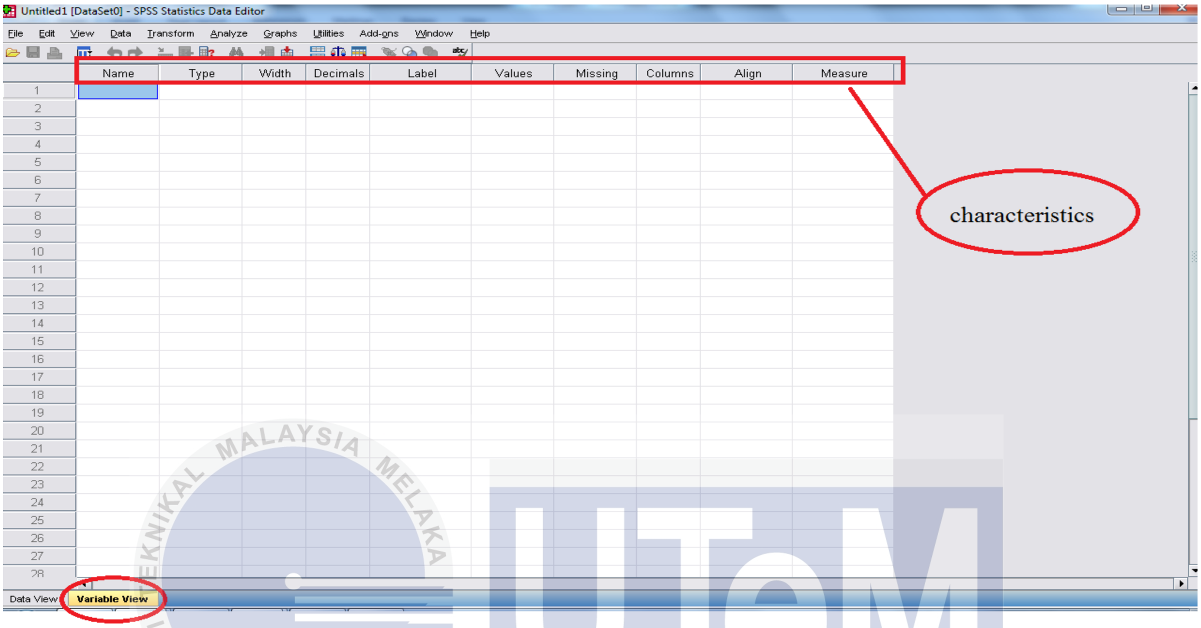


Figure 2.21 : Variable View spreadsheet [20]

The tool bar Analyze function is to select the method of statistical technique. The Figure 2.22 shows the list of statistical techniques at Analyze tool bar.

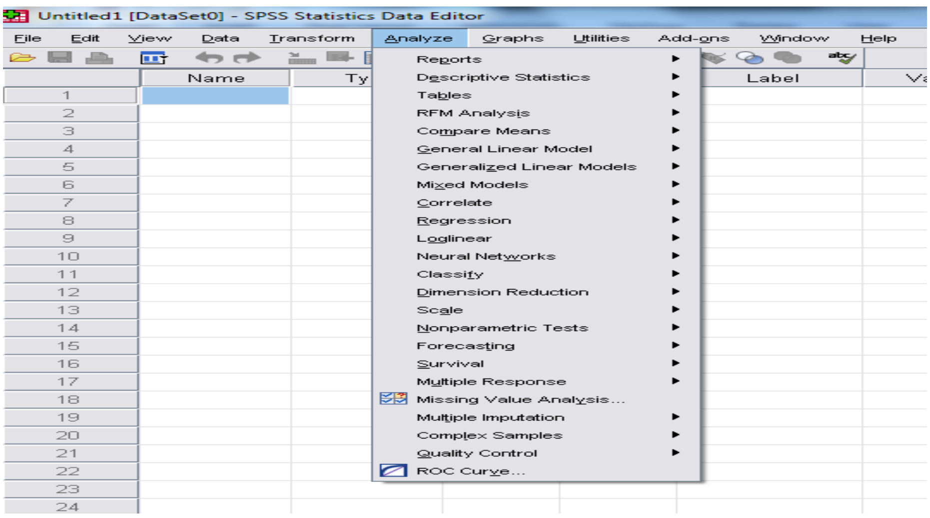


Figure 2.22 : List of statistical technique at Analyze tool bar [20]

By using a CCF statistical technique, the Bivariate Correlations are selected. The variable of data is inserted in variables box to compare the trace. Figure 2.23 shows the example data comparison in Bivariate Correlations.

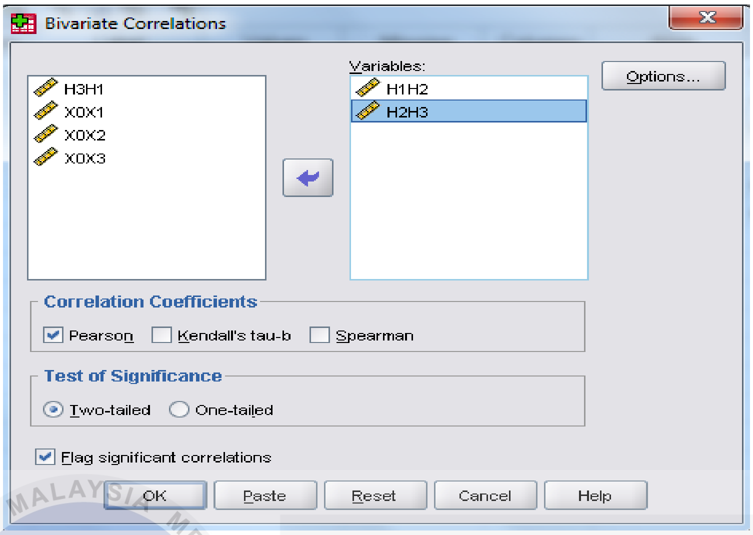


Figure 2.23 : Example data comparison in Bivariate Correlations [20]

The result of statistical technique is display at Output View. Figure 2.24 shows the example of the result in Output View. At this view, the result and information of data show in table. In this case, it makes easy to take the resultant reading.

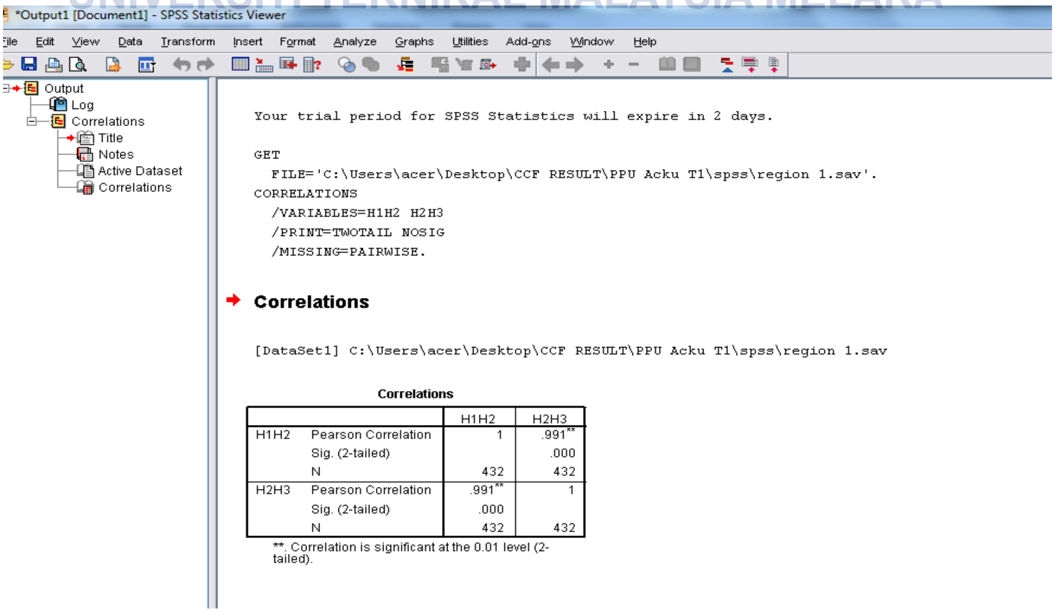


Figure 2.24 : Example result in Output View [20]

2.4 Summary of Frequency Sub-Band used for Research

Transformer failure can be detected using SFRA based on the frequency sub-bands according to IEEE Std C57. 149 2012, which is apply the Cross Correlation Coefficient (CCF) method. Beside that, CCF method is one of recommendation from IEEE Std C57. 149 2012 as analyzes tool. This technique can detect the health of the transformer condition. Table 2.7 shows the Frequency sub-band and failure mode in research.

Table 2.7 : Frequency sub-band used for research [8]

Region	Frequency range	Failure mode
1	20 Hz – 10 kHz	Core defects, winding turn to turn short circuit
2	5 kHz – 100 kHz	Axial winding deformation, overall bulk winding, open circuit winding May be occur: radial winding deformation, core defects, contact resistance, winding turn to turn short circuit
3	50 kHz – 1 MHz	Radial winding deformation May be occur : axial winding deformation, overall bulk winding, contact resistance, winding turn to turn short circuit, open circuit
4	> 1 MHz	May be occur : contact resistance, winding turn to turn short circuit, open circuit winding

CHAPTER 3

METHODOLOGY

This chapter will discuss about the principles of the methods used in the previous work, discussion on the selected technique, and description of the work to be undertaken.

3.1 Principles of the Methods used in Previous Work

According to first paper [19] by G. M. Kenedy, et. al. in 2007, it discussed about sweep frequency response analysis (SFRA) trace analyze using cross correlation coefficients. The SFRA method for paper [19] is used to detect the mechanical damage of transformer winding. This paper is used based on worldwide research finding as guide to discover the frequency sub-band to analyze the data. The frequency sub-band used is <2 kHz, 2 kHz to 20 kHz, 20 kHz to 400 kHz and 400 kHz to 1 MHz. In each region of frequency sub-band, it is shown that failure sensitivity in transformer is due to core deformation, open circuits, short turns and residual magnetism, bulk winding movement between windings, clamping structure, deformation within the main of tap winding, movement of the main and tap winding and ground impedance variations. The statistical technique, cross correlation coefficient (CCF) is used as an indicator to detect the condition of the transformer.

S. Ab. Ghani, et. al in 2012 through its research paper discussed about the SFRA result of distribution transformer in TNB Malaysia [4]. The SFRA method for paper [2] is used to detect the mechanical damage of transformer core and winding. This paper is based on worldwide research finding as guide to discover the frequency sub-band to analyze the data. The frequency sub-band used is <10 kHz, 5 kHz to 500 kHz and >400 kHz. In each region of frequency sub-band has its failure sensitivity in transformer. The failure is core and magnetic circuit problem, radial deformation and axial deformation. The statistical techniques: cross correlation coefficient (CCF), standard deviation (SD), and absolute sum of logarithm error (ASLE) is used as an indicator to detect the condition of the transformer.

3.2 Discussion on the Selected Technique

This research work follows the previous research work but the difference is there are some changes in the guidelines. This research uses the SFRA methods of FRA technique to detect the conditions of transformer. This research is based on IEEE Std C57. 149 2012 as a guide to discover frequency sub-band to analyze the data. The frequency sub band which used is 20 kHz to 10 kHz, 5 kHz to 100 kHz, 50 kHz to 1 MHz, and > 1MHz. In each region of frequency sub-band haves failure sensitivity in transformer which is the failure is core defect, winding turn to turn short circuit, axial winding deformation, overall bulk winding, open circuit winding, and radial winding deformation. The statistical technique used for this research is according to IEEE Std C57. 149 2012, cross correlation coefficient (CCF) method to detect the condition of the transformer. So, the difference of this research compared to paper [19] and [4] is the guidance used to analyze the condition of transformer.

3.3 Description of the work to be undertaken

Figure 3.1 shows the flow chart of the project development from start to end of the project. For this project, the objective and scope of this project are achieved when the flow of methodology of project implemented. In this section, the flow of project : literature review, obtain the SFRA measurement result data from TNB, abstract the SFRA measurement result data from FRA software, extract the frequency sub-band range from standard, verify the data using SPSS software, and using statistical technique to analyze and discuss the data will be explained.

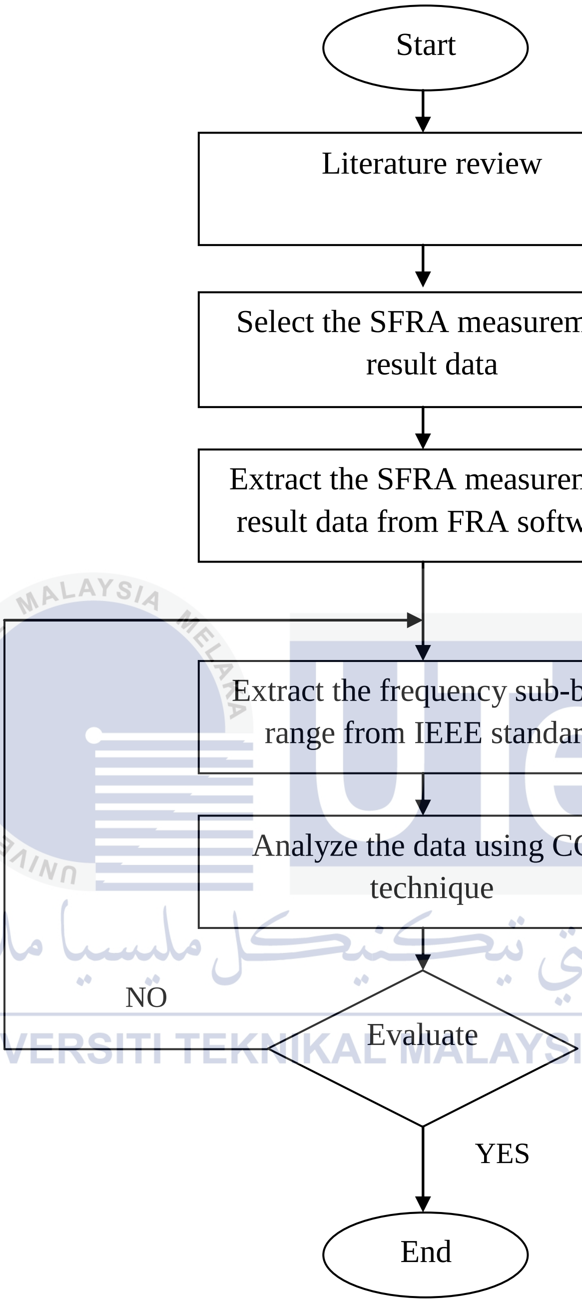


Figure 3.1 : Flow chart of the project

3.3.1 Literature Review

The first step of this project is literature review. This part is discusses about the related information and previous research done by other research in transformer failure. The information about this step is referring to the journal, paper, magazine and standard as reference. The concept of frequency response analysis (FRA), sweep frequency response analysis (SFRA), transformer failure, and statistical technique is discusses at this part.

3.3.2 Selection the SFRA Measurement Result Data from TNB

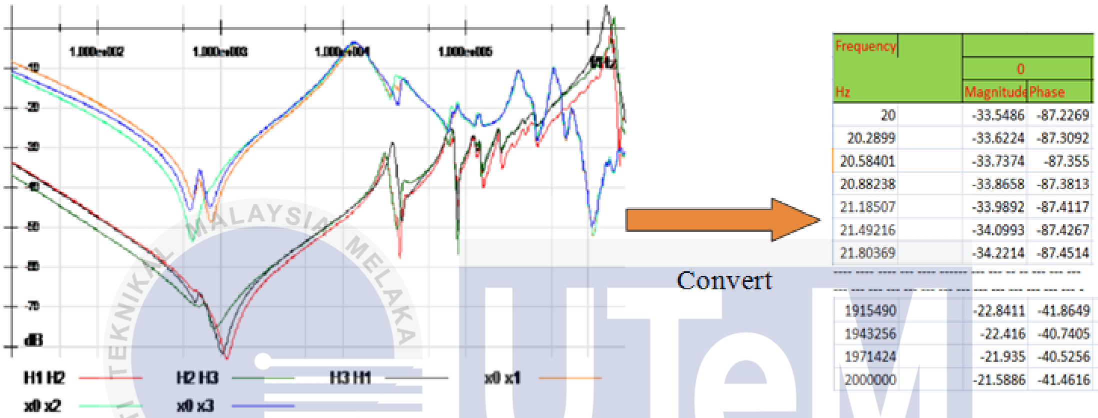
The second step of this project is selecting the SFRA measurement result data from ten TNB distribution transformers. The detail description is given in Table 3.1. The SFRA measurement result data taken from ten TNB distribution transformers were measured using Omicron FRAnalyzer device. The SFRA measurement setup and tested transformer connection setup were done by TNB distribution engineers.

Table 3.1 : Transformer detail from TNB distribution

No	Series Number	Transformer Location	Voltage Rating (kV)	Apparent Power Rating (MVA)	Manufacturer Year	Manufacturer
1	8345552	PPU Selayang Utama T1	33/11	15	1984	Takaoka Electric MFG Co Ltd
2	99359	PPU Bandar Utama T1	33/11	30	1996	Wilson Transformer
3	97807	PPU Jln Pudu T2	33/11	30	1994	Wilson Transformer
4	T53080	PPU KL East T2	33/11	15	1986	Hyundai Electrical
5	TN/869 JKS/15003	PPU Acku T1	33/11	15	1994	MTM Sdn. Bhd.
6	P/193/30014	PPU MBF Spring Creast T1	33/11	30	1996	MTM Sdn. Bhd.
7	8345556	PPU Bank Negara T2	33/11	15	1984	Takaoka Electric MFG Co Ltd
8	8144933	PPU Damansara Height T1	33/11	30	1981	Takaoka Electric MFG Co Ltd
9	TNB/92/95/75 01	PPU Kelibang T2	33/11	30	2008	MTM Sdn. Bhd.
10	93-23	PPU Seksyen 23 T2	33/11	30	1993	HEFEI Transformer

3.3.3 Extract the SFRA Measurement Result Data from FRA Software

The next step is to extract the SFRA measurement result data. The SFRA measurement result data taken from ten TNB distribution transformers were measured using Omicron FRAnalyzer device. The extracted data is data that has converted from Omicron FRAnalyzer software to Microsoft Excel format. Figure 3.2 shows illustrate of extracted data.



Frequency			
		0	
Hz		Magnitude	Phase
20		-33.5486	-87.2269
20.2899		-33.6224	-87.3092
20.58401		-33.7374	-87.355
20.88238		-33.8658	-87.3813
21.18507		-33.9892	-87.4117
21.49216		-34.0993	-87.4267
21.80369		-34.2214	-87.4514
1915490		-22.8411	-41.8649
1943256		-22.416	-40.7405
1971424		-21.935	-40.5256
2000000		-21.5886	-41.4616

SFRA measurement result data

Data extract in Microsoft Excel

Figure 3.2 : Data extracted into Microsoft Excel

The conversion of data from Omicron FRAnalyzer software into Microsoft Excel requires two procedures that must be followed. The data need to be exported and then need to be rearranged to make easy to be understand.

3.3.4 Extract the Frequency Sub-Band Range from Standard

By referring IEEE Std C57. 149 2012, the frequency sub-band range is followed. Table 3.2 shows the frequency sub-band range.

Table 3.2 : Frequency sub-band range

Range	Frequency
1	20 Hz to 10 kHz
2	5 kHz to 100 kHz
3	50 kHz to 1 MHz
4	> 1MHz

3.3.5 Analysis and Evaluate of the Data Using CCF Technique

Cross Correlation Coefficient (CCF) is a statistical technique to analyze and evaluate the condition of the transformer. CCF is use as indicator and the factor for selected the CCF method because of recommendation from IEEE Std C57. 149 2012. For this research, CCF is applying by using SPSS Statistic Software as analyze tool. Each phase comparison in each transformer for each region must be test using CCF method and each transformer produces six CCF value, three for HV winding and three for LV winding. So, the total of result for CCF value for ten transformers is sixty value of CCF.

The analysis for ten transformers is illustrated in graph format. The graph format for y axis is CCF level and for x axis is phase comparison. From this graph, the evaluation of transformer condition can detect by using region separated.

CHAPTER 4

RESULT AND DISCUSSION

This chapter explains about the results and discussion for this research. Omicron FRAnalyzer software is used for collect the SFRA (Sweep Frequency Response Analysis) result data. Interpretation of SFRA measurement results of TNB distribution transformer is according to IEEE Std C57.149 2012 and the SPSS Statistical Software is used to convert the SFRA measurement result data using CCF (Cross Correlation Coefficient) method. The results are analyzed using graph and it discussed by referring the result data. The discussion is covered about the description in each region, evaluation of transformers condition and summary of transformers condition.

4.1 SFRA Measurement Results

Figure 4.1 and 4.2 shows the trace and extracted data for PPU Bandar Utama T1. For PPU Selayang Utama T1, PPU Jln Pudu T2, PPU KL East T2, PPU Acku T1, PPU MBF Spring Creast T1, PPU Bank Negara T2, PPU Damansara Height T1, PPU Kelibang T2 and PPU Seksyen 23 T2 are shown at Appendix A in Figure (4.3 - 4.11). The data from of ten transformers from Omicron FRAnalyzer software is converted to Microsoft Excel format. The data from the graphical view (trace) is converting to numerical view. The data are arranged in H1H2, H2H3, H3H1, x0x1, x0x2 and x0x3 at Microsoft Excel format.

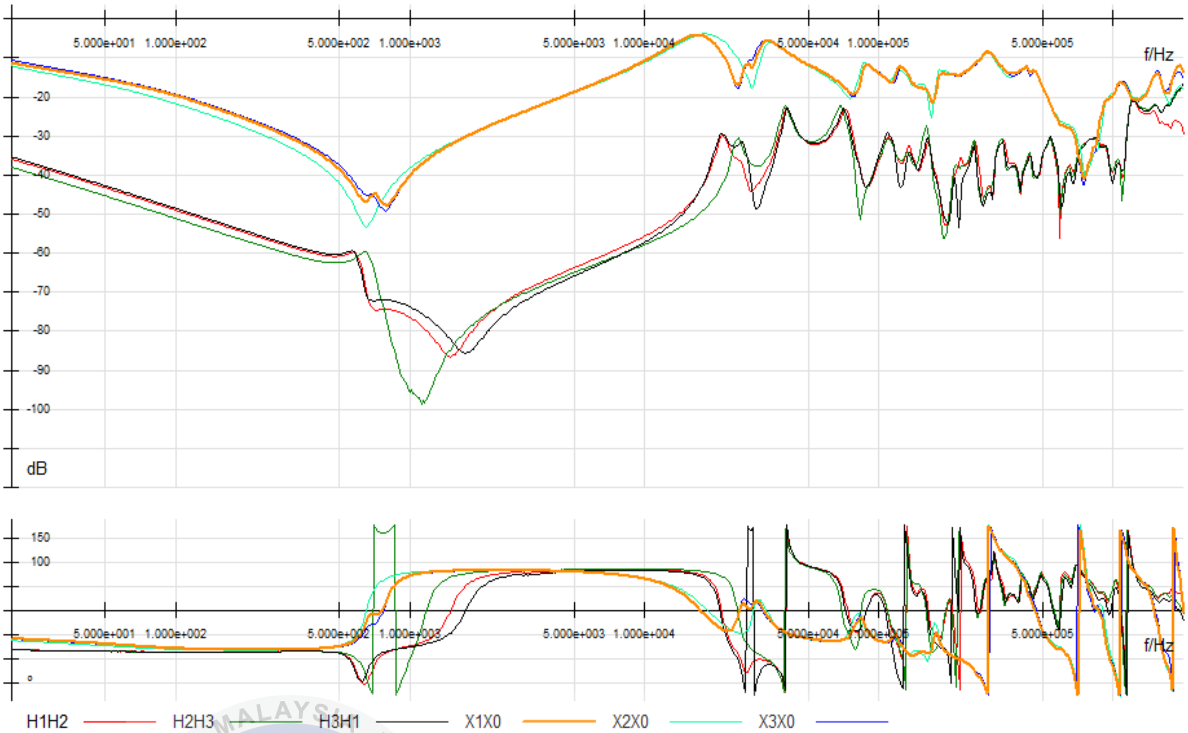


Figure 4.1 : The trace of HV and LV winding at PPU Bandar Utama T1

Frequency	Index										
	0		1		2		3		4		5	
Hz	Magnitud	Phase	Magnitud	Phase	Magnitud	Phase	Magnitud	Phase	Magnitud	Phase	Magnitud	Phase
20	-35.924	-81.2494	-37.9876	-81.546	-35.4092	-81.5866	-11.2958	-57.7609	-11.9787	-61.7605	-10.4431	-58.4278
20.2899	-36.0206	-81.3685	-38.0947	-81.6204	-35.5107	-81.6824	-11.4856	-58.7997	-12.1684	-62.3992	-10.6106	-59.0292
20.58401	-36.1268	-81.4542	-38.2057	-81.6913	-35.6218	-81.7635	-11.5624	-59.0773	-12.267	-62.6248	-10.71	-59.2669
20.88238	-36.2428	-81.5313	-38.3247	-81.7605	-35.7404	-81.83	-11.6333	-59.2784	-12.3582	-62.8168	-10.8006	-59.4726
21.18507	-36.3579	-81.5905	-38.4399	-81.8342	-35.8555	-81.9066	-11.6996	-59.4498	-12.4413	-62.9884	-10.8817	-59.6588
21.49216	-36.4586	-81.656	-38.5413	-81.872	-35.9572	-81.9585	-11.755	-59.5971	-12.5113	-63.1385	-10.9491	-59.8205
21.80369	-36.5711	-81.7148	-38.6545	-81.9508	-36.071	-82.0257	-11.8196	-59.7505	-12.5884	-63.2968	-11.0232	-59.9885
22.11974	-36.6818	-81.7793	-38.7652	-82.0058	-36.1814	-82.0891	-11.8826	-59.8974	-12.6632	-63.4521	-11.0947	-60.1489
22.44037	-36.8023	-81.8415	-38.8858	-82.0606	-36.3034	-82.1553	-11.9536	-60.0551	-12.7452	-63.6197	-11.1735	-60.3248
22.76565	-36.9105	-81.8985	-38.9949	-82.1267	-36.4092	-82.2049	-12.014	-60.1986	-12.8157	-63.77	-11.2412	-60.4812
1782502	-26.9491	48.76925	-21.25	30.53698	-20.8797	19.92353	-15.8431	-163.715	-20.2639	-166.4	-15.5383	-142.755
1808340	-26.1851	46.4297	-20.5828	28.51467	-20.1593	16.54144	-14.6901	172.5772	-19.7099	169.5924	-15.0381	-166.6
1834552	-25.872	42.99275	-19.978	25.51355	-19.5713	12.64341	-13.6956	147.4422	-19.0517	144.2222	-14.497	166.9129
1861144	-25.9027	39.57985	-19.4072	21.81749	-19.0376	8.542778	-12.8921	121.6955	-18.2987	118.0514	-14.0043	138.0814
1888122	-26.1853	37.1616	-18.8544	17.46935	-18.5004	4.176911	-12.2588	95.75201	-17.5774	91.51867	-13.6496	108.0988
1915490	-26.549	35.48672	-18.3184	12.25156	-17.9505	-0.83317	-11.8843	69.00224	-17.1857	65.15491	-13.533	77.97948
1943256	-27.1686	33.89056	-17.8584	5.840486	-17.4264	-6.65644	-12.1066	42.12505	-17.3246	41.49031	-13.846	49.36044
1971424	-28.1732	33.75563	-17.5872	-1.33533	-16.9303	-13.2231	-12.9093	18.46213	-17.6108	22.20423	-14.5113	24.49762
2000000	-29.6334	35.64572	-17.4462	-8.45348	-16.4497	-21.2213	-13.7627	-1.87974	-17.7893	4.603867	-15.2941	3.947291

Figure 4.2 : The data extracted in Microsoft Excel format at PPU Bandar Utama T1

4.2 Cross Correlation Coefficient (CCF) Result

The Table 4.1 shows the numerical parameter result for CCF method. The extracted data from SFRA measurement result data is simulated by using SPSS Statistics Software in CCF parameter. The measurement of ten transformers is done at high voltage winding and low voltage winding. For high voltage winding measurement, the comparisons are H1H2 to H2H3, H1H2 to H3H1 and H2H3 to H3H1. For low voltage winding measurement, the comparisons are x0x1 to x0x2, x0x1 to x0x3 and x0x2 to x0x3.

According to IEEE Std C57.149 2012, the four frequency sub-band was used to detect the transformer failure: Region 1 (20 Hz to 10 kHz), Region 2 (5 kHz to 100 kHz), Region 3 (50 kHz to 1 MHz), and Region 4 (> 1 MHz). For this research, only three regions (Region 1, 2 and 3) are used to analyze the condition of the transformers because the Region 4 (> 1 MHz) is sensitive to the effect of measuring lead [1, 22]. Figure (4.12 – 4.17) shows the example of phase comparison region for PPU Jln Pudu T2.

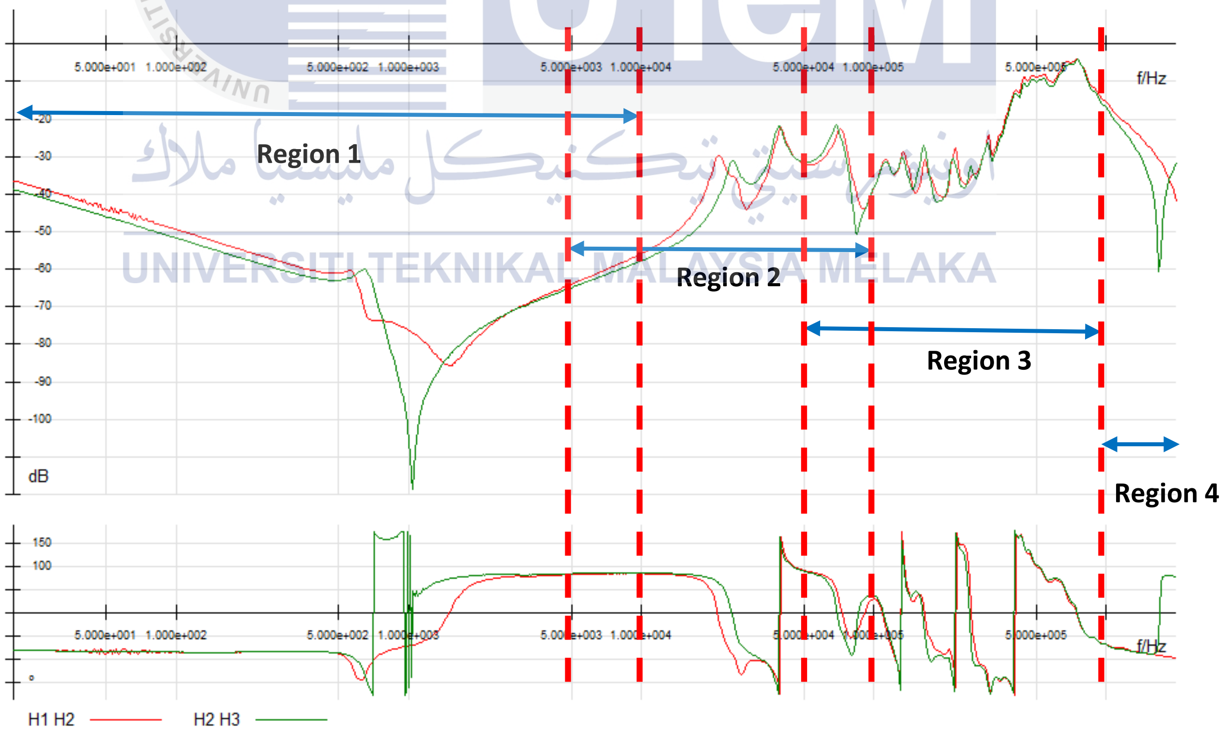


Figure 4.12 : Comparison H1H2 to H2H3 at PPU Jln Pudu T2 (HV winding)

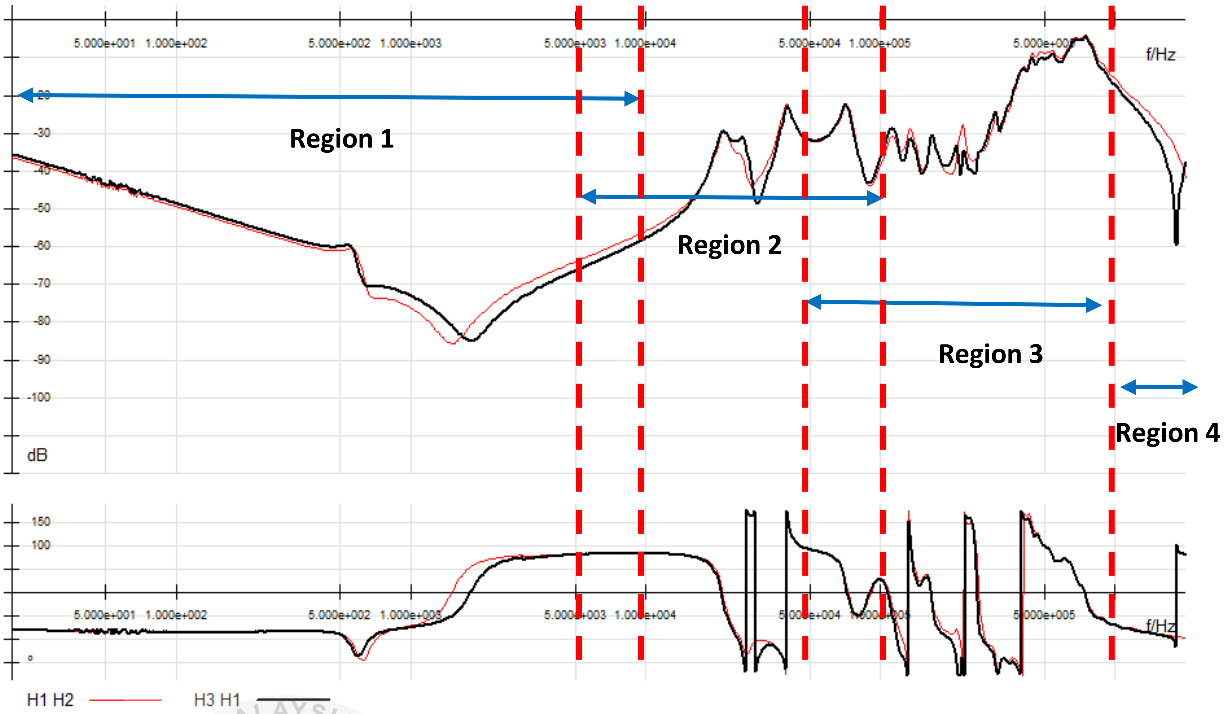


Figure 4.13 : Comparison H1H2 to H3H1 at PPU Jln Pudu T2 (HV winding)

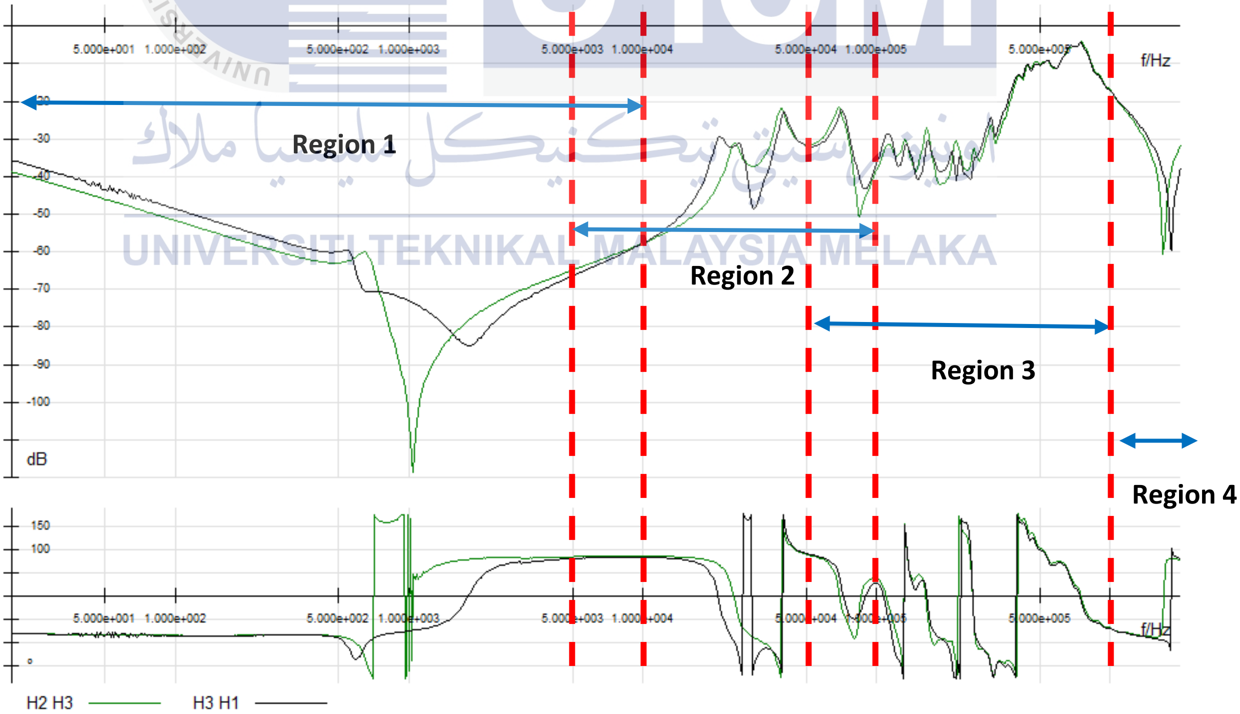


Figure 4.14: Comparison H2H3 to H3H1 at PPU Jln Pudu T2 (HV winding)

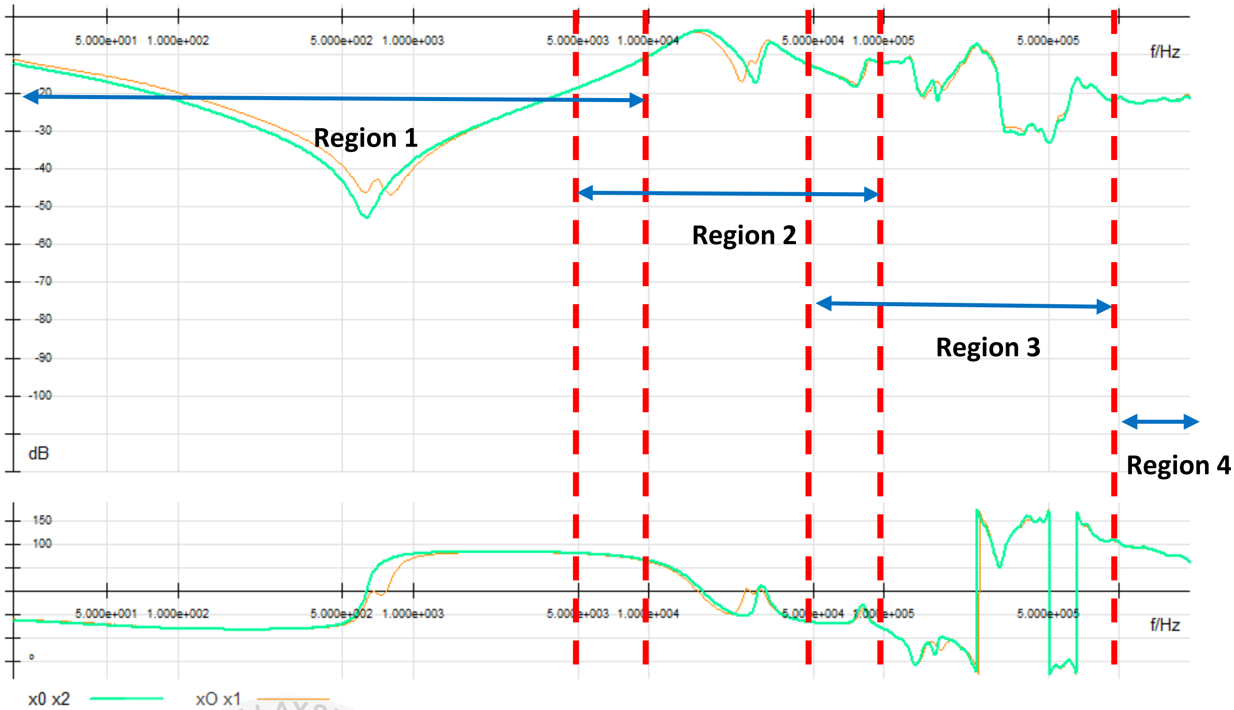


Figure 4.15 : Comparison x0x1 to x0x2 at PPU Jln Pudu T2 (LV winding)

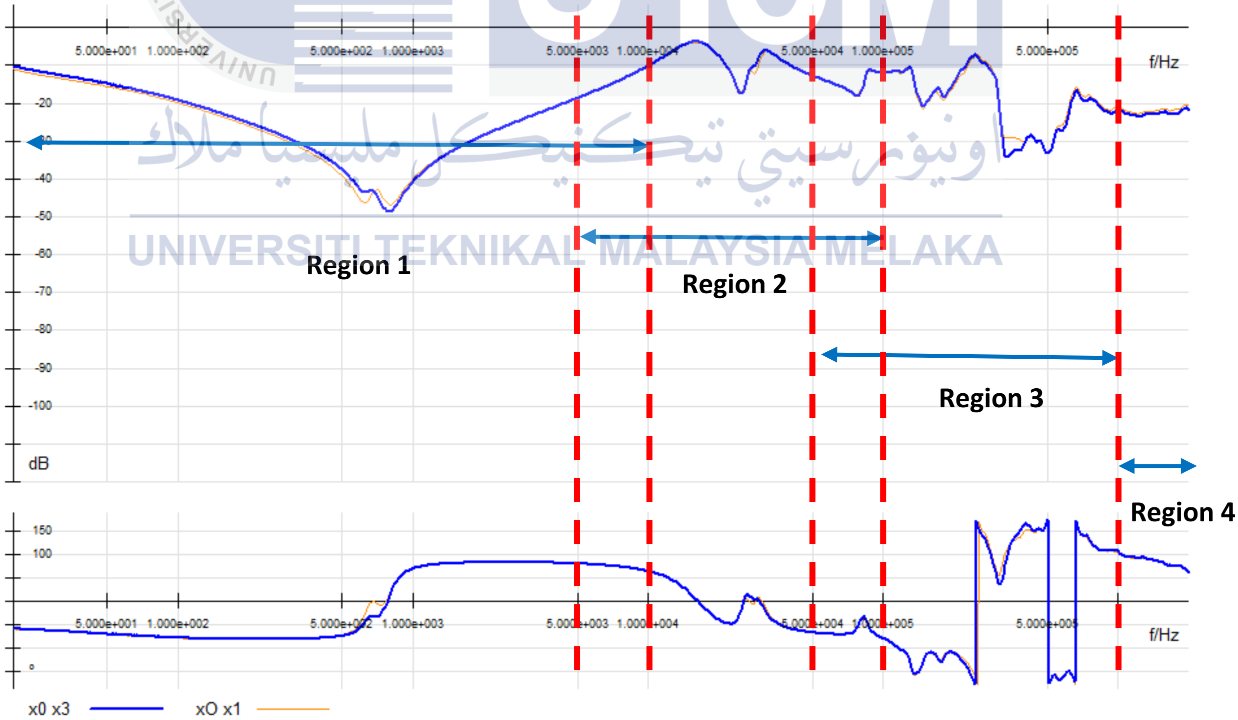


Figure 4.16 : Comparison x0x1 to x0x3 at PPU Jln Pudu T2 (LV winding)

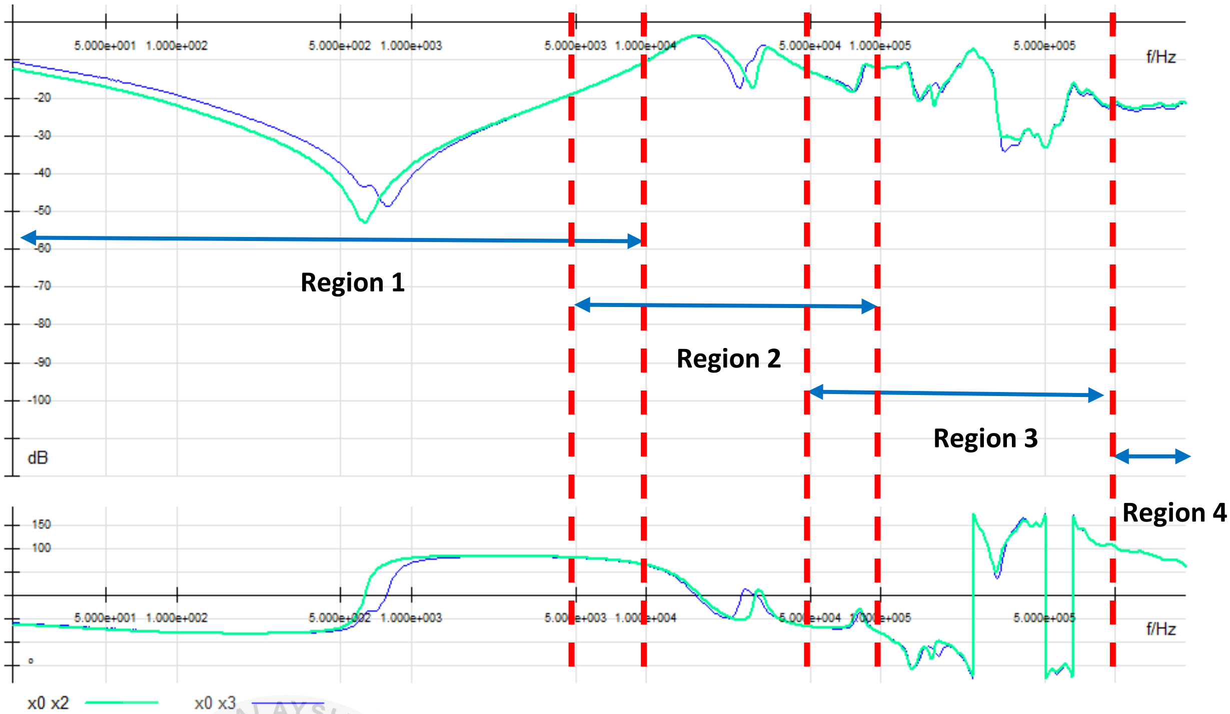


Figure 4.17: Comparison x0x2 to x0x3 at PPU Jln Pudu T2 (LV winding)

Table 4.1 : Result from phase comparison using CCF method

Region	Frequency	Winding	Phase Comparison	Non Defect Transformers								Defect Transformers	
				PPU Selayang Utama T1	PPU Bandar Utama T1	PPU Jln Pudu T2	PPU KL East T2	PPU Acku T1	PPU MBF Spring Creast T1	PPU Bank Negara T2	PPU Damansara Height T1	PPU Kelibang T2	PPU Seksyen 23 T2
1	20 Hz to 10 kHz	HV	H1H2 to H2H3	0.999	0.999	0.999	0.950	0.991	0.995	0.999	1.000	0.975	0.922
			H1H2 to H3H1	1.000	1.000	0.999	0.999	0.999	1.000	1.000	1.000	0.999	1.000
			H2H3 to H3H1	0.999	0.999	0.998	0.963	0.996	0.996	0.999	0.999	0.984	0.922
		LV	x0x1 to x0x2	0.987	0.995	0.992	0.994	0.932	0.981	0.987	0.996	0.975	0.779
			x0x1 to x0x3	0.999	0.998	0.997	1.000	0.959	0.999	0.999	0.997	0.997	0.999
			x0x2 to x0x3	0.992	0.990	0.982	0.995	0.996	0.975	0.984	0.987	0.989	0.764
2	5 kHz to 100 kHz	HV	H1H2 to H2H3	0.977	0.908	0.923	0.971	0.983	0.988	0.980	0.974	0.970	0.987
			H1H2 to H3H1	0.990	0.981	0.982	0.985	0.934	0.945	0.988	0.995	0.883	0.912
			H2H3 to H3H1	0.982	0.912	0.912	0.944	0.909	0.915	0.980	0.981	0.866	0.922
		LV	x0x1 to x0x2	0.997	0.914	0.937	0.998	0.993	0.993	0.997	0.993	0.978	0.989
			x0x1 to x0x3	0.999	0.995	0.996	0.999	0.991	0.989	1.000	0.996	0.994	0.991
			x0x2 to x0x3	0.998	0.886	0.919	0.998	0.986	0.985	0.998	0.999	0.989	0.978
3	50 kHz to 1 MHz	HV	H1H2 to H2H3	0.998	0.878	0.998	0.987	0.994	0.971	0.999	0.998	0.959	0.940
			H1H2 to H3H1	0.995	0.963	0.997	0.981	0.992	0.971	0.999	0.998	0.976	0.798
			H2H3 to H3H1	0.999	0.928	0.997	0.996	0.993	0.990	0.999	0.998	0.951	0.888
		LV	x0x1 to x0x2	0.986	0.983	0.986	0.999	0.996	0.876	0.973	0.993	0.888	0.938
			x0x1 to x0x3	0.991	0.997	0.990	0.996	0.999	0.954	0.975	0.991	0.996	0.981
			x0x2 to x0x3	0.990	0.981	0.989	0.997	0.992	0.954	0.989	0.995	0.899	0.939
4	> 1MHz	HV	H1H2 to H2H3	0.691	0.608	0.963	0.998	0.604	0.320	1.000	0.998	0.989	0.509
			H1H2 to H3H1	0.080	0.521	0.994	0.998	0.630	0.828	1.000	0.996	0.999	0.441
			H2H3 to H3H1	0.611	0.993	0.982	0.999	0.326	0.203	1.000	0.991	0.981	0.035
		LV	x0x1 to x0x2	0.991	0.514	0.955	0.994	0.997	0.898	0.964	0.933	0.916	0.889
			x0x1 to x0x3	0.998	0.946	0.974	0.986	0.997	0.979	0.954	0.993	0.975	0.926
			x0x2 to x0x3	0.992	0.624	0.962	0.965	0.995	0.952	0.990	0.965	0.914	0.976

4.3Description in Each Region

The present study was designed to determine the condition of ten transformers according to IEEE Std C57.149 2012 as a guide which is analyze the three regions (Region 1, 2, 3 and 4). However, only three regions (Region 1, 2 and 3) are used to analyze the condition of the transformers because the Region 4 (> 1 MHz) is sensitive to the effect of measuring lead [1, 22]. The description of each region was discussed in 4.3.1, 4.3.2 and 4.3.3. The analysis based on the result in Table 4.1.

4.3.1 Region 1: 20 Hz to 10 kHz

The results of this study for region 1 (20 Hz to 10 kHz) indicate that CCF for HV winding of non defect and defect transformers is in strong correlation. The phase comparison between H1H2 to H3H1 for PPU Selayang Utama T1, PPU Bandar Utama T1, PPU MBF Spring Creast T1, PPU Bank Negara T2, PPU Damansara Height T1, and PPU Seksyen 23 T2 are showing the perfect correlation with the CCF value is 1.000. Beside that, the phase comparison between H1H2 to H2H3 for PPU Damansara Height T1 has also shown the perfect correlation. The lowest correlation value for HV winding at this region in phase comparison H2H3 to H3H1 and H1H2 to H3H1 at PPU Seksyen 23 T2 which is the value of CCF is 0.922.

The current study found that the LV winding for this region is a strong correlation in non defect transformers and weak correlation in defect transformer. The perfect correlation for LV winding for this region is 1.000 at PPU KL East T2 and the lowest correlation value for LV winding in phase comparison x0x2 to x0x3 with the CCF value is 0.764 at PPU Seksyen 23 T2.

Figure 4.18 shows the statistical results of CCF in this region illustrated in chart format. By referring to the Figure 4.18, PPU Seksyen 23 T2 obviously indicate the transformer is not healthy especially in LV winding compare with other transformers. From phase to phase comparison of CCF numerical results, it indicates a problem related to the transformer core defect or winding turn to turn short circuit or all in the H2H3 (yellow phase) and x0x2 (yellow phase) phase. In this region, PPU Kelibang T2 transformer not indicated in stress condition.

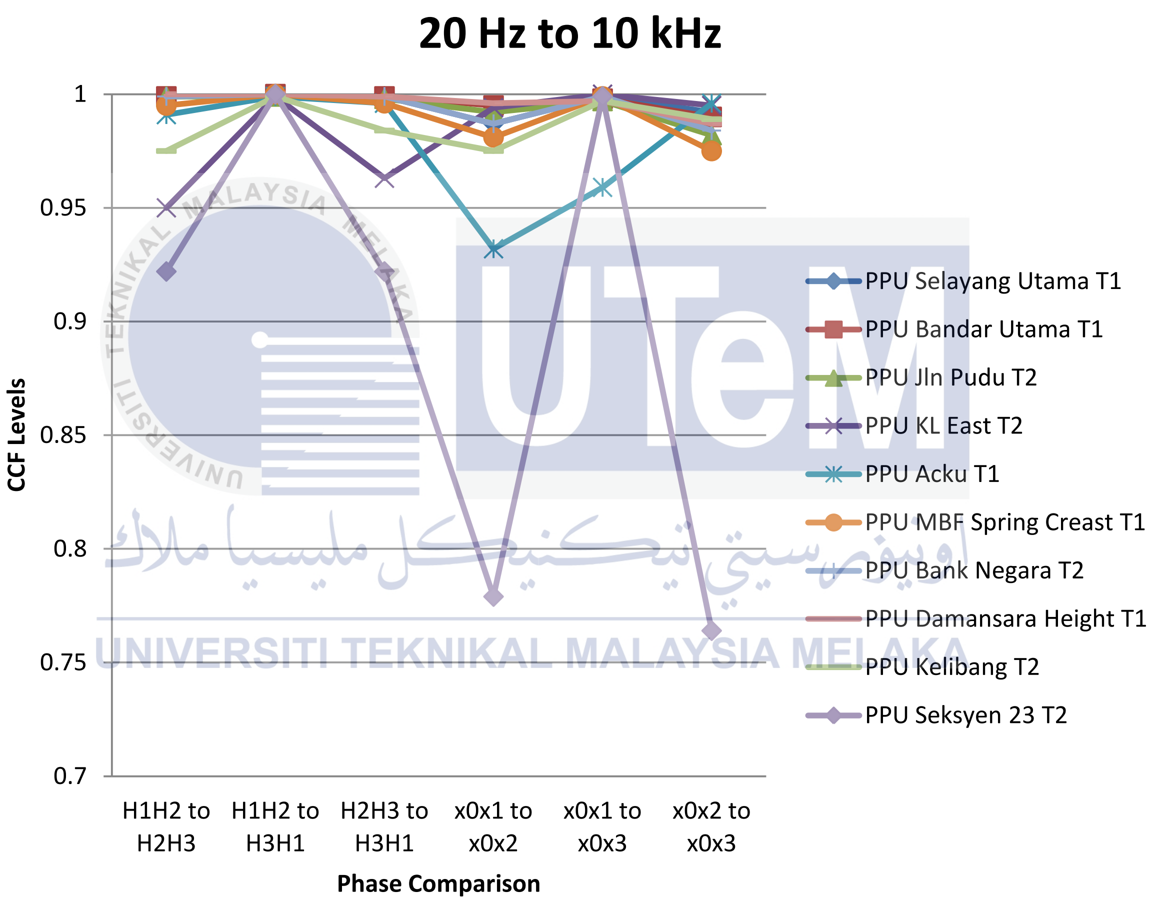


Figure 4.18 : CCF statistical parameter result for Region 1

4.3.2 Region 2: 5 kHz to 100 kHz

The research study was designed to determine the condition of transformers. Based on frequency sub band in Region 2 (5 kHz to 100 kHz), all transformers indicate the value of CCF is closely each other in HV and LV winding. However, the lowest value of CCF at HV winding is dominated by PPU Kelibang T2 while the LV winding held by PPU Bandar Utama T1. In HV winding, the phase comparison between H1H2 to H3H1 for PPU Damansara Height T1 is showing the highest correlation with the CCF value is 0.995. The lowest correlation value for HV winding is 0.866 at PPU Kelibang T2 between phase comparisons H2H3 to H3H1. In LV winding, the CCF statistical results of defect transformers obviously show a strong correlation compare with other transformers. The highest correlation value for LV winding is 1.000 at PPU Bank Negara T2 and the lowest correlation value is 0.886 is dominated by PPU Bandar Utama T1.

The numerical results of CCF in this region are simplified using chart format illustrated in Figure 4.19. By referring to Figure 4.19, PPU Kelibang T2 obviously indicates the transformer is not healthy condition. This case shows the stress condition in HV winding at phase comparison H1H2 to H3H1 and H2H3 to H3H1. However, this study finds the unexpected results. It is shown that the LV winding of non-defect transformer experience a stress condition which is the phase comparison of x0x2 to x0x3 and x0x1 to x0x2 at PPU Bandar Utama T1. Phase to phase comparison results indicate a problem related to the transformer axial winding deformation, overall bulk winding or open circuit winding in H3H1 (blue phase) and x0x2 (yellow phase) at PPU Kelibang T2 and PPU Bandar Utama T1.

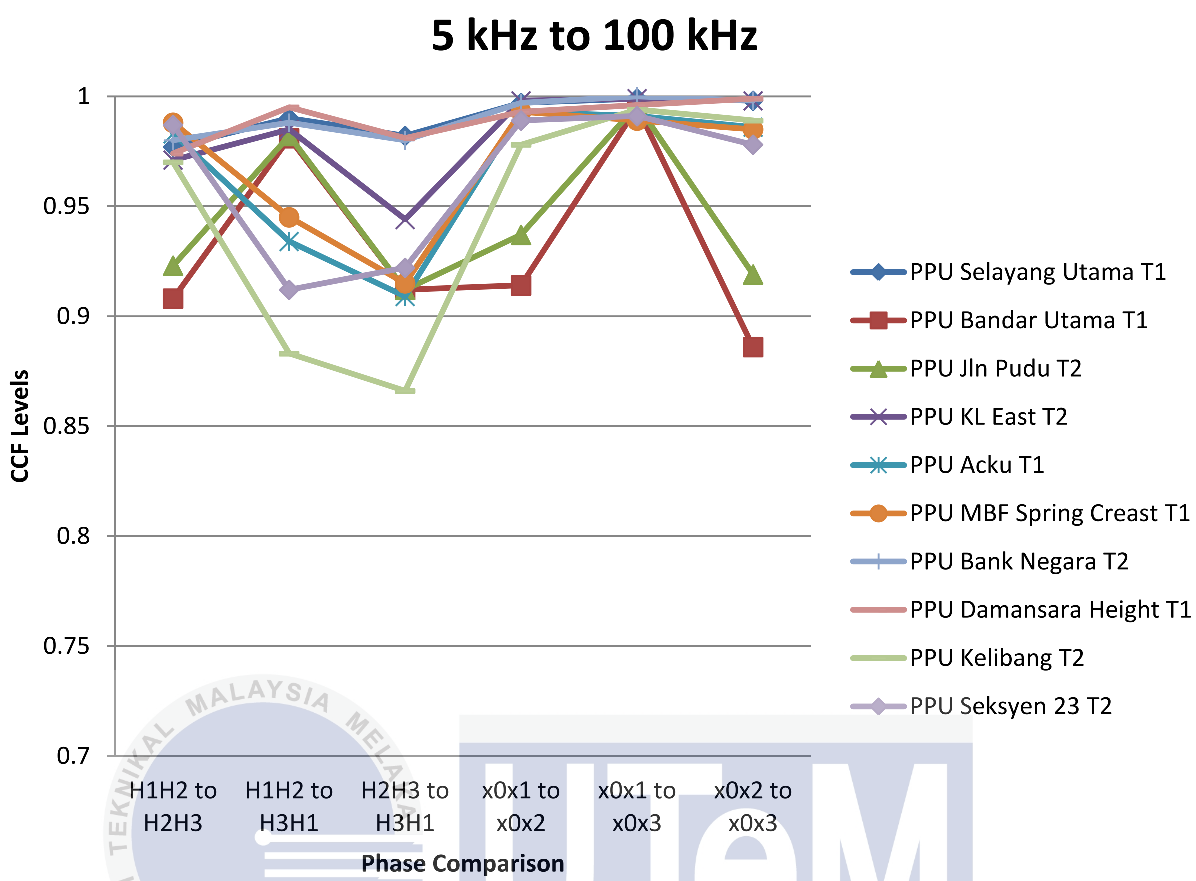


Figure 4.19 : CCF statistical parameter result for Region 2

4.3.3 Region 3: 50 kHz to 1 MHz

The results of this study for Region 3 (50 kHz to 1 MHz) indicate that CCF for HV and LV winding at PPU Selayang Utama T1, PPU Jln Pudu T2, PPU KL East T2, PPU Acku T1, PPU Bank Negara T2, and PPU Damansara Height T1 is in strong correlation. In HV winding, the phase comparison between H1H2 to H2H3, H1H2 to H3H1 and H2H3 to H3H1 for PPU Bank Negara T2 shows the highest correlation with CCF value of 0.999. Besides that, the phase comparison between H2H3 to H3H1 for PPU SelayangUtama T1 also shows the value of CCF of 0.999. The lowest correlation value for HV winding is 0.798 at PPU Seksyen 23 T2 between phase comparisons H1H2 to H3H1. In LV winding, the CCF statistical results show the highest correlation at PPU KL East T2 and PPU Acku T1 with the CCF value of 0.999. The lowest correlation value for this region in phase comparison x0x1 to x0x2 at PPU MBF Spring Creast T1 with the CCF value is 0.876.

Figure 4.20 shows the statistical results of CCF in this region illustrated in chart format. By referring to the Figure 4.20, PPU Seksyen 23 T2 obviously indicate the transformer is not in healthy condition in HV winding. PPU Seksyen 23 T2 shows that it is in stress condition while PPU Kelibang T2 indicates that is failure occurred in operation at LV winding. PPU MBF Spring Creast T1 shows the lowest value of CCF at LV winding. In this case, there are several possible explanations for this result. A possible explanation for this might be that only one phase comparisons get lowest correlation but other phase in good condition. So, it cannot clearly define which the phase at PPU MBF Spring Creast T1 is not in healthy condition. From phase to phase comparison of CCF numerical results, it indicates a problem related to the radial winding deformation in the H3H1 (blue phase) at HV winding for PPU Seksyen 23 T2 and x0x2 (yellow phase) at LV winding for PPU kelibang T2.

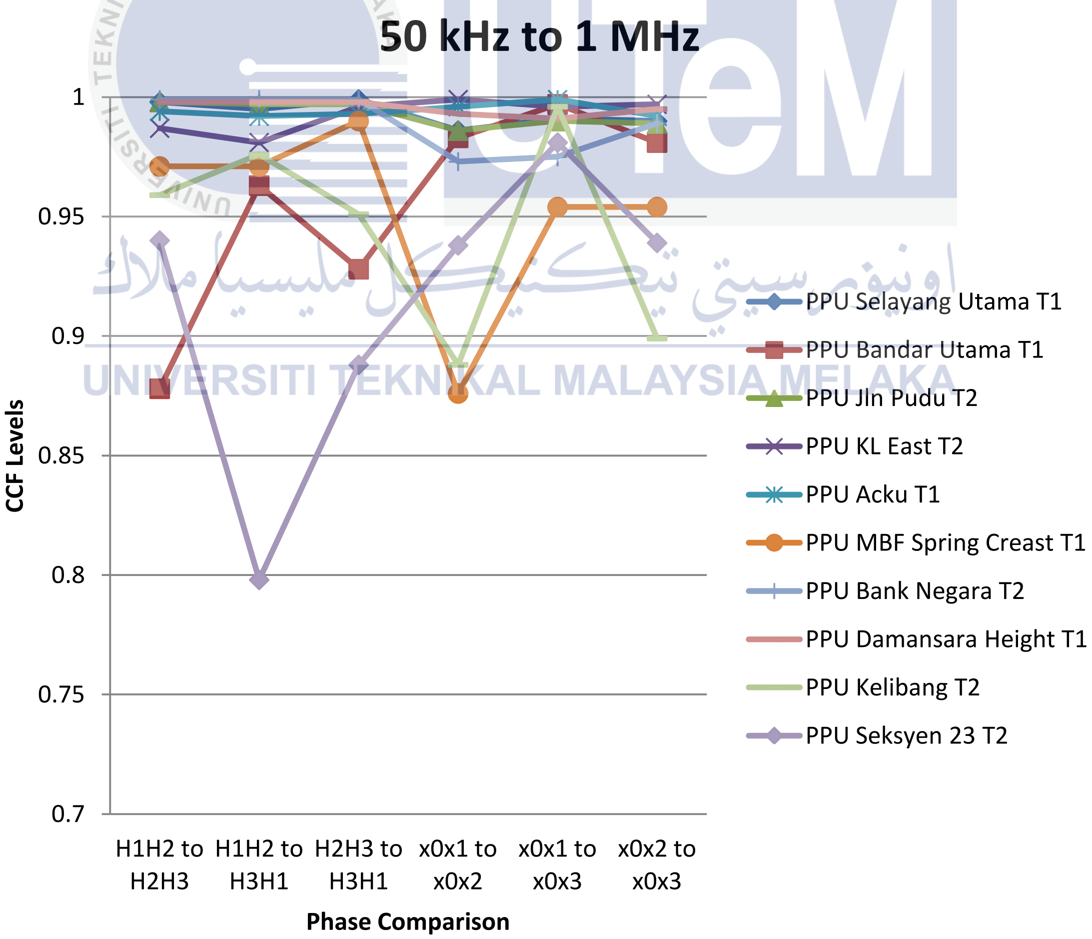


Figure 4.20 : CCF statistical parameter result for Region 3

4.4 Evaluation of Transformers Condition

The evaluation of transformer condition is divided by three groups: non defect condition, weak condition and defect condition. The evaluation depends on the graph in Figure 4.1, 4.2 and 4.3. The non-defect condition of transformer measured by the correlation of the approaching with the value is 1 or with damage less than 10% for each phase comparison. Therefore, the health of transformers that is in 90% and above evaluated as a healthy condition transformer. The healthy transformer is PPU Selayang Utama T1, PPU Jln Pudu T2, PPU KL East T2, PPU Acku T1, PPU Bank Negara T2 and PPU Damansara Height T1.

The second evaluation of transformer condition is weak condition. The weak condition of transformer is defined as the transformers have a potential to suffer damage but still can be operated. If the transformer is not going through any maintenance, the transformer may be collapse or operate in stress condition. The weak condition evaluated when only one phase comparison have value of correlation in below than 89% either in HV and LV winding. Based on graphs, the weak condition of transformer is PPU Bandar Utama T1 and PPU MBF Spring Creast T1.

The next evaluation of transformer is for the defected transformer. The defect condition of transformer is defined as the transformer that cannot operate normally because of damaged in internal parts and the transformer must be replaced with other transformer. The defected transformer evaluated when more than one phase comparison have value of correlation in below than 89% either in HV and LV winding. Based on the graphs, the defect transformer is at PPU Kelibang T2 and PPU Seksyen23 T2.

4.5 Summary of Transformer Condition

The evaluation of condition of the transformer is detected by using Cross Correlation Coefficient (CCF) method which is three condition of transformer analyzed by using result of CCF. The defected transformer used as a test subjects and the failure mode at defected transformer was detected. Table 4.2 shows the summary of transformer condition. In addition, the phase comparison which is value of correlation is 90% and above evaluated as healthy transformer and the value of correlation is below than 90% is evaluated as unhealthy transformer. Additional, unhealthy transformer is evaluated based on the number of phase comparison in HV and LV winding which is value of correlation is below than 90%. If only one phase comparison experience with lowest correlation in winding, it will be categorized as weak condition of transformer since it has potential to suffer from damage.

Table 4.2 : Summary of transformers condition

Failure Mode	Winding	Phase	PPU Selayang Utama T1	PPU Bandar Utama T1	PPU Jln Pudu T2	PPU KL East t2	PPU Acku T1	PPU MBF Spring Creast T1	PPU Bank Negara T2	PPU Damansara Height T1	PPU Kelibang T2	PPU Seksyen 23 T2
Core defects, Winding turn to turn short circuit	HV	Red										
		Yellow										
		Blue										
	LV	Red										
		Yellow										
		Blue										
Axial winding deformation, Overall bulk winding, Open circuit winding	HV	Red										
		Yellow										
		Blue										
	LV	Red										
		Yellow										
		Blue										
Radial winding deformation	HV	Red										
		Yellow										
		Blue										
	LV	Red										
		Yellow										
		Blue										
STATUS			Healthy	Weak	Healthy	Healthy	Healthy	Weak	Healthy	Healthy	Unhealthy	Unhealthy

Good condition

Middle condition

Bad condition

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter discussed about the conclusion and recommendation of this project. This project is completely done and suggestions for improvement of this project for future work are presented in recommendation part.

5.1 Conclusion

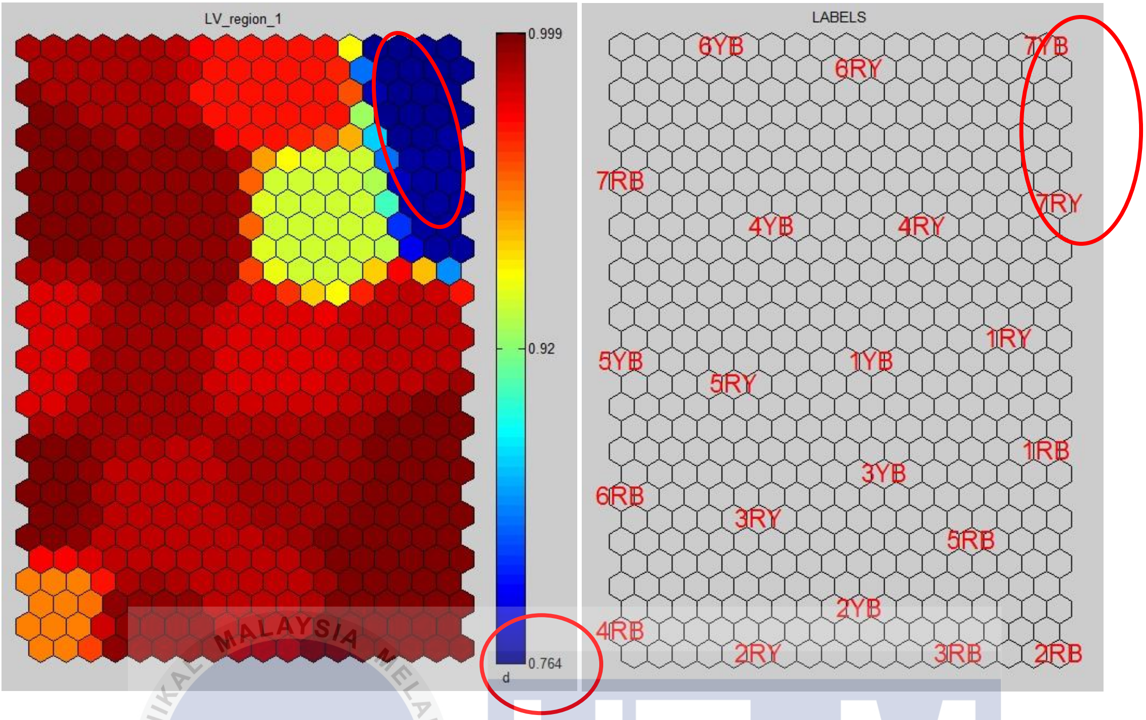
In conclusion, the sweep frequency response analysis (SFRA) is used to detect the transformer failure in mechanical fault in winding and core by using injected signal sweep of individual sinusoidal signals into one terminal. Ten transformers from TNB distribution department is selected to this research. The frequency sub band is extracted according to IEEE Std C57. 149 2012. Previously, the research of interpretation on transformer from SFRA is based on worldwide research finding as guide such as Cigre Working Group A2/26, IEEE Draft Guide PC 57.149, and Chinese Standard DL911/2004. According to new IEEE standard (IEEE Std C57 149.2012), the interpretation result can be confirmed and it can be used in asset management analysis by utility company such as Tenaga Nasional Berhad (TNB). From this research, frequency sub band from IEEE Std C57 149.2012 discovered. The important information gained from this research is about the frequency sub-band from standard which is the transformer analysis that depends on this frequency sub-band. Table 6.1 shows the frequency sub band from new IEEE standard. Ten real life data of transformers are used to evaluate the transformer condition using Cross Correlation Coefficient (CCF) method. The finding from this research is two transformers detected with unhealthy condition, two transformers detected with weak condition and other transformer detected with healthy condition. However, weak condition of transformer could be operate normally but must be maintained to avoid suffering damage in the future.

Table 5.1 : Frequency sub-band from IEEE standard

Region	Frequency range	Failure Mode
1	20 Hz – 10 kHz	Core defects, Winding turn to turn short circuit
2	5 kHz – 100 kHz	Axial winding deformation, Overall bulk winding, Open circuit winding
3	50 kHz – 1 MHz	Radial winding deformation
4	>1 MHz	May be occur : Contact resistance, Winding turn to turn short circuit, Open circuit winding

5.2 Recommendation

In recommendation, the analysis data from CCF to graph can be improved by using Self Organization Map (SOM). SOM is used as a analyze tool and it can show the many of transformers condition in one visualization by insert the CCF data in SOM. By using the visualization, the condition of the transformer can be evaluating easily using colors in SOM topology. The potential by using SOM is it can be asset management division Utilities Company such as Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn Bhd (SESB), etc. Figure 6.1shows the example of analyze data using SOM.



(a) (b)

Figure 5.1 : a) SOM topology b) Label of transformer data

Based on Figure 5.1, the SOM topology for low voltage in region 1 show the smallest value for CCF is 0.764 at dark blue area. The label for this topology shows that transformer 7 in defect condition. Summary analyze from this topology, transformer 7 experience with core defect or winding turn to turn short circuit or both in phase yellow.

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APPENDIX A

The trace of HV and LV winding in each transformer

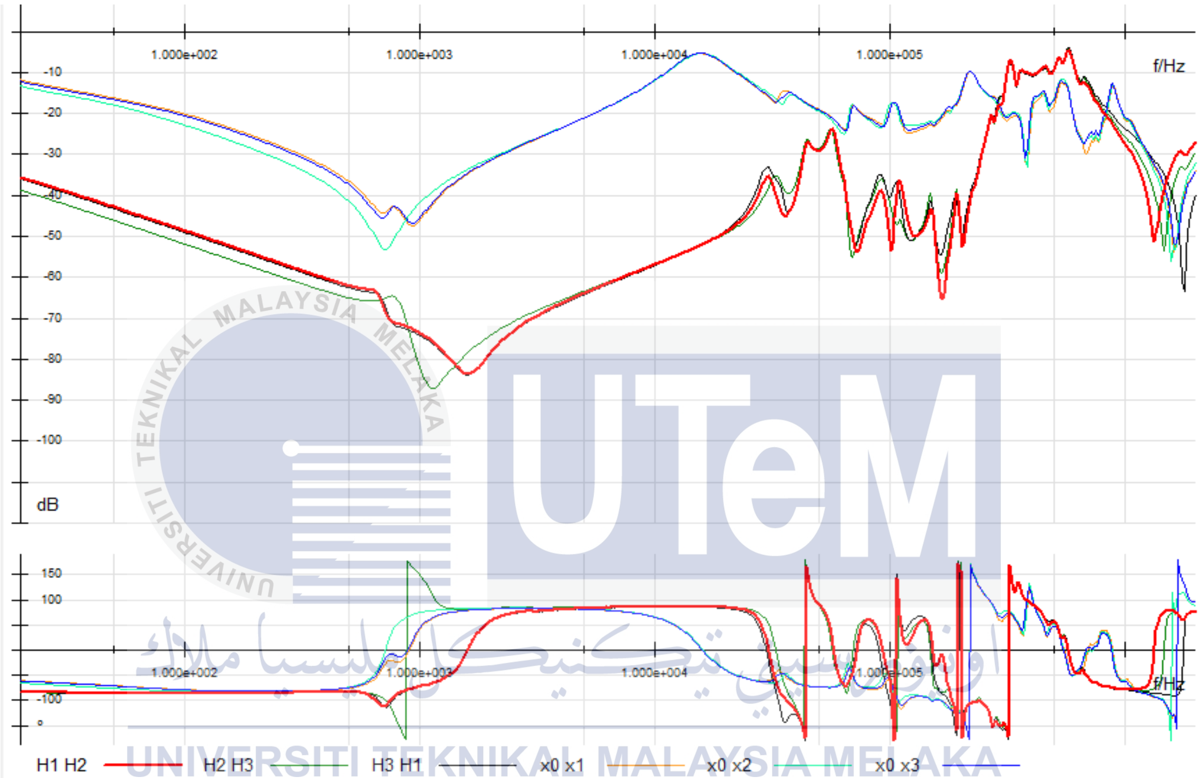

Figure 4.3 : The trace of HV and LV winding at PPU Selayang Utama T1

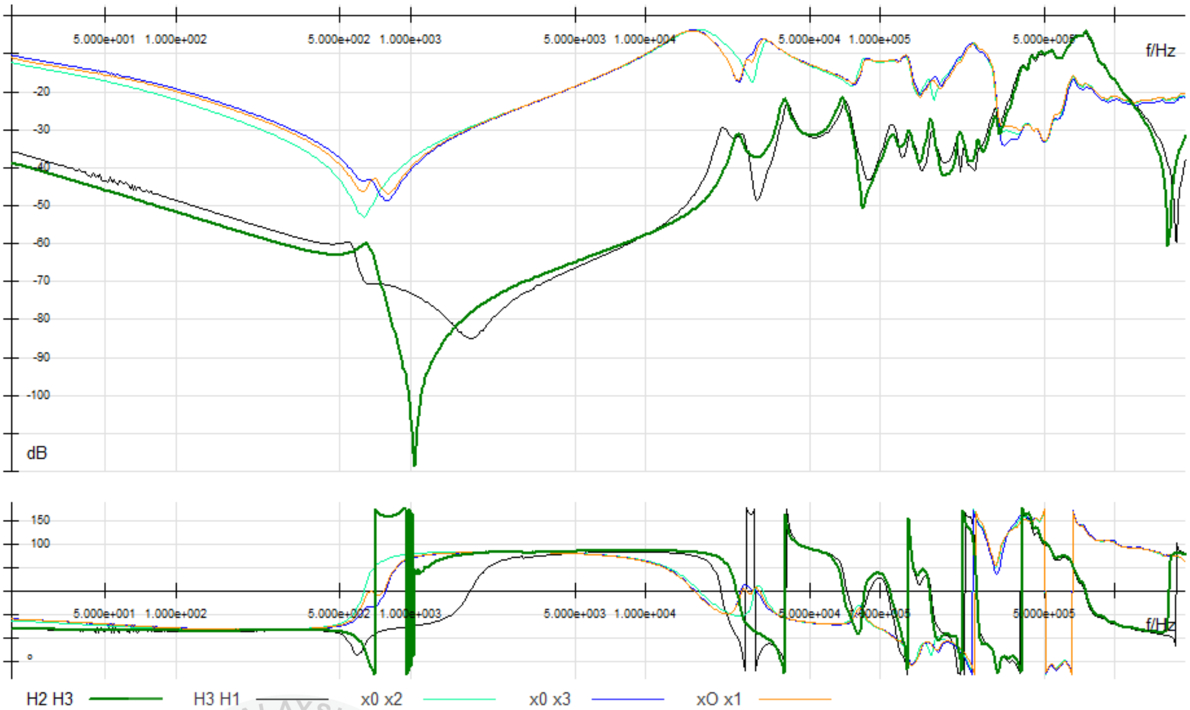

Figure 4.4 : The trace of HV and LV winding at PPU Jln Pudu T1

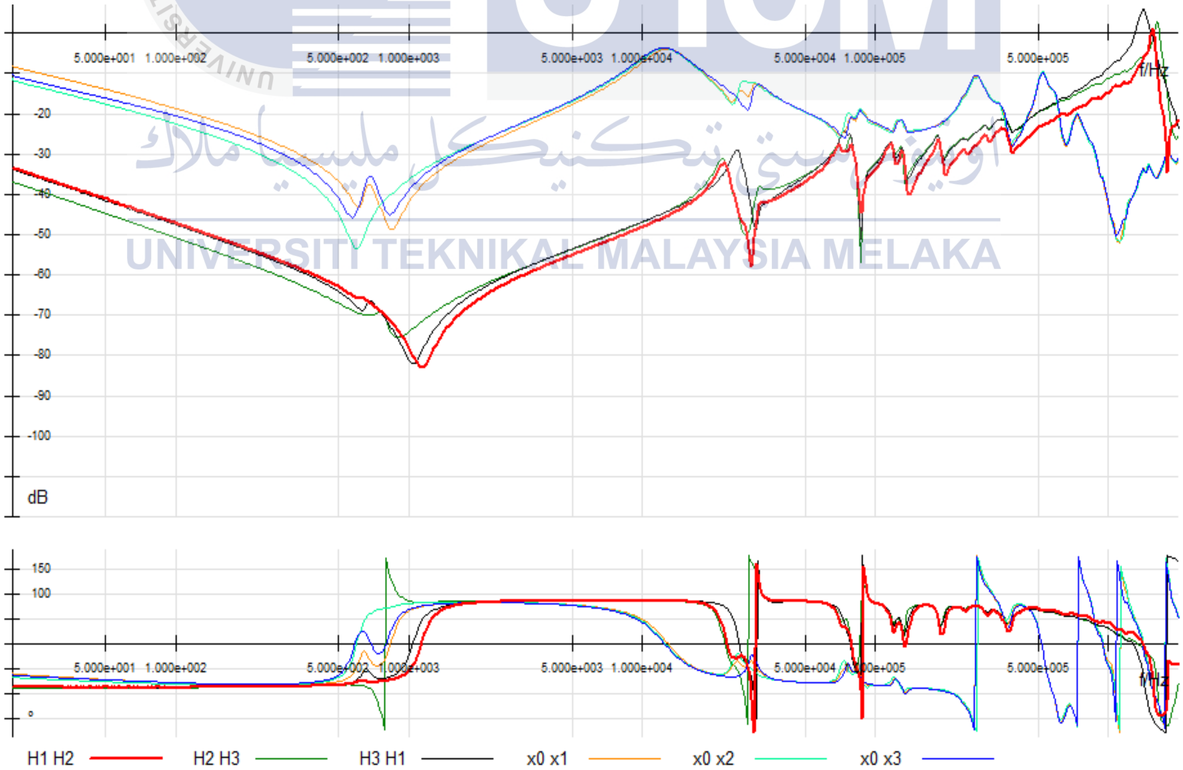

Figure 4.5 : The trace of HV and LV winding at PPU KL East T1

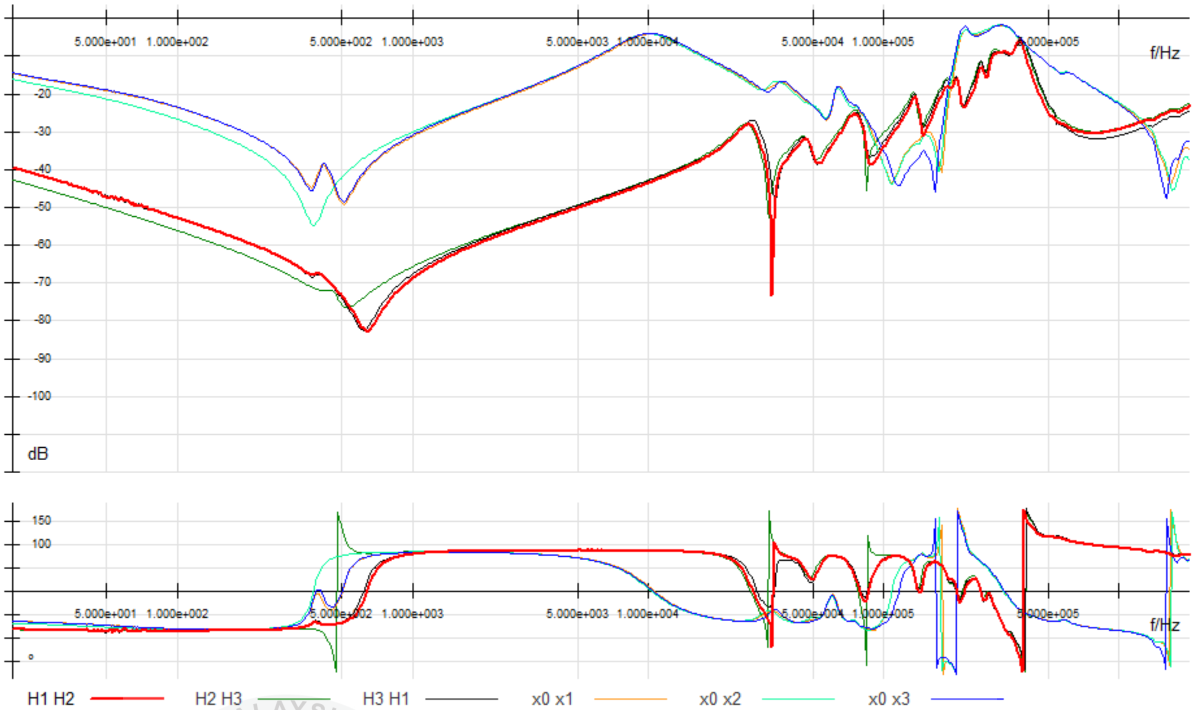

Figure 4.6 : The trace of HV and LV winding at PPU Acku T1

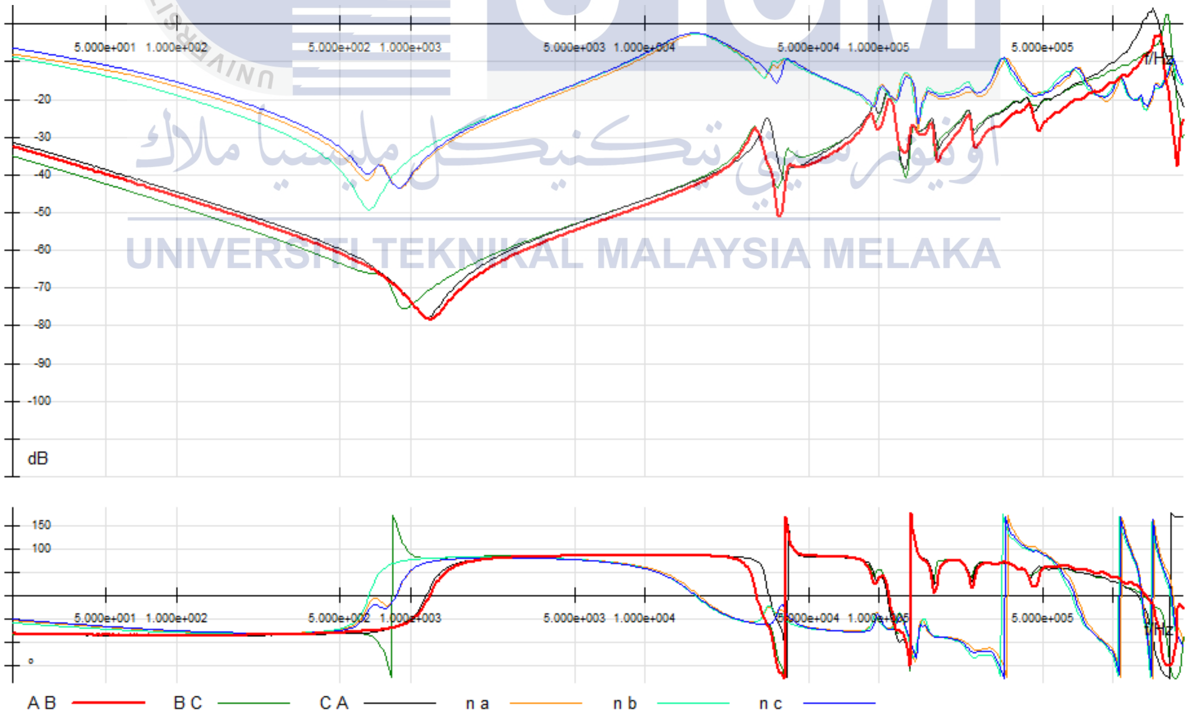

Figure 4.7 : The trace of HV and LV winding at PPU MBF Spring Creast T2

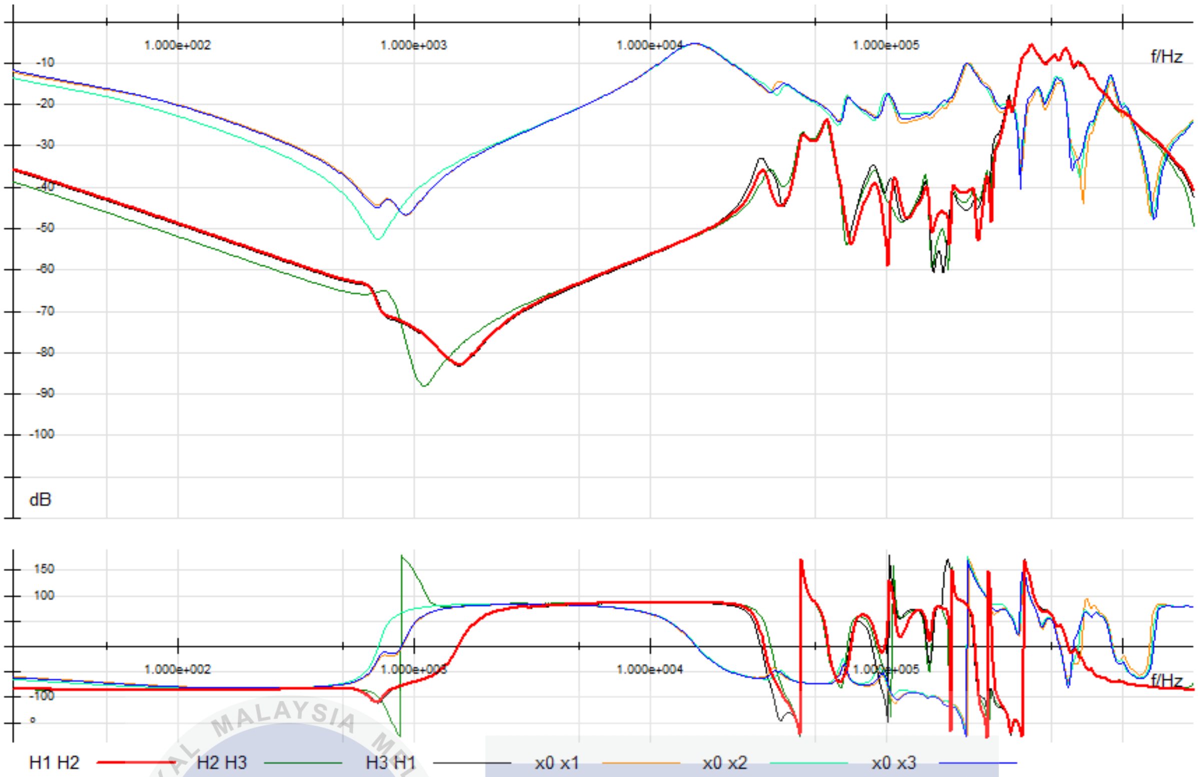

Figure 4.8 : The trace of HV and LV winding at PPU Bank Negara T2

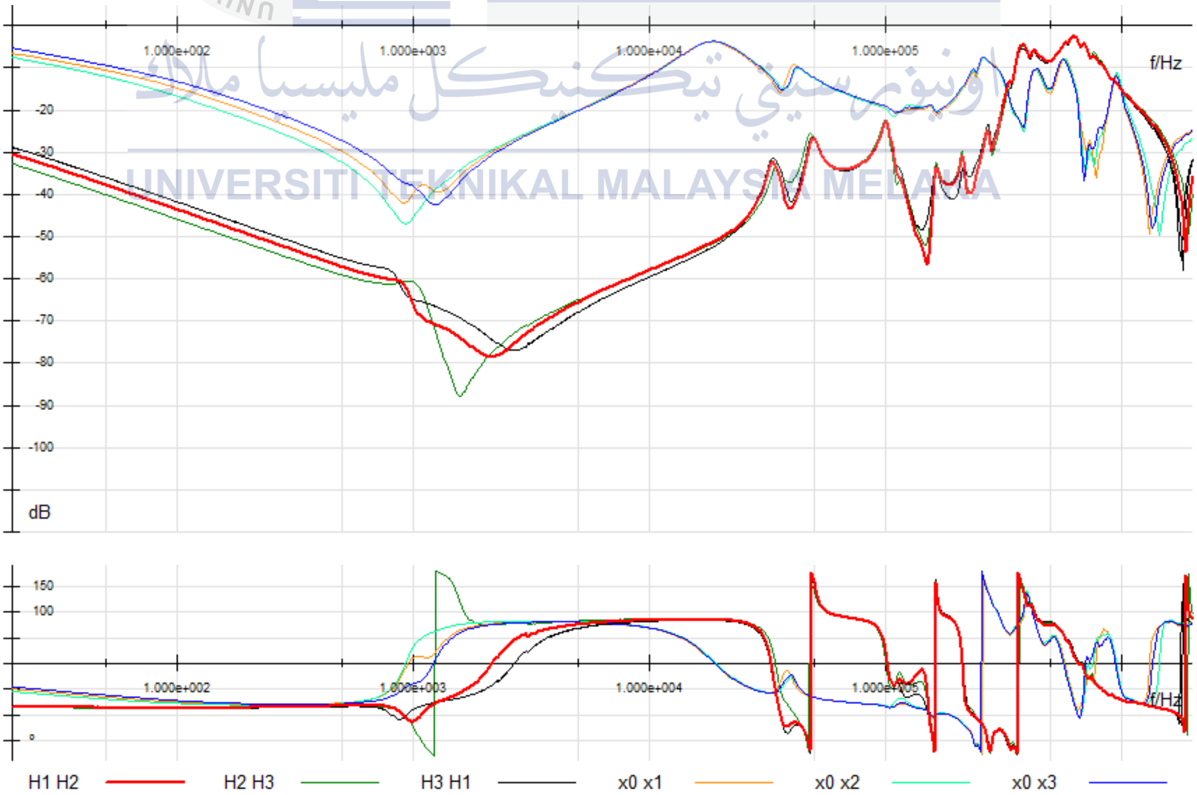

Figure 4.9 : The trace of HV and LV winding at PPU Damansara Height T1

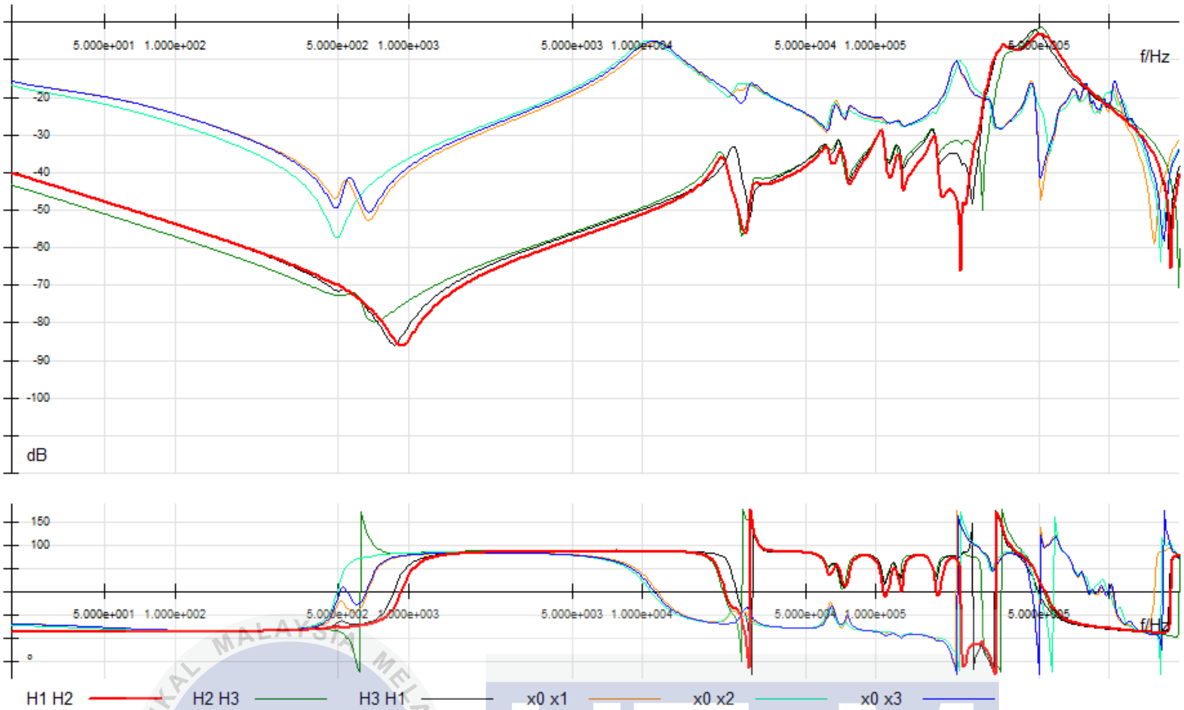

Figure 4.10 : The trace of HV and LV winding at PPU Kelibang T2

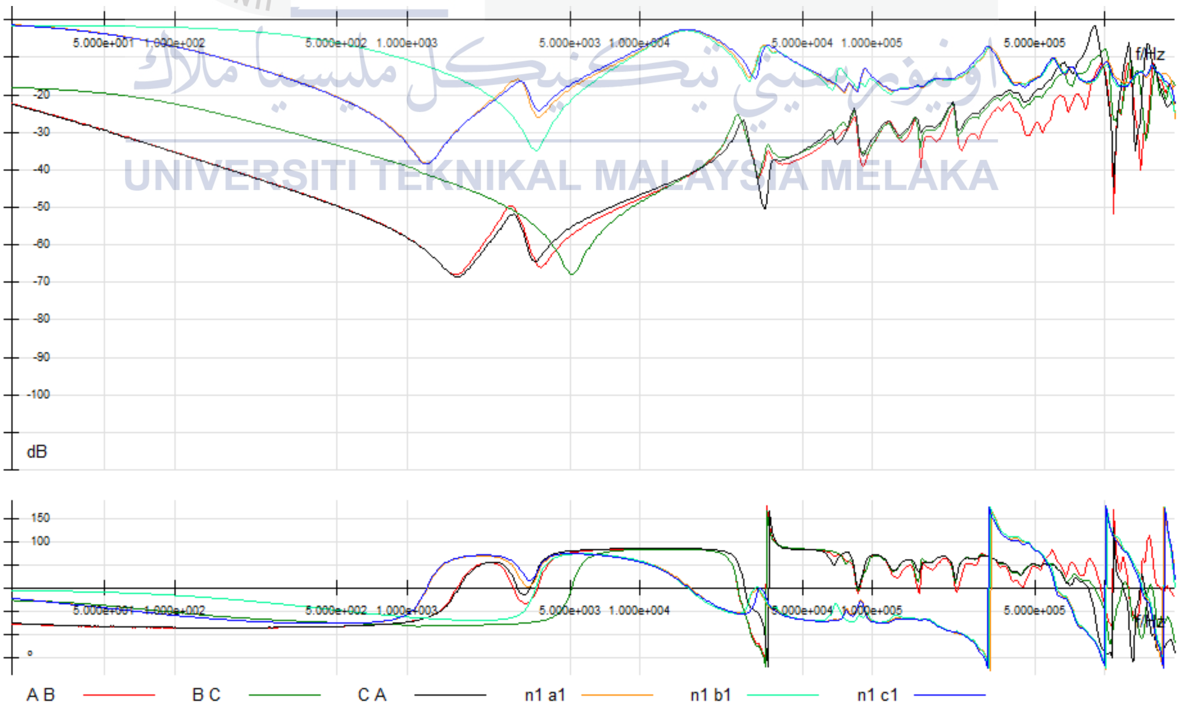

Figure 4.11 : The trace of HV and LV winding at PPU Seksyen 23 T2