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TITLE : SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA) USING TIME FREQUENCY DISTRIBUTION (TFD)

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SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA) USING TIME FREQUENCY DISTRIBUTION (TFD)

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

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2014

"I hereby declare that I have read through this report entitle "SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA) USING TIME FREQUENCY DISTRIBUTION (TFD)" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

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Date : ....

I declare that this report entitle “SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA) USING TIME FREQUENCY DISTRIBUTION (TFD)” is the result of my own research except as cited in the references. The report has not been accepted for any defree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………………

Name : …………………………………………

Date : …………………………………………

To my beloved mother and father

ACKNOWLEDGEMENT

Assalamualaikum W.B.T and greeting to all reader. I would like to take this opportunity to express my greatest appreciation to my supervisor, Mr Sharin bin Ab Ghani on his kindness to let me do my Final Year Project under his supervision. I really indebted to many people, especially my family and friends who help me in any way weather indirectly or directly way to complete this research.

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ABSTRACT

Sweep Frequency Response Analysis (SFRA) is a powerful method can be applied in order to detect or trace the mechanical faults occurs in the transformer. SFRA by using Time Frequency Distribution (TFD) is the method or technique has been selected to be used because TFD able to reduce the noise and also produce the reliable result. This project starts with constructing the tested transformer which are healthy and unhealthy transformer with Omicron Bode 100 devices. Healthy transformer will be the reference for analysis between the healthy and unhealthy transformer such as radial fault transformer, axial fault transformer and also shorten turn transformer. The result from Omicron Bode 100 is in the form of magnitude varies with frequency. The process occurs inside the Omicron Bode 100 is only injected the signal with sweeping frequency in the range of 10 Hz to 2 MHz into the terminal transformer and the result will display at the software Omicron Lab- Bode Analyzer Suite. Next, by using software MATLAB, the result will be convert into TFD). Based on literatures, it proves that TFD capable to trace or detect the presence of mechanical faults within the transformer. Moreover, TFD is a simple method and able to implement in order to obtain the reliable result. In this project, TFD is executed in the form of spectrogram where the time and frequency plot together in one graph. Basically, spectrogram is the common tools for time-frequency analysis. Finally, the analysis will be compared between the healthy transformer and unhealthy transformer to detect the type of mechanical faults that are occurring in the transformer.

ABSTRAK

Sweep Frequency Response Analysis (SFRA) merupakan suatu kaedah yang dapat digunakan untuk mengesan atau mengenal pasti kerosakkan mekanikal yang berlaku dalam pengubah (transformer Kaedah SFRA dari Time Frequency Distribution (TFD) merupakan kaedah yang telah dipilih untuk digunakan kerana TFD dapat mengurangkan gangguan (noise) dan dapat menghasilkan keputusan yang benar. Projek ini dimulakan dengan menjalankan pengujian atau percubaan keatas pengubah (transformer) sama ada rosak mahupun tidak dengan menggunakan peralatan Omicron Bode 100. Pengubah (transformer) yang tidak rosak akan dijadikan sumber rujukan dalam menganalisis diantara pengubah rosak dan yang tidak rosak. Hasil dari Omicron Bode 100 adalah dalam bentuk magnitud berkadar pada kekerapan. Proses yang berlaku di dalam Omicron Bode 100 adalah isyarat dimasukkan dalam bentuk kekerapan menyapu (sweep frequency) di dalam lingkungan 10 Hz sehingga 2 MHz ke dalam terminal pengubah dan hasilnya akan ditunjukkan di perisian Omicron Lab- Bode Analyzer Suite. Seterusnya, dengan menggunakan perisian MATLAB, hasil dari perisian Omicron Lab- Bode Analyzer Suite akan ditukar dalam bentuk TFD). Berdasarkan literatur, membuktikan bahawa TFD mampu untuk mengesan kehadiran kerosakkan mekanikal di dalam pengubah. Malahan, TFD merupakan teknik yang mudah dan mampu dilaksanakan untuk menghasilkan keputusan yang boleh dipercayai. Di dalam projek ini, TFD dilaksanakan di dalam bentuk spectrogram di mana masa dan kekerapan berada di dalam satu graf. Akhir sekali, analisis ini akan dibandingkan diantara pengubah yang rosak dan pengubah yang tidak rosak untuk mengesan jenis kerosakkan mekanikal yang berlaku di dalam pengubah.

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LIST OF GLOSSARY

UTeM	Universiti Teknikal Malaysia Melaka
SFRA	Sweep Frequency Response Analysis
TFD	Time Frequency Distribution
RVM	Recovery Voltage Measurement
DGA	Dissolved Gas in oil Analysis
FT	Fourier Transform
IFRA	Impulse Frequency Response Analysis
AC	Alternating Current
FRA	Frequency Response Analysis
STFT	Short Time Frequency Transform

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Transformer is an electrical device that converts or change an alternating current (ac) of a certain value of voltage to an alternating current of different value voltage without changing the frequency [1],[2]. A transformer is a very large contribution mainly in power transmission. If any of the transformer experiencing failure or fault in power transmission system, electricity cannot be distributed in the factory and household. There are four types of fault which are electrical, thermal, environmental and mechanical faults. The most difficult fault to observe is mechanical faults [3],[4]. This is because mechanical fault occurs at the winding and the core inside of the transformer itself. Figure 1.0 shows the transformer experienced mechanical faults. The types mechanical faults that are occur in the Figure 1.0 are the windings of the transformer collapsed and also windings of the transformer loosened.

Figure 1.0: The transformer experienced mechanical faults [2]

There are a few of faulty diagnostic technique that can be applied including method recovery voltage measurement (RVM), the dissolved gas in oil analysis (DGA). However, all of these methods are not relevant in order to detect the transformer winding deformation [4],[5]. The structures of the transformer are made up of a combination of capacitance, resistance, self inductance and also mutual inductance. When a fault occurs in the winding, the frequency response from the winding will change immediately. This is happening due to the parameter of transformer is changed.

The winding displacement can affect the transformer insulation withstand. Therefore, SFRA is used by using TFD method in order to analyze the signal and interpret the signal to classify the transformer whether healthy or unhealthy transformer.

1.2 Motivation

Mechanical faults occurs within the power transformer is very difficult to detect or trace because most of the power transformer built with cover. By using Sweep Frequency Response Analysis (SFRA), the power transformer able to check whether the transformer is healthy or unhealthy. To detect the present of mechanical faults by using Omicron Bode 100 is convenient, however to transfer the signal into time-frequency distribution (TFD) is very difficult. In this technology era, the skill to detect mechanical faults to the transformer is indispensable. This is because the power transformer is very costly and to replace the power transformer with the new transformer is not a good solution. Moreover, SFRA is not only able to detect the mechanical fault but also electrical faults occur in the power transformer. This project is needed to reduce the rate of damage that can cause significant losses to the industries and also manufacturing by establish the monitoring system that can help in diagnosing the faults occur within the power transformer.

1.2 Problem Statement

First of all, this project was implemented to detect the mechanical faults that are occurring in the power transformer. This is because the presences of mechanical faults are quite difficult to trace because of the transformer built with its cover. Basically, power transformers are crafted and designed to endure or detain this current from short circuit, however the strong electrodynamics forces resulting from short circuit will affect the transformer windings and also the core collapse. Mechanical faults could be trace by using Time Frequency Distribution (TFD) methods from SFRA [4],[5],[6],[7]. Therefore, TFD is proposed to be used in order to detect the presence of mechanical faults in the transformer. Basically, TFD is a new method use to determine and identify the mechanical fault occurred in the power transformer[4]. The different between TFD and Fourier Transform (FT) are FT only 1 Dimensional representation and TFD is 2 Dimensional representations. From [4],[8] it states that FT is the methods for Impulse Frequency Response Analysis (IFRA), not the same with TFD which is from Sweep Frequency Response Analysis (SFRA). For this is the reasons why TFD is selected and be used due to the factor of TFD having a 2 Dimensional representatives are both the time and frequency applied at the same time in one plot graph. From [4] and [8] it states that the results from the sweep frequency system are very much repeatable then impulse frequency system. At this point of view, SFRA is better than IFRA in order to achieve the result precisely.

1.4 Objective

1. To investigate the effectiveness of Sweep Frequency Response Analysis (SFRA) using Time Frequency Distribution (TFD) as a diagnostic technique in single phase transformer
2. To analyze the capability of Omicron Bode 100 for the detection of mechanical faults occurring in single phase transformer.
3. To examine the frequency ranges of the mechanical faults occurring using Time Frequency Distribution (TFD).

1.5 Scope of research

1. The application of Omicron Bode 100 device is used for the SFRA measurement system.
2. SFRA measurement conducted on three types of single phase transformers with two transformers already in defective condition while the other one is non-defect transformers.
3. Analyze the mechanical fault occurring in the single phase transformer
4. SFRA using TFD measurement results is taken for comparison between healthy and mechanical faults transformer

1.6 Report Outline

This report consists of 5 chapters. In chapter 1, this report focuses on the background of the project, problem statement, objectives of research and scope of the research. In chapter 2, the literature review of this project is precisely describes in detail. It contains the general theory of transformer, type of faults in the power transformer, fault diagnosis in the SFRA, the frequency ranges, time-frequency distribution and also the type of diagnosis applied.

Chapter 3 discusses the method used and the procedure that is used in the experiment. Furthermore, in this chapter it explains in more detail about the constructing of the Omicron Bode 100, testing each of simulated transformer faults and non defect transformer condition. Next, Chapter 4 discusses the preliminary result regarding to the hardware and software in this project. Last but not least, Chapter 5 will discuss the conclusion and recommendation can be made from this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, it explains several of relevant information about theory characteristic of the transformer. Furthermore, it also includes the variant type of faults in the power transformer, fault diagnosis using Sweep Frequency Response Analysis (SFRA), frequency ranges used for evaluating the transformer core, type of diagnosis applied to the power transformer. Last but not least, TFD is applied to the power transformer in order to detect the faults occurs.

2.2 Type of Faults in Power Transformer

Initially, the power transformer is designed to endure or detain the short circuit current. But even so, the effect of the mechanical forces notably short circuit may affect the power transformer in terms of life expectancy. This is because when the presence of mechanical forces will achieve a limit, the impact will cause the insulation of the mechanical strength in the transformer to become poor.

There are several type of deformation in winding that may occur in the power transformer such as axial deformation and radial deformation[9]. Other than that, the effect of axial and radial winding deformation may occur the core lamination is damaged. When the core laminations have damage, the winding of the transformer may lead to shorten turn on the transformer itself as illustrated in Figure 2.0. The Figure 2.1 and 2.2 shows the direction of forces when the radial and axial deformation occurs. From Figure 2.1 indicates that hoop buckling occurs when the force moving inward to the transformer resulting the winding of the transformer experienced dented. In Figure 2.2 indicates the winding of the transformer collapsed after effect of the force acting downwards.

Figure 2.0: Shorten turn occurs when core lamination experience damaged [9]

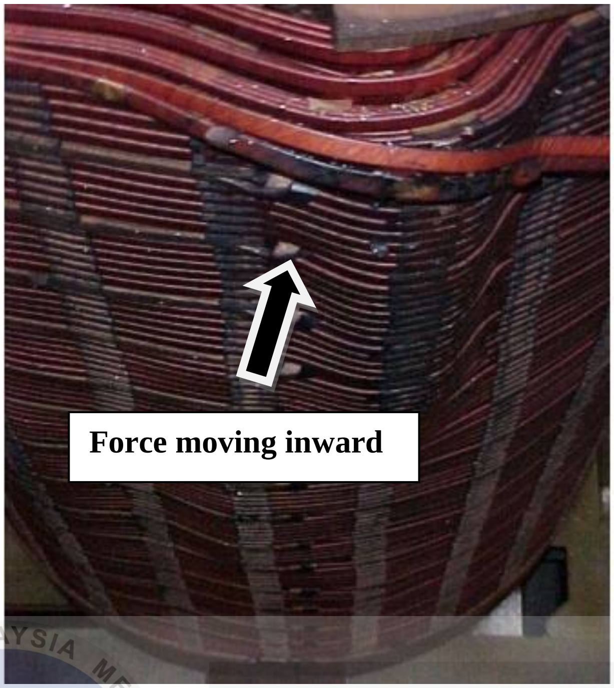


Figure 2.1: The direction of forces when the radial deformation occurs [9]

Figure 2.2: The direction of forces when the axial deformation occurs [9]

A power transformer failure can be divided in several parts[8]. Firstly is the transformer winding fault which occurs due to the phase to phase faults, turn to turn faults, phase to ground, open winding. Next is core fault which are due to the core insulation failures and also shorted laminations. Then, it's the terminal faults that are caused by loose connections, short-circuits and open leads. After that, its abnormal operating conditions that are due to the over fluxing, overloading and overvoltage. Lastly are the internal transformer faults. There are several factor that makes up this faults, firstly is due to the external short-circuit, resulting in damage to the transformer winding. The effect caused the deformation to winding structure, hoop buckling, turn to turn faults, and loosened of clamping structure. Secondly is transportation that occurred when the transport of new or serviced transformers that may cause of damage to the internal structure of a transformer. Although, a little change in winding path, it will lead to breakdown to transformer for future short-circuits current. Third is seismic events that occurred by catastrophes like Earthquakes that cause inner damages and also the mechanical fault on power transformers. Lastly is overvoltage arises that are occurred when presenting of lightning strikes and also due to the switching operation.

2.3 Fault Diagnosis Using SFRA

SFRA is use to detect or trace the number of fault conditions no matter whether the faults are mechanical or electrical faults [9]. Basically, SFRA is use to detect mechanical faults [4,][5],[6],[7],[8]. An electrical fault describes the affecting of the magnetizing inductance of the transformer and the winding resistance as the self inductance of the windings. For these cases, these effects are only visible at low frequencies in the result of SFRA [6],[9],[10]. The types of mechanical faults are radial compression failure (buckling in inner windings), hoop tension failure (buckling in outer windings), tilt in conductors, axial collapse and core displacements.

2.4 Frequency Ranges for Evaluating Transformer Condition

There are several ranges of frequency used to determine the transformer situation from the SFRA measurement results. According to Table 2.0 the ranges of frequency can be classified into three parts which is the frequency below 10 kHz is for low sub band, frequency from 5 kHz to 500 kHz is for middle sub band and frequency more than 400 kHz is high sub band [13]. From all of these frequency ranges, faults can be precisely identified in the transformer such as low sub band indicates core and magnetic circuit occurs, middle sub band indicates radial geometrical movement, and high sub band indicates axial deformation occurs.

Table 2.0: Frequency ranges in the SFRA method [13]

Frequency Sub-bands	**Indication Faults**
Below 10 kHz (Low Sub Band)	Core and magnetic circuit occur
5kHz to 500kHz (Middle Sub Band)	Radial geometrical movement between is detected
400kHz and above (High Sub Band)	Axial deformation occurs

2.5 Frequency Response Analysis (FRA) as a Diagnosis

From the [6],[8],[9],[12] prove that FRA is a powerful method for trace and identify the transformer mechanical damages, which are difficult and very hard to detect by conventional measurements. According to the fact of the transformer winding may be modeled as a network of resistances, capacitance and inductances. When a fault occurs in the transformer construction, the values all of these parameters are changed and the frequency response from the winding will also change.

Frequency Response stands for steady-state response of a system to a sweep frequency sinusoidal voltage of low amplitude [11],[13]. Figure 2.3 shows that a single transformer winding is split into several parts which are the cascaded pi network comprising for self/mutual inductances, resistance, series/shunt capacitances and shunt dielectric conductance. In other words, it can be considered that the mutual inductances are roll up into the series of inductance [13]. The total transfer functions of the network represent poles reaction as the resonant frequencies for the winding model. Divided between turns of winding under test required same to the short circuit of the R-L-C network with a shift in resonant pole to another frequency. By referring through this model, the transfer function can be examine [11]. Not only that, the method can also be analyzed any changes its parameters inductance and capacitance either from shifting the advent a new pole frequency of resonant. All of transformer has a typical transfer function known as a fingerprint [13]. A non-linear response is a result from the relationship between capacitive and inductive impedance.

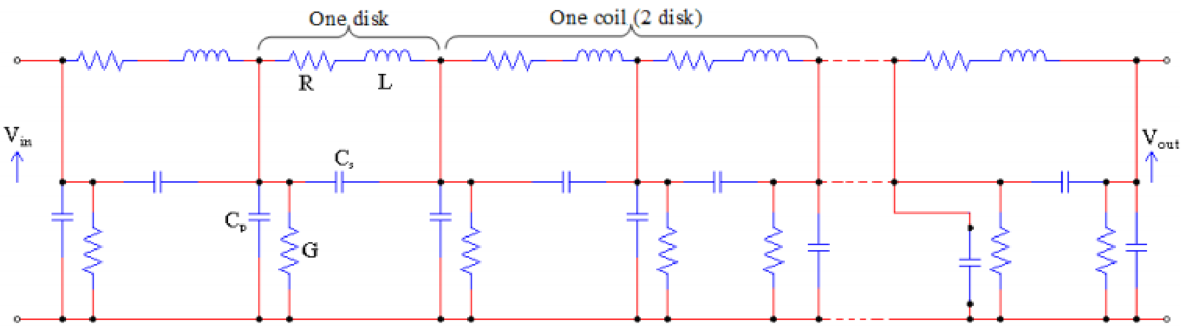


Figure 2.3: Transformer distributed parameter model [13].

For resistances, the changes are whether a rising or falling in transfer function magnitude at a critical frequency. Winding inductances and also capacitances are the main function of material properties. Furthermore, if any movement of winding occurs can affect to the result experiencing exchange to its values [12],[13]. Table 2.1 shows the physical parameter and the type of the faults. From this table, the physical parameter can be divided into four types which are inductance, shunt capacitance, series capacitance and lastly resistance. All of this parameter will indicate the different type of faults depending on its parameter changes.

Table 2.1: The Physical Parameter and the Type of the Faults [13].

Physical parameter	Type of fault
Inductance	Disk deformation, local breakdown, winding short circuits
Shunt capacitance	Disc movements, buckling due to large mechanical forces, loss of clamping pressure
Series capacitance	Ageing of insulation
Resistance	Shorted of broken disk, partial discharge

FRA is also functioning as a monitoring and comparing technique in power transformer. FRA can helps in measuring the impedance of the winding even in wide range of frequency. In this project, SFRA method was used to detecting the mechanical faults only. SFRA are very well known and widely used in the world to diagnosis the power transformer [4],[5],[6],[7]. Since the SFRA is less effect of the noise unlike IFRA, SFRA is applied in the power transformer using TFD. A network analyzer is required in order to produce the performance of the transformation in the frequency domain.

2.6 TFD is applied to the power transformer

TFD is a powerful method in order to show that the energy of the signal can be distributed into the two dimensional (2D) time frequency space. Basically, the signal processing may harness the features produce by the concentration of signal energy in two dimensions which are time and frequency than only one either time or frequency [5][7][13][14]. TFD can clearly show the signal from its start till the end as illustrated in Figure 2.4. Furthermore, Figure 2.4 is example of TFD in the term of spectrogram where time and frequency plot together in a single graph, each contour level based on the colour indicates the energy level going from dark blue, which is indicate lowest energy until the dark red base for higher energy

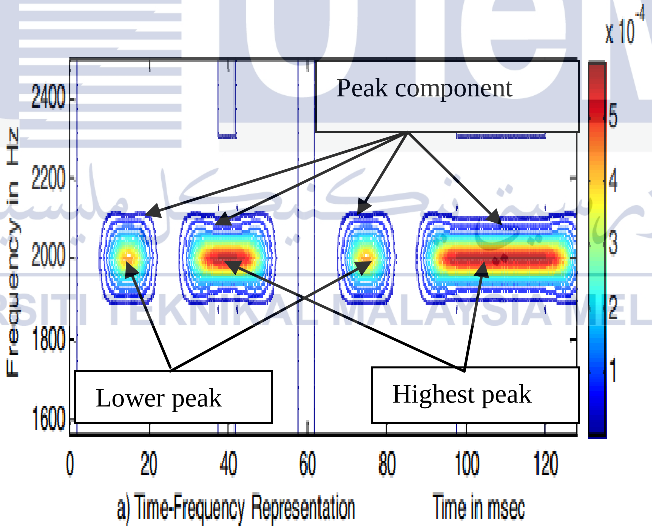


Figure 2.4: Time frequency representation [14]

2.6.1 Time Frequency Representation

The concepts of time frequency signal are very concerned about the analysis and processing of the signals with time-varying frequency content [15]. Time frequency distribution (TFD) is proposed because TFD capable to show how the energy of the signal distributed in the two-dimensional time-frequency space. Processing of the signal afford to work the features produced from the signal energy in the two dimensions which are time and frequency together and not only time or frequency separately.

In the signal analysis, there are two types of classical representation which are referred on the temporal representations (t), and another one based on representation of spectral from Fourier transform, s(f) [13] . From [13] prove that these two types of representations and also associated to the classical methods like autocorrelation or power spectrum to be very powerful in the interpreted of static signal. However these methods can fail to achieve the full character when the signal is not in static or stationary signal. By way of example, assuming the SFRA is a linear of a frequency modulated (FM) signal [13],[14]. The waveform spectrum as shown in Figure 2.5 (b) displayed there are no demonstration of how the frequency of the signal changing varies with time. Not only have that, the time domain graph Figure 2.5 (a) was also not given in full detail in the signal. From this understanding, the Figure 2.5 (a) and Figure 2.5 (b) are not reliable in order to interpret the data.

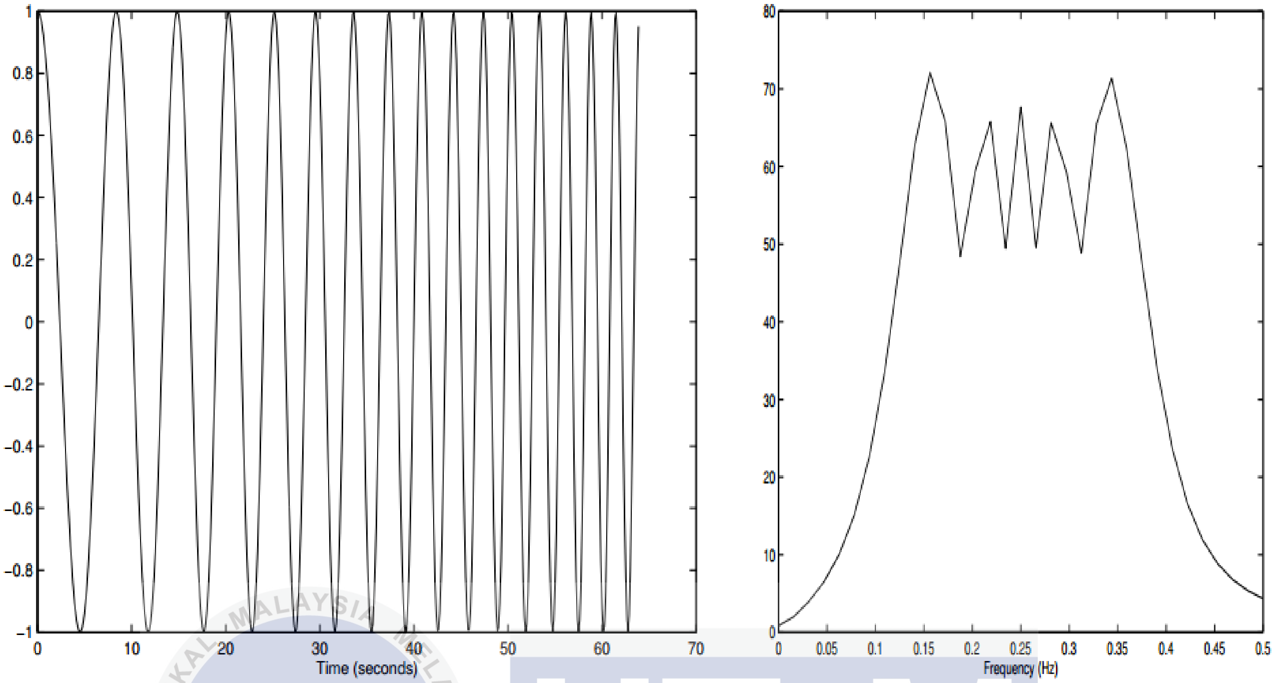


Figure 2.5: SFRA signal (a) Time domain (b) Fourier domain representation [13]

To solve the problem regarding to the frequency and time domain, it is done by plotting the combination of graph time-frequency distribution as illustrated in Figure 2.6 [13],[14]. From the Figure 2.6, there are very easy and straight forward to find the linear relationship between frequency and time because both of the frequency and time are plotted in the same time in one graph. As a matter of fact, the TFD graph can help in order to identify the start and stop times of the signal frequency. On the other hand, TFD can be used in the analysis consider as real-time SFRA signals.

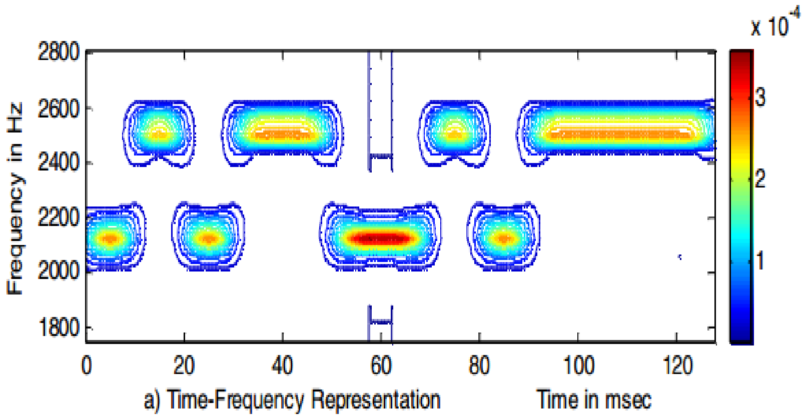


Figure 2.6: The time-frequency representation of the SFRA waveform [14]

2.6.2 Spectrogram

A spectrogram is one of the time-frequency representation or distribution, which is a part of both frequency and time that indicates the energy distribution in a signal over the time - frequency plane [15]. The spectrogram format mostly the horizontal axis represents time, the vertical axis is frequency, and the intensity of each dot in the picture represents the amplitude of a particular frequency at a particular time [15]. Spectrogram calculated using short-time Fourier transform (STFT). The STFT used to determine the sinusoidal frequency and phase signal as it changes with time. In this project used discrete STFT where data to be transformed could be separated into chunks or frames that are normally overlap each other. The equation of discrete-time STFT as illustrated in Equation 1.

$$\mathbf{STFT\{x(t)\}(m,}\boldsymbol{w}\mathbf{) = X(m,}\boldsymbol{w}\mathbf{) =} \sum_{n=-\infty}^{\infty} \boldsymbol{x[n]w[n-m]e^{-jwn}} \text{---------------------------}\mathbf{Equation\ 1}$$

Where the signal is x[n], window is w[n], m is discrete and ω is continuous.

2.7 Omicron Bode 100 devices

The Omicron Bode 100 devices is a tool that is specially designed for multifunctional test and measurement, particularly for professionals such as scientist, engineers, and teachers engaged in the field of electronic or electrical. It have distinctive concept which is the universal hardware will be controlled by the software (Omicron Lab- Bode Analyzer Suite) on a computer [16]. Omicron Bode 100 also capable to work as frequency response analyzer, impedance meter, gain phase meter and also a sine wave generator [16]. In this project, Omicron Bode 100 devices were applied to analyze the frequency response of the transformer. Figure 2.7 shows the measurement setup of SFRA with tested transformer.

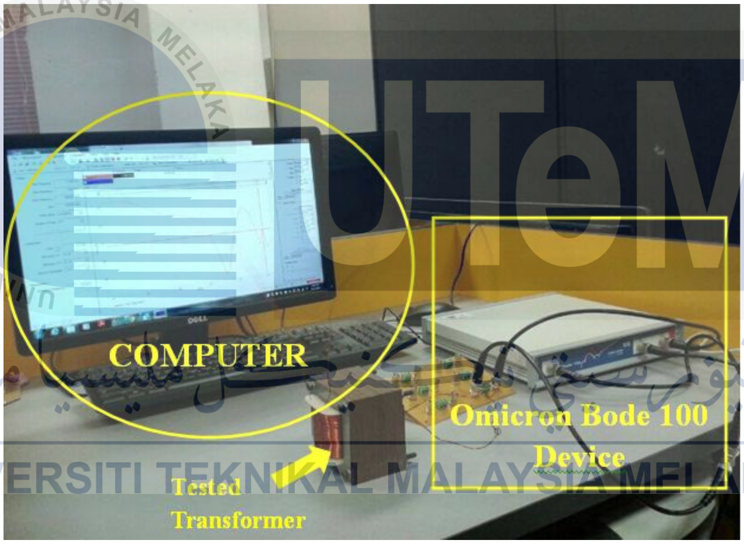


Figure 2.7: Typical measurement setup for Omicron Bode 100 [16]

2.8 Summary of the review

Basically, all the information and detail about the transformer have been discussed in this chapter. The type of faults occurs within the transformer especially focus on the mechanical fault/failure. All of the descriptions in this chapter are shown in Table 2.2. From Table 2.2, although there are several methods can be applied to the transformer such as Dissolved Gas Analysis (DGA), Recovery Voltage Measurement (RVM) and Sweep Frequency Response Analysis (SFRA) in order to detect the faults, but only one could trace the mechanical faults/failure in the transformer that is the SFRA. TFD is selected from SFRA methods to analyze and interpret the signal from the transformer to analyze the transformer either its healthy or unhealthy [13],[14].

Table 2.2: The Overall of Literature Review

Type of mechanical faults occur in the power transformer	winding deformation(axial forces), winding displacement(radial forces) and loosened winding
The cause of mechanical faults occur	External Short-circuit and Catastrophes like Earthquakes
Type of diagnosis applied to the power transformer	Dissolved Gas Analysis (DGA), Recovery Voltage Measurement (RVM) and Sweep Frequency Response Analysis (SFRA)
The suitable diagnosis method can be apply in power transformer	Sweep Frequency Response Analysis (SFRA)

In this project, the frequencies ranges are shown in Table 2.2 which are three different ranges of frequency are used to show the different types of faults/failures. Table 2.4 indicates the frequency ranges in SFRA method and its indication faults. The frequency sub-bands can be classified into three ranges which are low sub band (below 10 kHz), middle sub band (range between 5 kHz to 500 kHz) and high sub band (ranges between 400 kHz and above).

Table 2.3: Frequency ranges in the SFRA method [13].

Frequency Sub-bands	**Indication Faults**
Below 10 kHz (Low Sub Band)	Core and magnetic circuit occur
5kHz to 500kHz (Middle Sub Band)	Radial geometrical movement between is detected
400kHz and above (High Sub Band)	Axial deformation occurs

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will deeply describe all the descriptive technique, methodology and the experiments which are using several types of single phase transformer consisting of a healthy and unhealthy transformer. Furthermore, this chapter also discusses about the development of software and hardware where the software used is Omicron Lab-Bode Analyzer Suite and MATLAB. For the hardware turn is connection of Omicron Bode 100 with device under test (DUT). Figure 3.0 shows the list of tasks that is compulsory to be completed for every stage following the project planning. Indeed, the next section will describe the exact view about the project methodology, particularly constructing the connection of Omicron Bode 100 with the DUT, testing each of simulated transformer faults (unhealthy transformer) and non defect transformer condition (healthy transformer). The result in graphical form of the Omicron Lab-Bode Analyzer Suite will be in the frequency domain which is magnitude versus frequency. Last but not least, the result will be converted into time frequency distribution (TFD) through MATLAB.

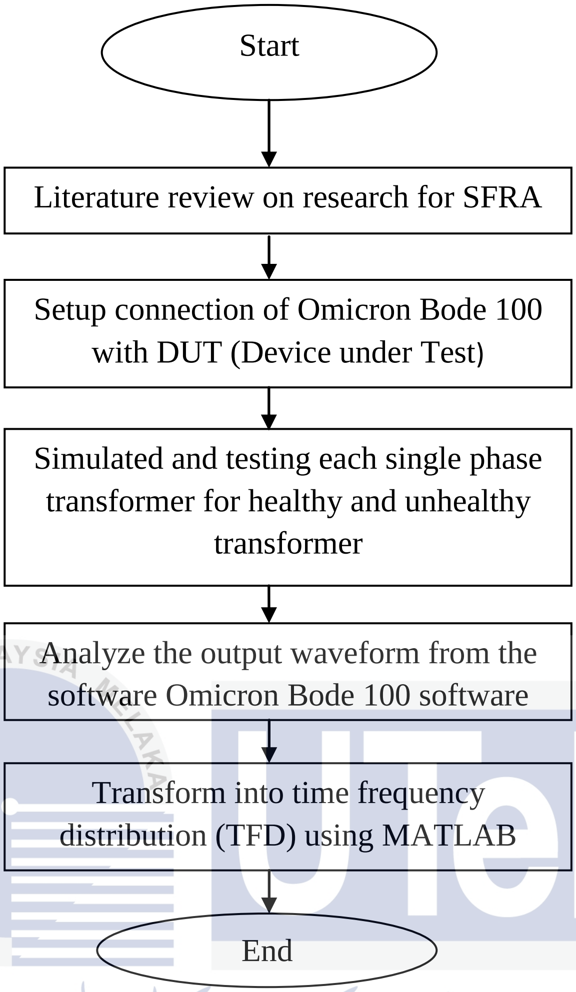


Figure 3.0: Flow chart for the research methodology

3.2 Construction the Connection of Omicron Bode 100 With DUT

Omicron Bode 100 consists of Bode 100, BNC 50 ohm cable, USB cable and DUT connector board as illustrated in Figure 3.1. USB cable from Bode 100 will connect to the computer. The BNC 50 ohm cable must be connecting with Bode 100 and DUT connector board. Next, DUT need to connect to the DUT connector board as indicated in Figure 3.2. DUT in this project will be single phase transformer either healthy or unhealthy.

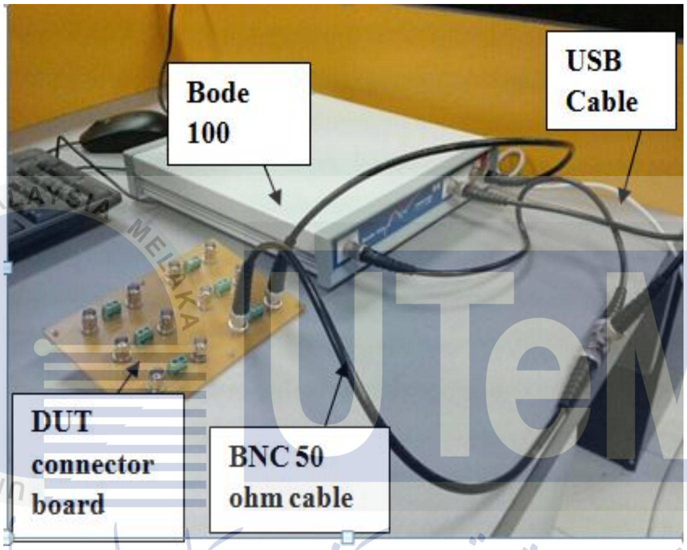


Figure 3.1: The set up of Omicron Bode 100 [16]

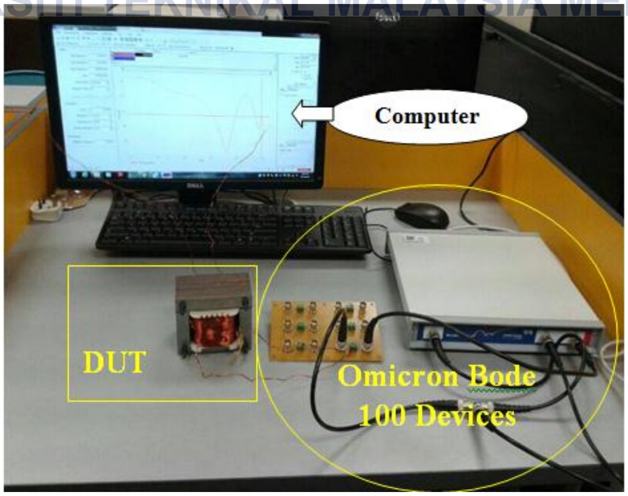


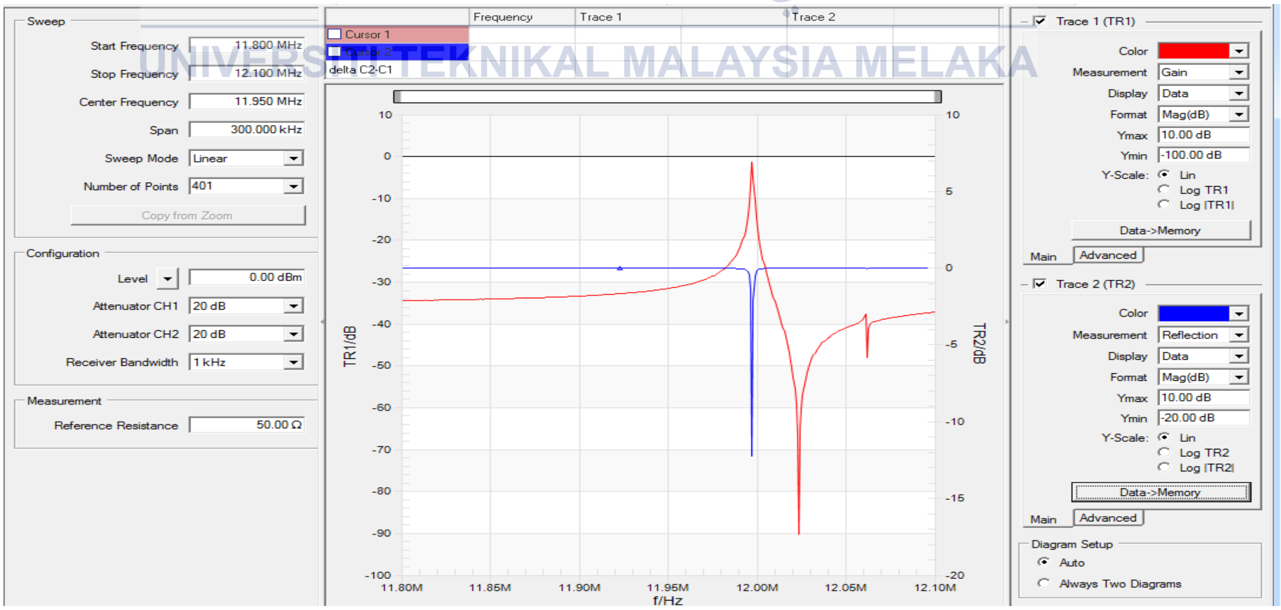
Figure 3.2: Connection of Omicron Bode 100 devices with DUT [16]

3.3 Experimental Software Setup According to Available FRA Standard

After constructing the connection of Omicron Bode 100 with the DUT, the basic setup for the test, and measurement by referring to the available standard of FRA measurement need to be done in the software Omicron Lab- Bode Analyzer Suite. Based on the Omicron Bode 100 manual standard, the setup need to be utilizing by the following setting the frequency mode. All the parameter needs to be setup according to the Table 3.0 [16]. Figure 3.3 shows the example of the waveform displayed by Omicron Lab-Bode Analyzer Suite and the both sides of the waveform consists of parameter to be set up.

Table 3.0: Parameter to be setup in the Omicron Lab- Bode Analyzer Suite (software) [16]

Start Frequency	10Hz
Stop Frequency	2MHz
Reference	External
Attenuator for CH1 & CH2	20dB
Receiver Bandwidth	1kHz
DUT Delay	0s
Number of Points	201 or more
Sweep Mode	Logarithmic
Reference Resistance	50 Ohm



Sweep
Start Frequency 11.800 MHz
Stop Frequency 12.100 MHz
Center Frequency 11.950 MHz
Span 300.000 kHz
Sweep Mode Linear
Number of Points 401

Configuration
Level 0.00 dBm
Attenuator CH1 20 dB
Attenuator CH2 20 dB
Receiver Bandwidth 1 kHz

Measurement
Reference Resistance 50.00 Ω

☑ Trace 1 (TR1)
Color
Measurement Gain
Display Data
Format Mag(dB)
Ymax 10.00 dB
Ymin -100.00 dB
Y-Scale: ● Lin ○ Log TR1 ○ Log |TR1|

☑ Trace 2 (TR2)
Color
Measurement Reflection
Display Data
Format Mag(dB)
Ymax 10.00 dB
Ymin -20.00 dB
Y-Scale: ● Lin ○ Log TR2 ○ Log |TR2|

Diagram Setup
● Auto
○ Always Two Diagrams

Figure 3.3: Example of the waveform displayed by Omicron Lab-Bode Analyzer Suite [16]

3.4 Frequency Ranges in the SFRA Measurement Results

The result obtains from Omicron Lab-Bode Analyzer Suite in the form of magnitude versus frequency graph [16]. The ranges of frequency can be divided into three parts of sub bands as discuss in the Chapter 2. It helps to make the measurement easier and accurate before the data convert into TFD. Figure 3.4 shows the frequency ranges from 10 Hz until 2 MHz. The low sub band is measured from 10 Hz until 10 KHz, where middle sub band is measured from 5 KHz until 1 MHz and lastly, high sub band is measured from 400kHz to 2 MHz [13].

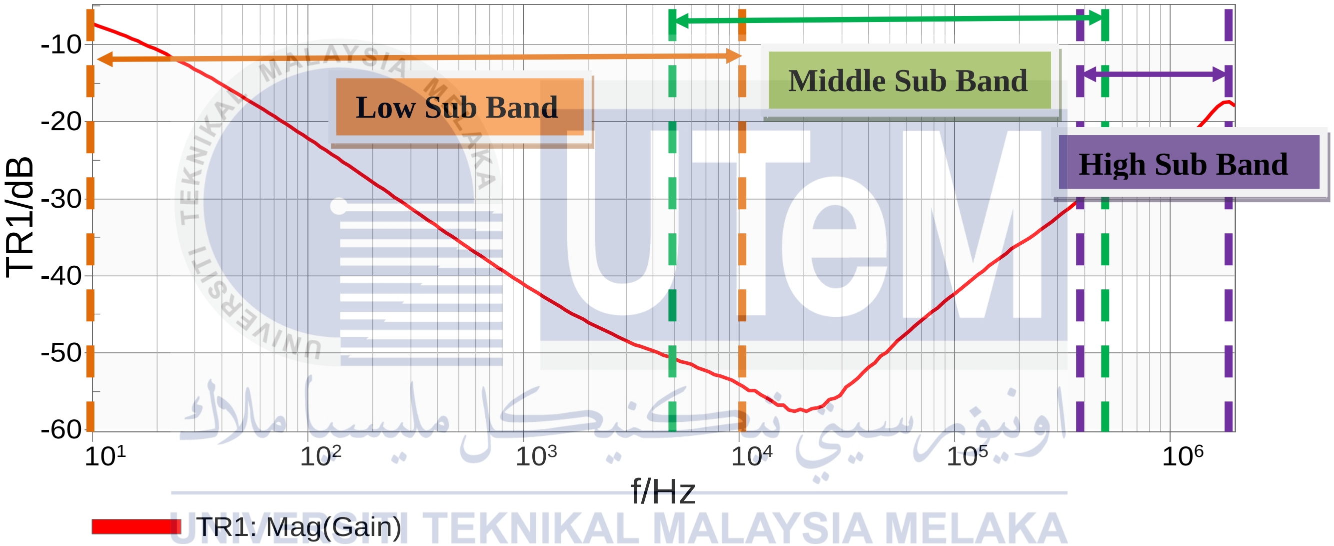


Figure 3.4: Frequency Ranges from 10Hz until 2MHz [13]

3.5 Simulated and Testing Each Single Phase Transformer For a Healthy and Unhealthy Transformer.

First and foremost, several types of identifying transformer which is healthy and unhealthy is to look at the act of the transfer function before and after the winding has been simulated with both types of faults. Basically, transfer function from winding will produce different waveform compared to the healthy transformer waveform. By referring to Table 2.1, when any changes in the inductance occur, it will produce faults such as disk deformation, local breakdown or winding short circuits. Next when the shunt capacitance occur changes, the faults occur in either disc movements, buckling due to large mechanical forces or loss of clamping pressure. For a series of capacitance changes, the faults occurred is ageing of insulation. Lastly when resistance occur changes, the faults occurs either shorted of broken disk or partial discharge. Figure 3.5 shows the position of the physical parameter in transformer that is forming RLC circuit. Where the green line indicates the high voltage winding, green line indicates the low voltage winding and red line indicates the inter winding [11].

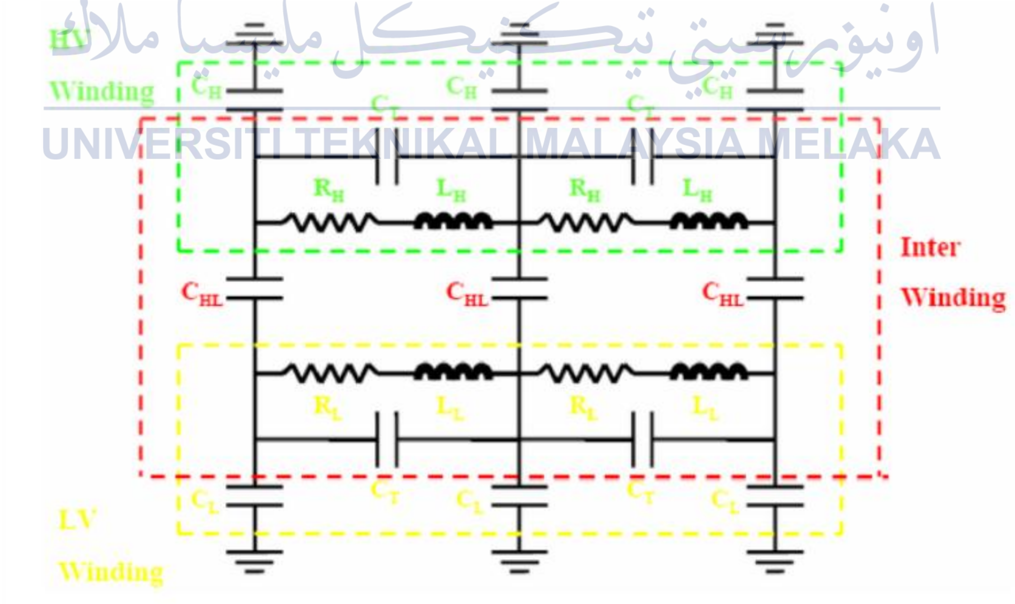


Figure 3.5: Equivalent Circuit with Combination of RLC Components [11]

3.5.1 Radial winding Deformation (Hoop buckling)

The winding of the transformer is compressed to simulate the real life hoop buckling damage in the transformer. Figure 3.6 shows the winding of the transformer experienced radial problem at the secondary side of the low voltage winding. Normally, hoop buckling occurs inside the transformer winding due to the compressive force acting during fault. Next, the winding will loses their actual shape and produce a "bump" on the windings. The other causes such as gassing and transformer integrity also may result [12].

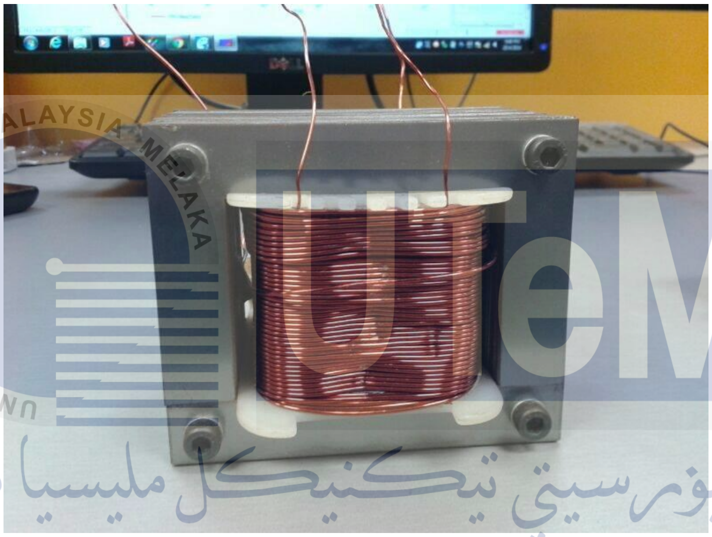


Figure 3.6: Radial winding deformation [11]

3.5.2 Axial Winding Deformation

This kind of fault/failure can be produced by shifting and make several of the secondary winding become not tight and causing fall down. Figure 3.7 show the winding of the transformer experienced an axial failure. Axial winding deformation occurs in the transformer winding due to the excess axial force. Furthermore, windings shifting relatively to each other also cause this fault occurs. From the other factor such as gassing and transformer integrity also may result [12].

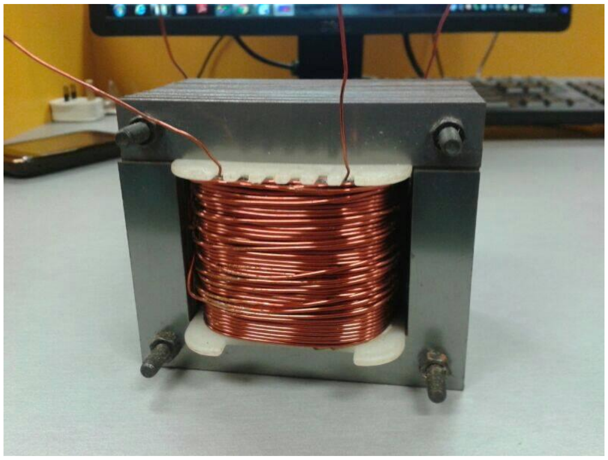


Figure 3.7: The deformation of axial fault [11].

3.5.3 Shorten Turn Transformer

Basically, shorten turn fault more to the electrical fault. However, the effect of the mechanical fault may result the core lamination experience damaged. In any part of the core lamination is damaged, or lamination of the core is bridged by any conducting material will cause sufficient eddy current to flow, and the part of the core becomes overheated.

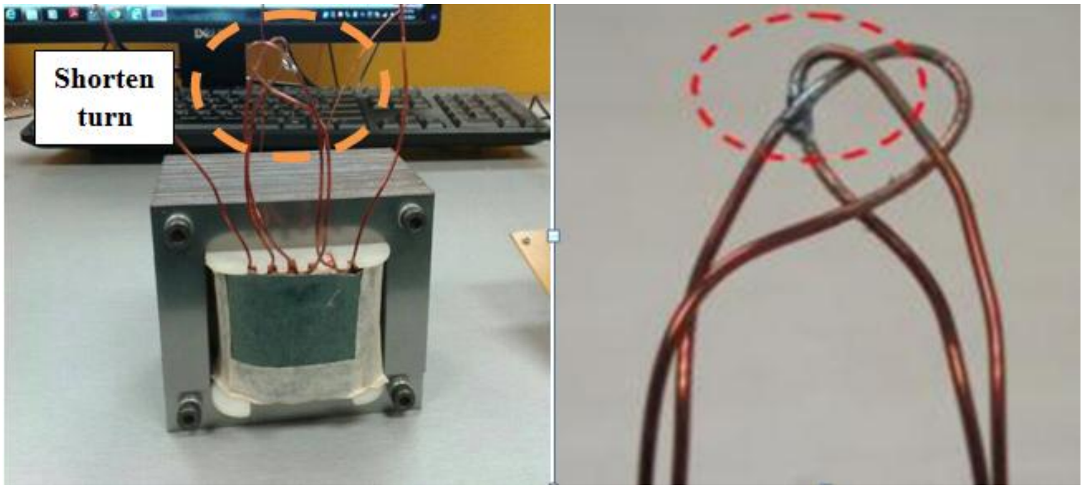


Figure 3.8: The shorten turn fault transformer [11].

3.5.4 The Non Defect Transformer

The non defect transformer is a healthy transformer without any type of fault occurs in the transformer winding or the transformer core. The Figure 3.9 shows the non defect transformer that is used to compare between the transformer failures. The winding of the non defect transformer do not experience any defect. The non defect transformer used as a reference to identify other transformer which is unhealthy.

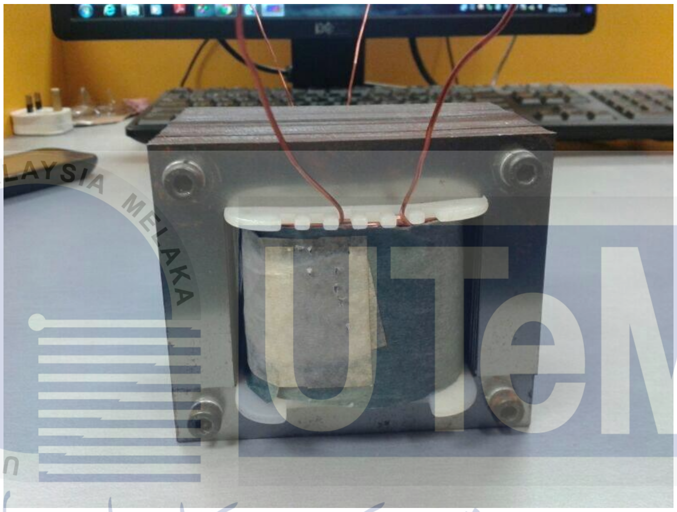


Figure 3.9: The non defect transformer [11]

3.6 TFD using MATLAB

MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. MATLAB able to display or plot signal either in two dimensional and also three dimensional. In this project, MATLAB was used to plot time domain and frequency domain together in one graph. Basically, Omicron Lab- Bode Analyzer Suite capable to convert the data into discrete (Microsoft Office Excel). The data from frequency domain will be converting into time domain and lastly both of the data will be plot into TFD. Figure 3.10 shows the example of TFD signal in the form of spectrogram. The coding of MATLAB as illustrated in APPENDIX part.

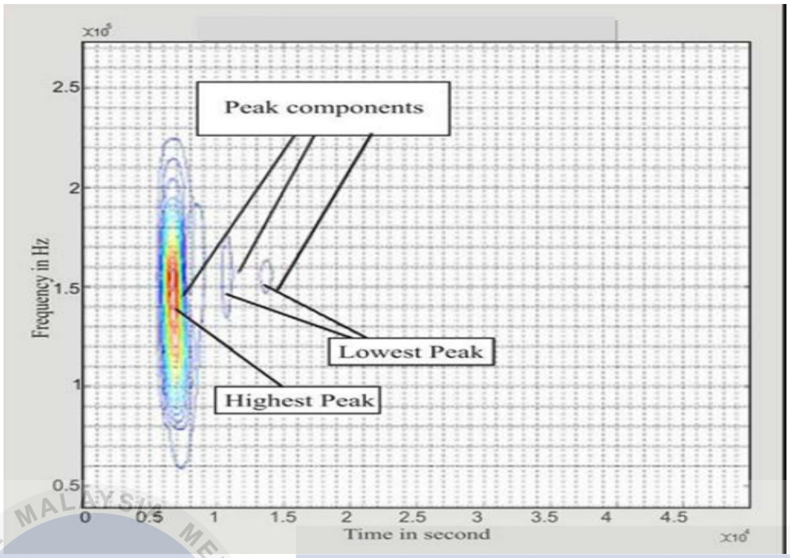


Figure 3.10: TFD signal in the form of spectrogram [15]

3.7 Summary of Methodology

In this methodology section, the entire procedures are followed by referring to the flowchart which is shown in Figure 3.0. To determine the waveform data, Omicron Bode 100 was connected to the DUT which is the transformer for both healthy and unhealthy transformer. The graph from the software Omicron Lab- Bode Analyzer Suite will be converting into TFD by using MATLAB.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Generally in this chapter, will explain about the discussion and result for this project. The result description obtained from SFRA measurement test is divided into two parts which are High Voltage winding (HV) and Low Voltage winding (LV). All the result from Omicron Lab-Bode Analyzer Suite will be demonstrated in this chapter. Nevertheless, the analysis and discussion only focused on the MATLAB result in TFD.

4.2 SFRA measurement result

For this section, all the SFRA measurement result obtained from the single phase transformer which is healthy or unhealthy are described. For this measured transformer, about eight figures which are related to the healthy (HV and LV sides), and followed by mechanical faults (HV and LV sides). The result from this part will be converting into TFD using MATLAB.

4.2.1 Non Defect Transformer Response

Figure 4.0 and Figure 4.1 shows the high voltage (HV) and low voltage (LV) side of the transformer. The result from non defect transformer will be the reference for all tested transformer. Non defect transformer is a very important to make sure all the damaged transformer can be investigated. In addition, the result of non defect transformer is compulsory to be reliable in order to be a reference. As mention before in part 3.2, the result will be divided into three parts which are low sub band, medium sub band and high sub band.

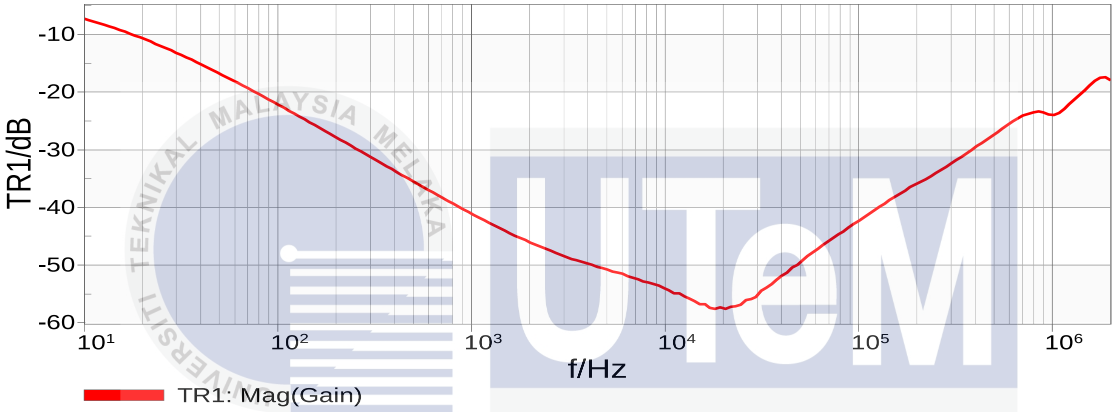


Figure 4.0: HV non defect transformer

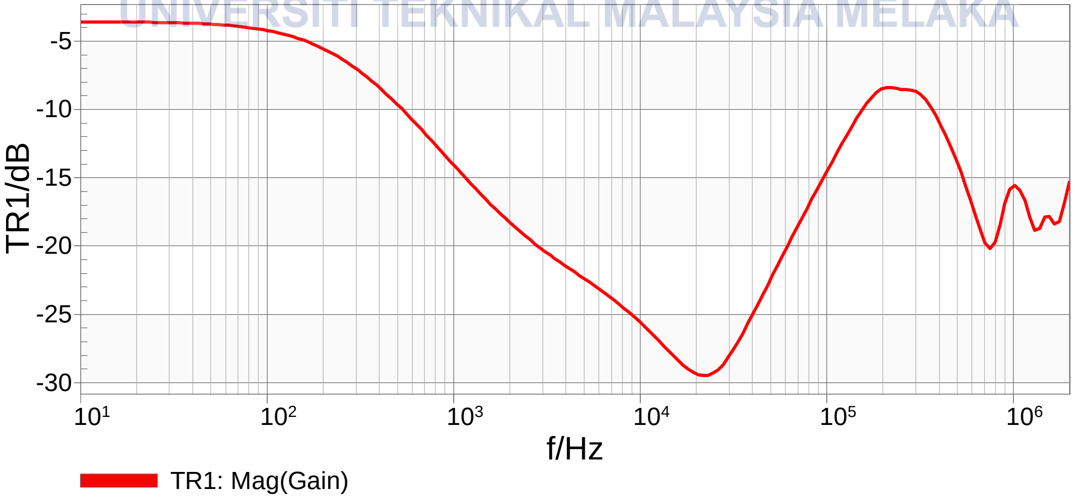


Figure 4.1: LV non defect transformer

4.2.2 Radial Winding Deformation Response

Radial winding deformation can be traced using SFRA method in the middle sub band region. Figure 4.2 and Figure 4.3 indicates the result of radial winding deformation for both side which are HV side and also LV side. This project is very concern with the changes of the magnitude precisely. There is no change in the HV side however; the significant differences can be seen in the LV side when the magnitude slightly increases in negative value at 200 KHz. This large change of magnitude is in the middle sub band

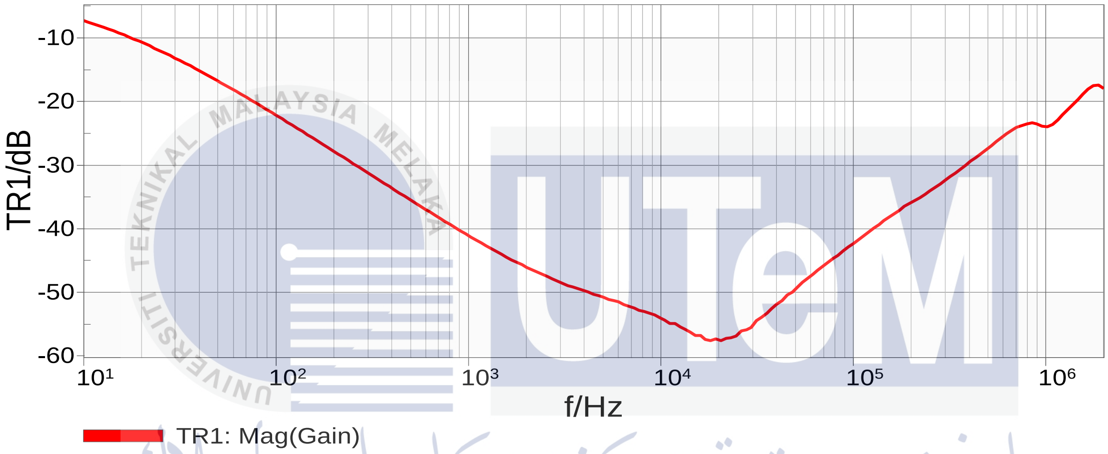


Figure 4.2: HV Radial winding deformation

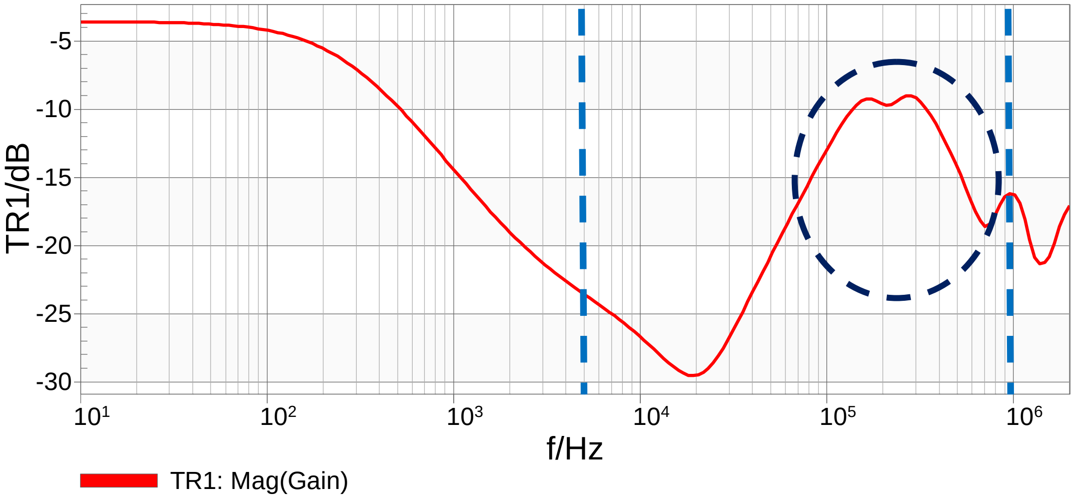


Figure 4.3: LV radial winding deformation

4.2.3 Axial Winding Deformation Response

For the axial winding deformation tested, the result afford to traced the mechanical faults in the transformer where the both sides of tested transformer which are HV and LV side capable to display the significant differences as illustrated in Figure 4.4 and Figure 4.5. Figure 4.4 shows the magnitude is slightly increase in negative value at 20 KHz, while Figure 4.5 displays the magnitude huge increase in negative value at 400 KHz until 2 MHz. From this observation, only LV side capable to detect the axial winding deformation on the high sub band.

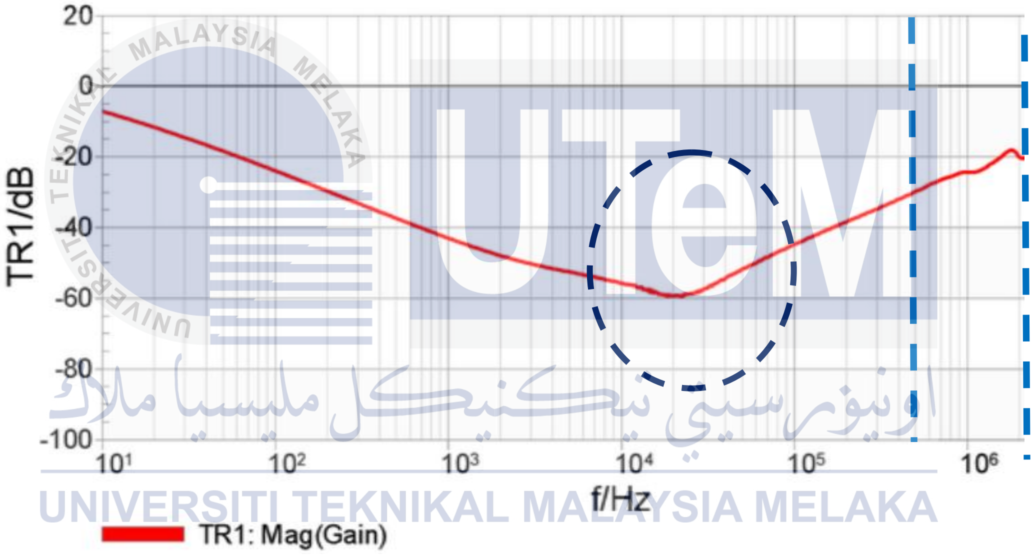


Figure 4.4: HV axial winding deformation

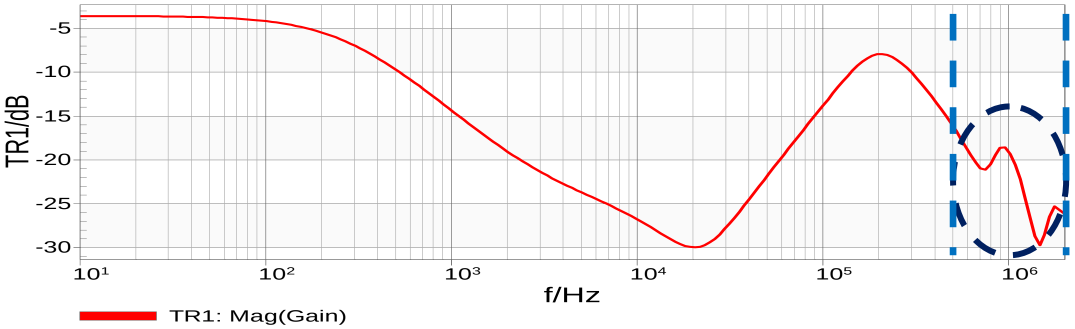


Figure 4.5: LV axial winding deformation

4.2.4 Shorten Turn Faults Response

Shorten turn faults can be traced on the low side band region, where the frequency less than 10 KHz. From the result in Figure 4.6 and Figure 4.7, can be seen the greater difference for both side either HV or LV side of transformer. Based on Figure 4.6, the magnitude is not increasing smoothly in negative value at the range of 50 Hz up to 800 Hz and then the magnitude slightly decreases (bump shape) at 1 KHz to 5 KHz. Meanwhile, in Figure 4.6 also experienced changes as Figure 4.5. All of these greater differences between faults transformer with non defect transformer occurs at low side band region.

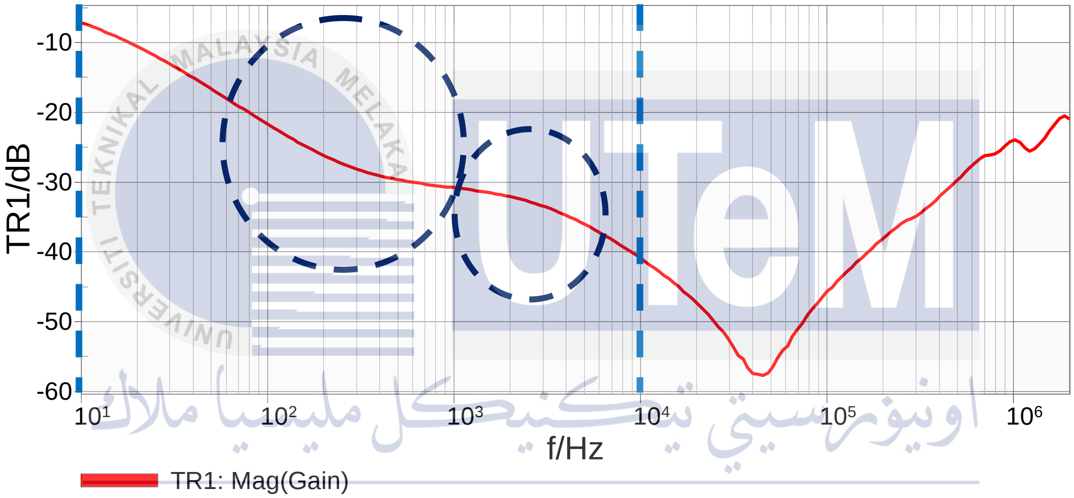


Figure 4.6: HV shorten turn faults

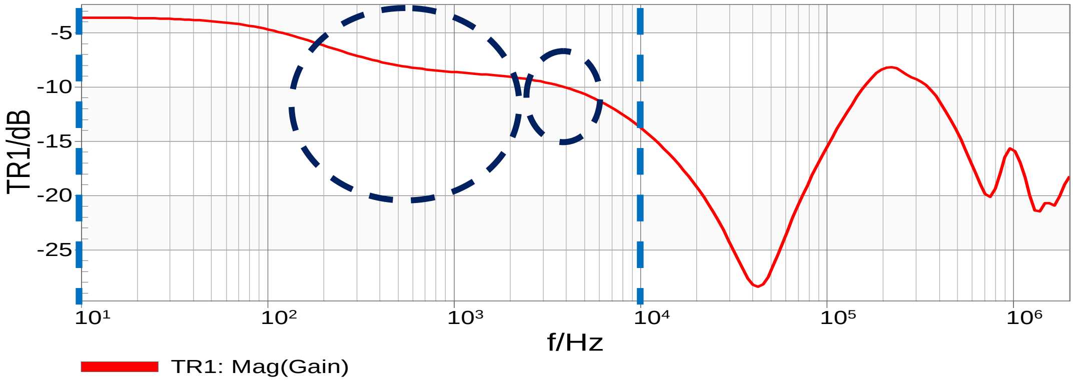


Figure 4.7: LV shorten turn faults

4.3 TFD Measurement Result

In this section, the results from TFD measurement enable the system to be observed at the specified frequency ranges. Spectrogram time frequency analysis able to used in order to extract the useful information from time-varying signals. In this project, TFD is indispensable to identify the changes in frequency at certain ranges of time. This is because time representation only shows how the signal varies with time and the frequency representation only shows the frequency content of the signal itself. The respectively representation will not capable to display sufficient information representation and classify of time-varying signals. The powerful methods that have been used to analyze time-varying signal is time-frequency analysis. In fact, spectrogram is the ordinary time-frequency analysis method that largely used to measure the parameters of the signal of interest. Type of information can be obtain from the TFD is instantaneous energy/power.

The information obtains from TFD can be used for signal classification whether the signal indicates healthy or unhealthy transformer. All the TFD measurement performed for four types of transformer which are one of the transformers is healthy and others are unhealthy transformer. In addition, both side of transformer either HV side or LV side included in this experiment. All changes can be seen with alteration in the energy level. The entire graph in spectrogram consists of energy levels which are from one (dark blue) up to ten (dark red). Figure 4.8 and Figure 4.9 is the reference for Figure 4.10 until Figure 4.15.

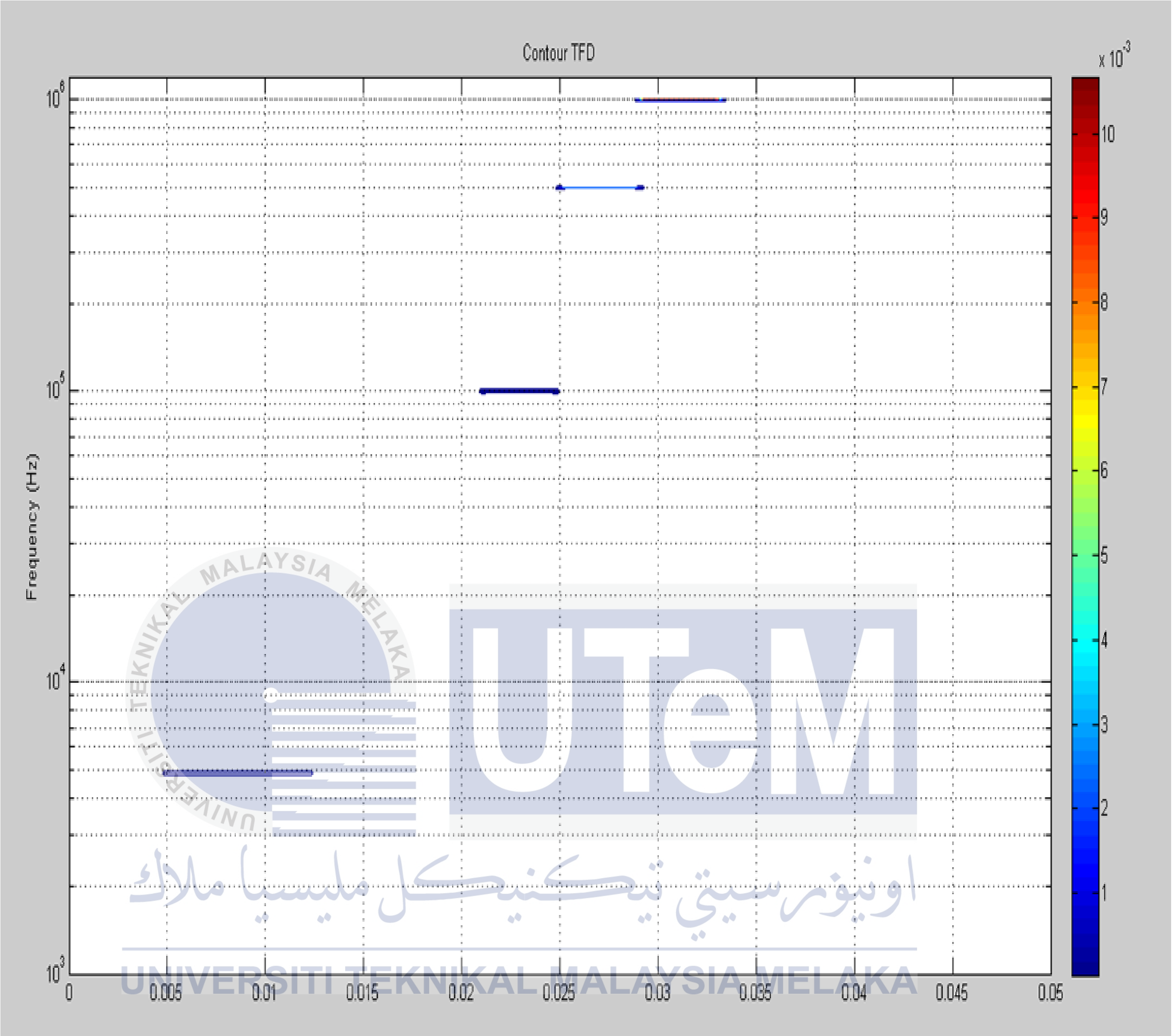


Figure 4.8: HV non defect transformer

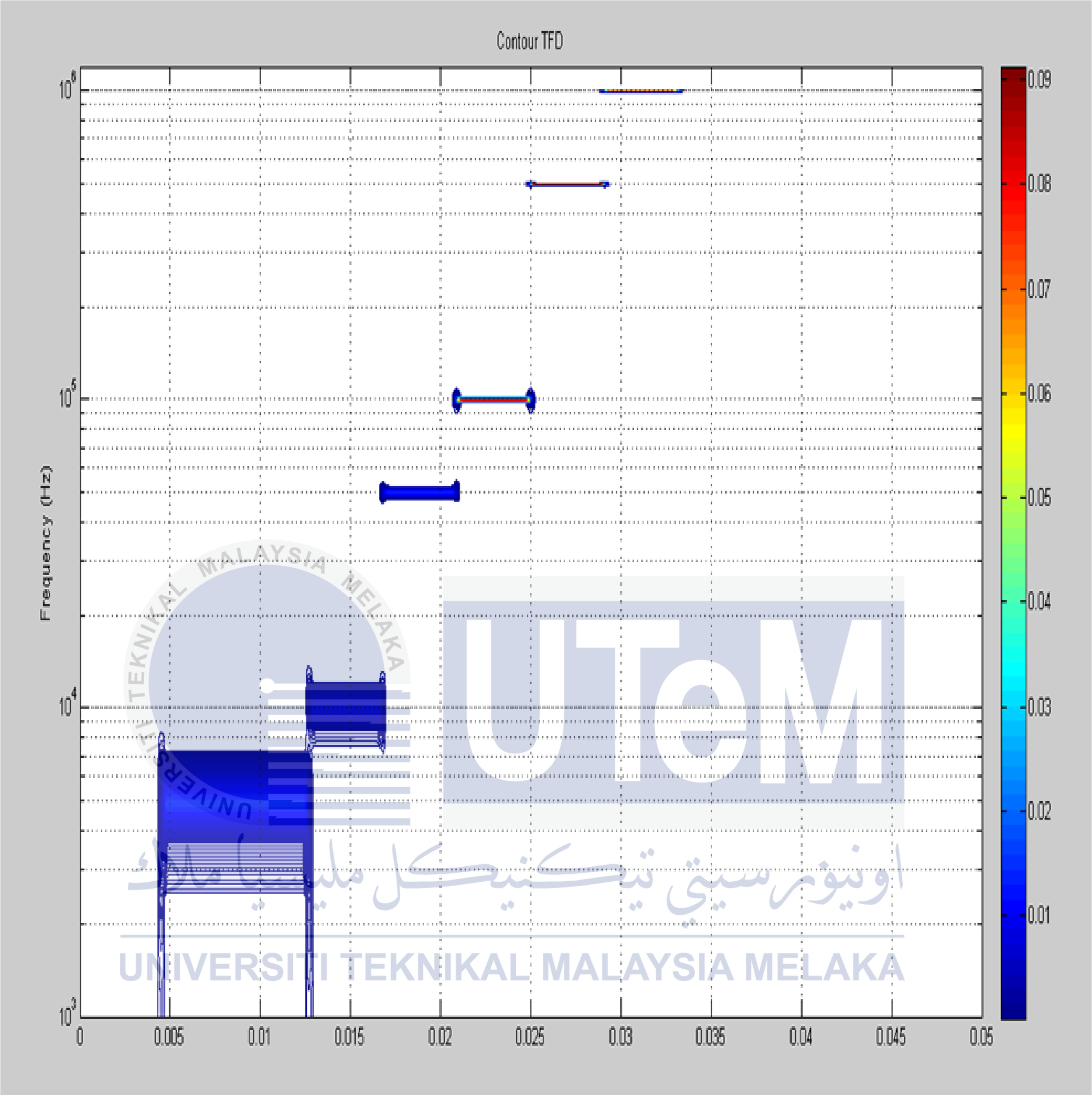


Figure 4.9: LV non defect transformer

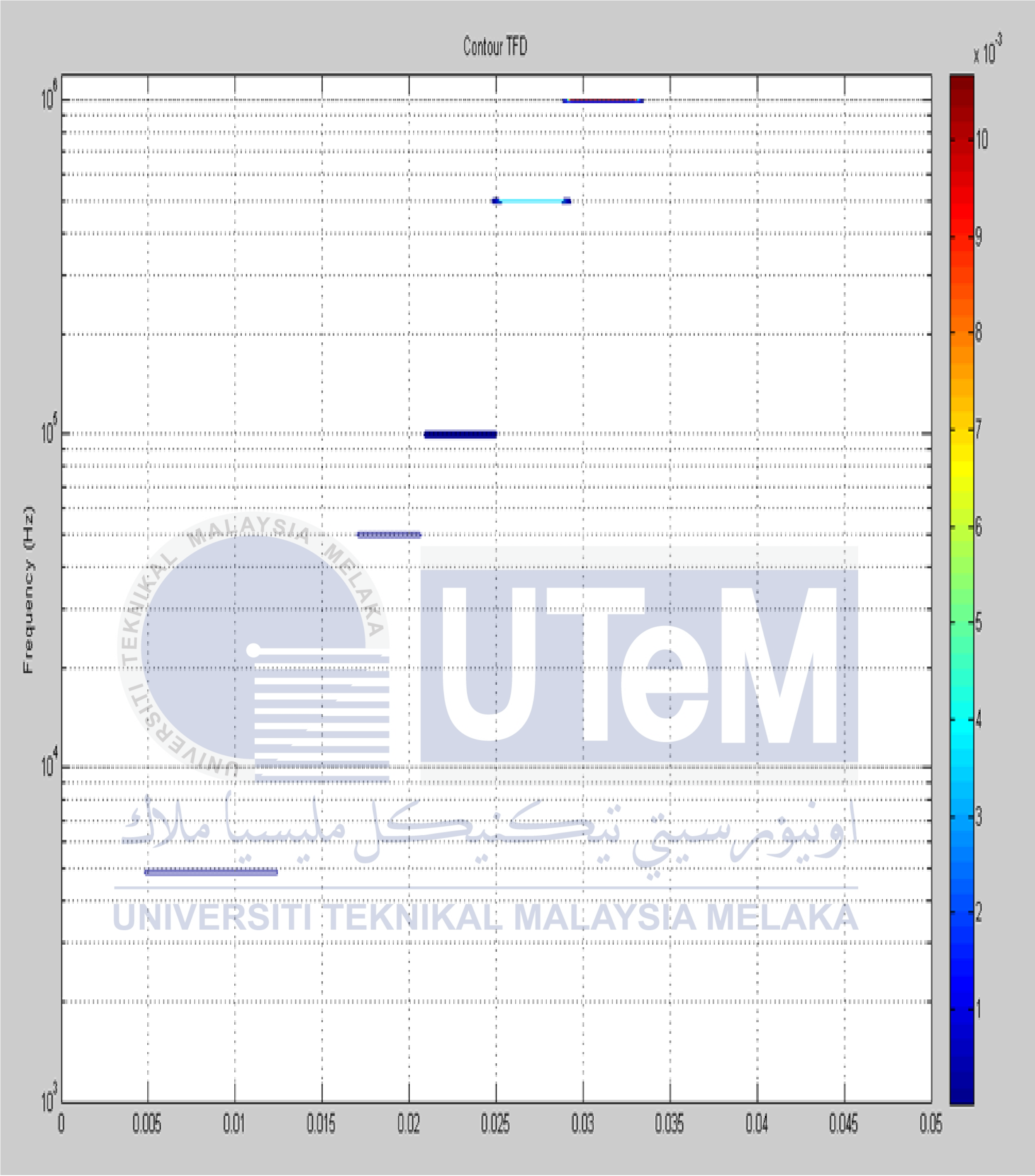


Figure 4.10: HV radial winding deformation

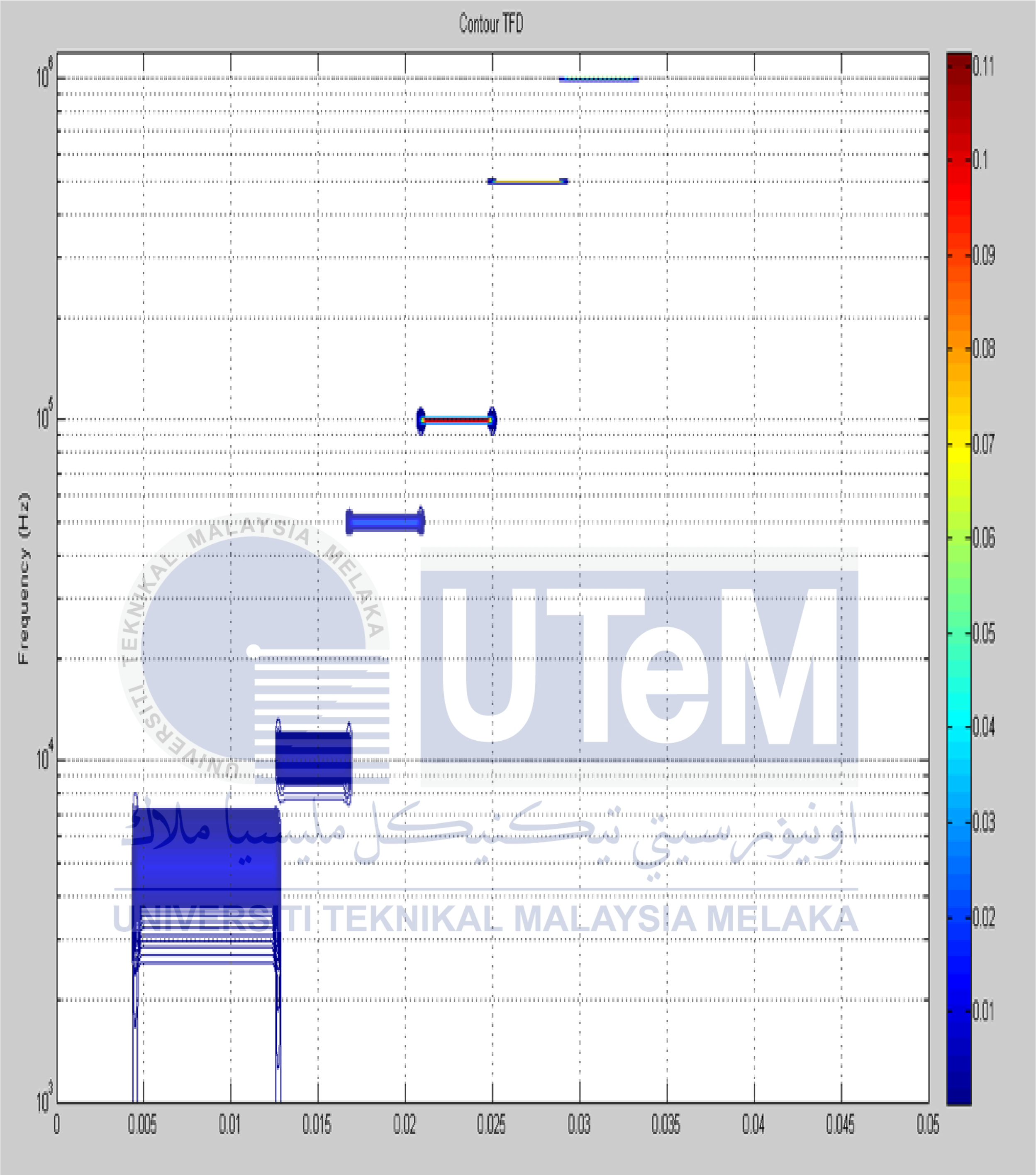


Figure 4.11: LV radial winding deformation

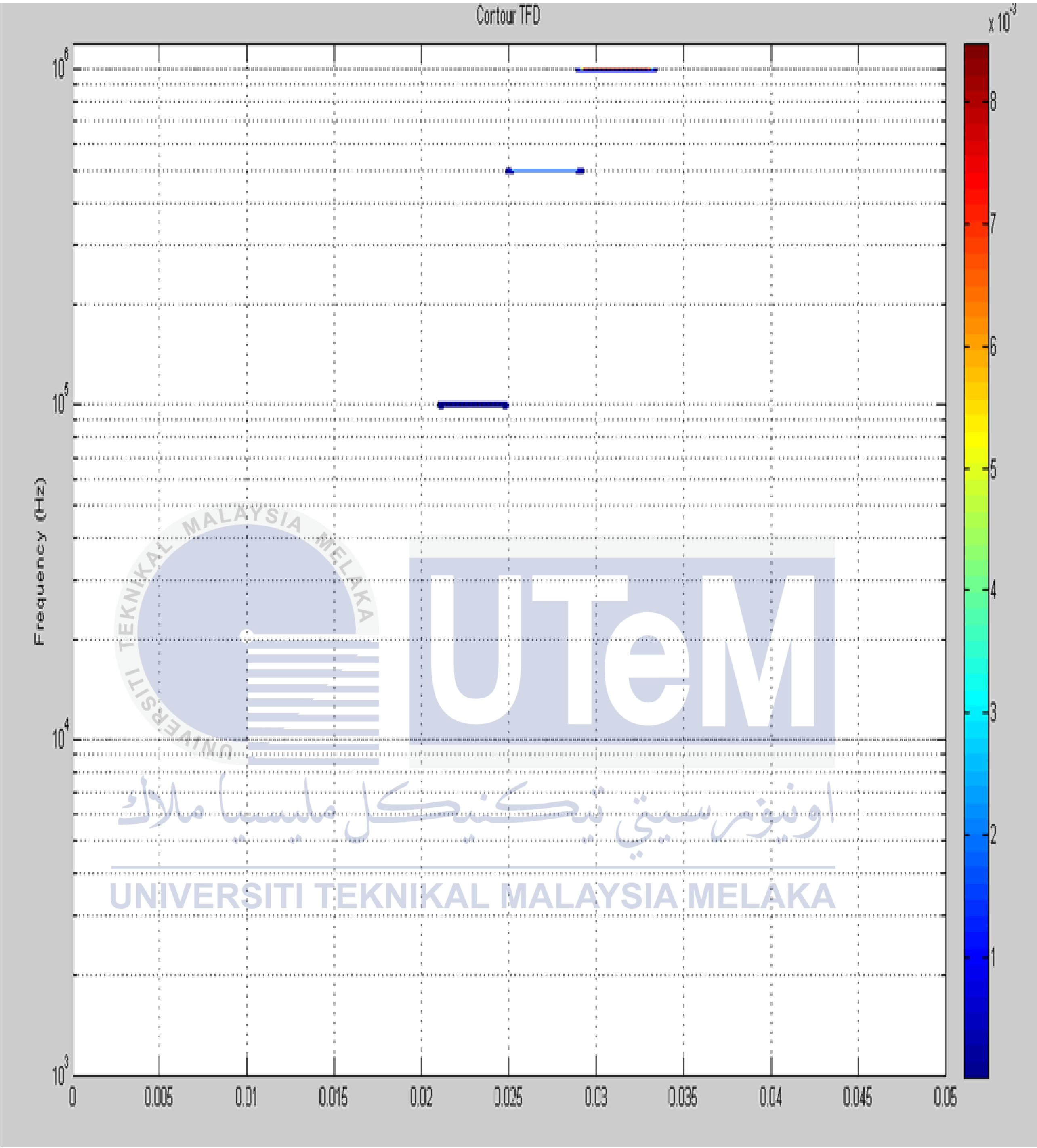


Figure 4.12: HV axial winding deformation

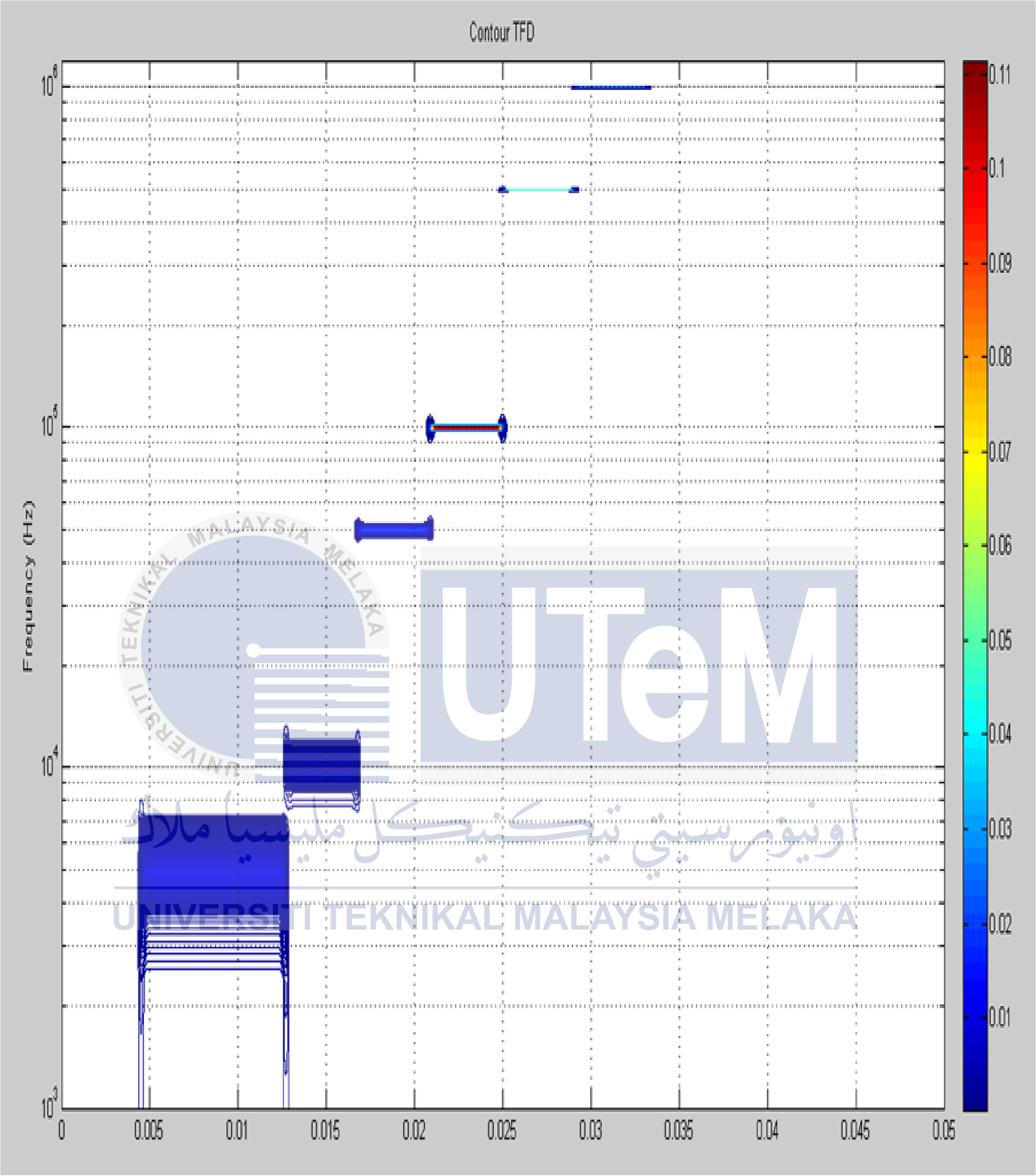


Figure 4.13: LV axial winding deformation

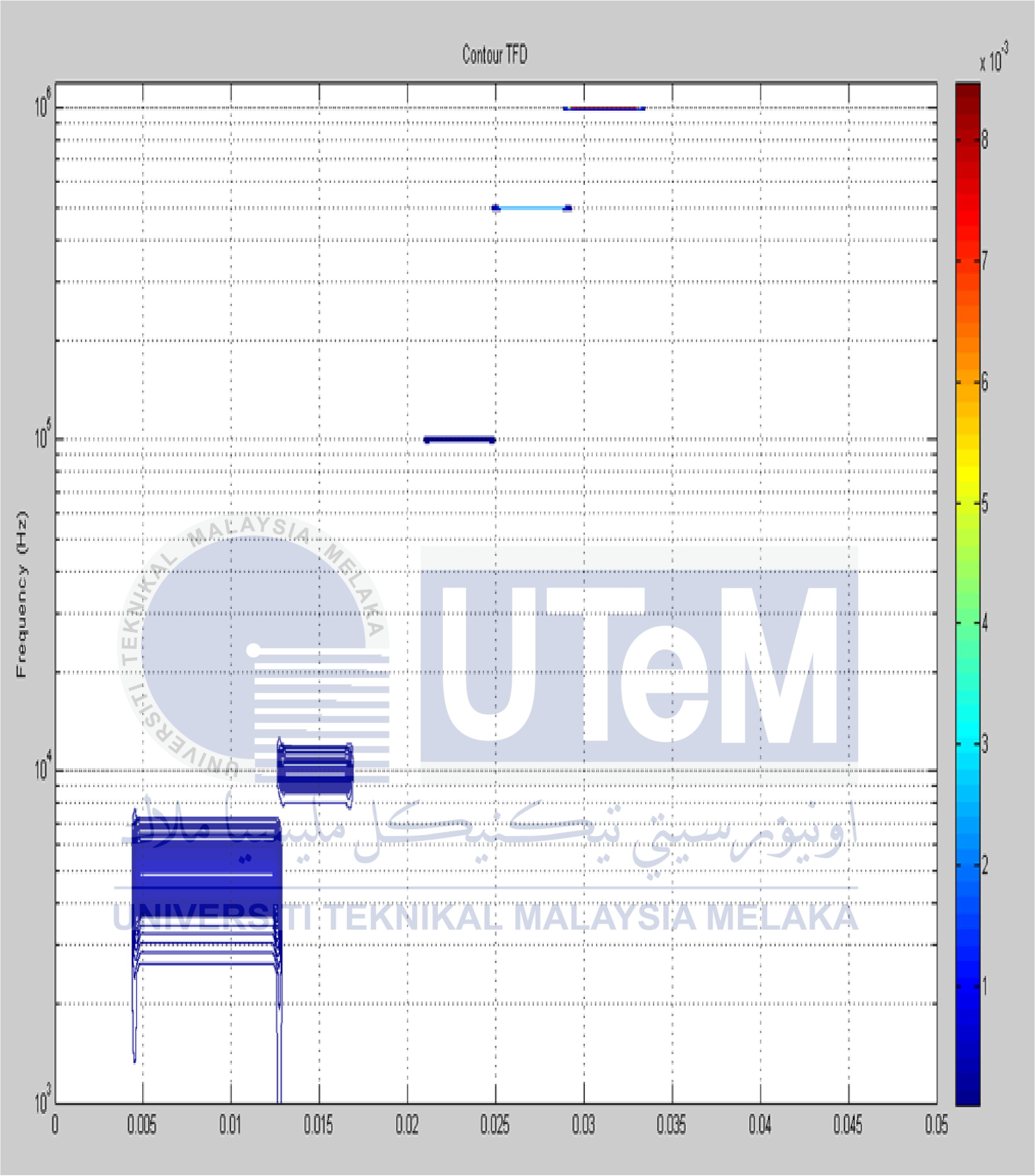


Figure 4.14: HV shorten turn faults

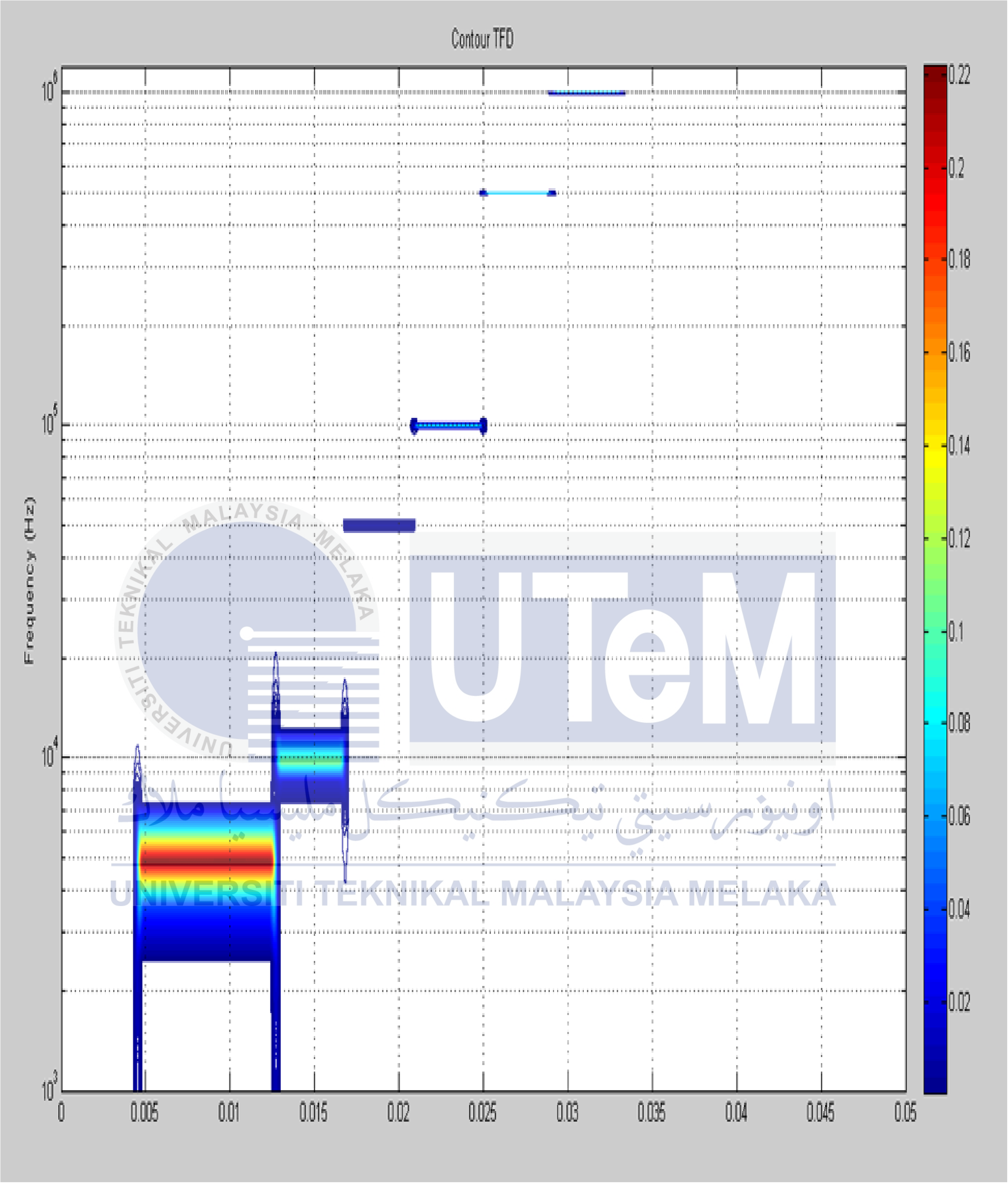


Figure 4.15: LV shorten turn faults

4.4 Analysis the Result in TFD

Non defect transformer or healthy transformer is a reference in order to compare the difference between healthy transformer and unhealthy transformer. The difference can be identified by performing the accurate and precise observation with the changes of colour at the peak component. All the colour at the peak component is a energy level.

a) Radial winding deformation (HV)

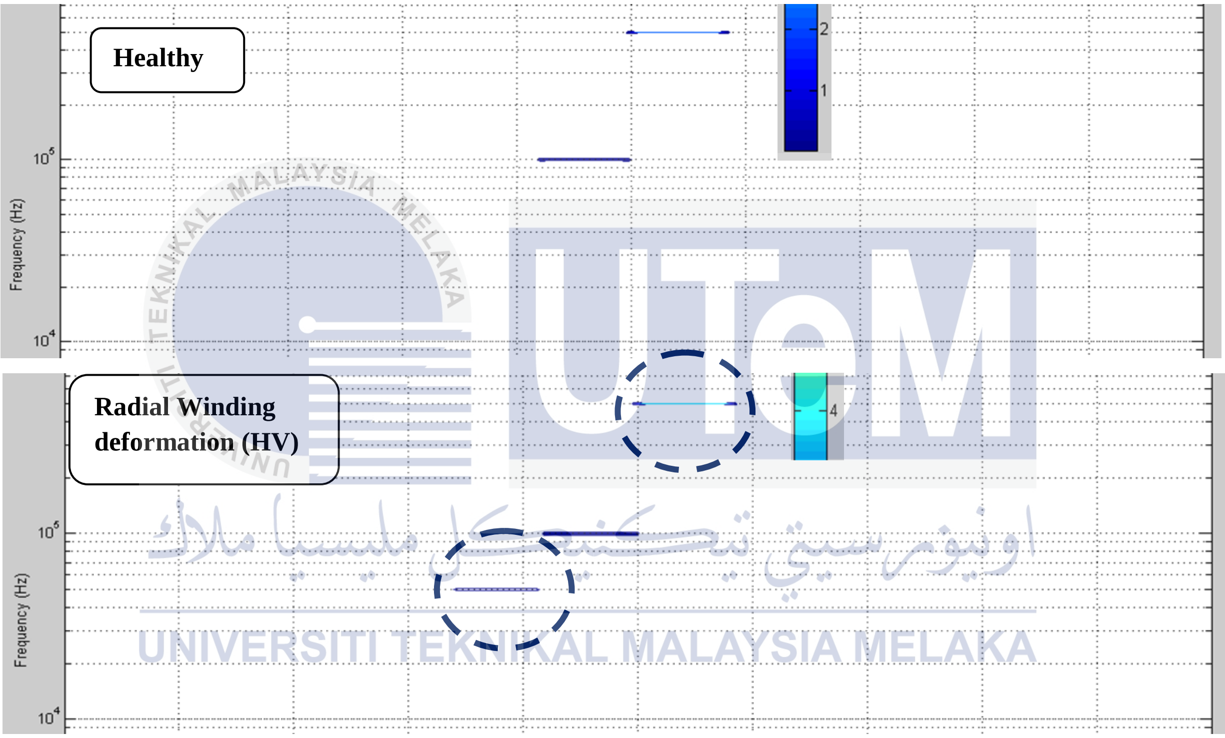


Figure 4.16: Comparison between healthy transformer and radial winding deformation (HV)

Figure 4.16 indicates the difference between healthy and radial winding deformation in HV side. From this comparison, consists of two significant differences which are firstly at 500 kHz the peak component for healthy transformer located at the point of two of energy level $(2x10^3)$ while the radial winding deformation (HV) located at the point of four of energy level $(4x10^3)$. Second difference is a healthy transformer, there is no peak component at 50 kHz however at radial winding deformation (HV) founded a peak component at there. All of these differences occur at the middle sub band and prove that TFD capable to detect the radial winding deformation on the HV side.

b) Radial Winding Deformation (LV)

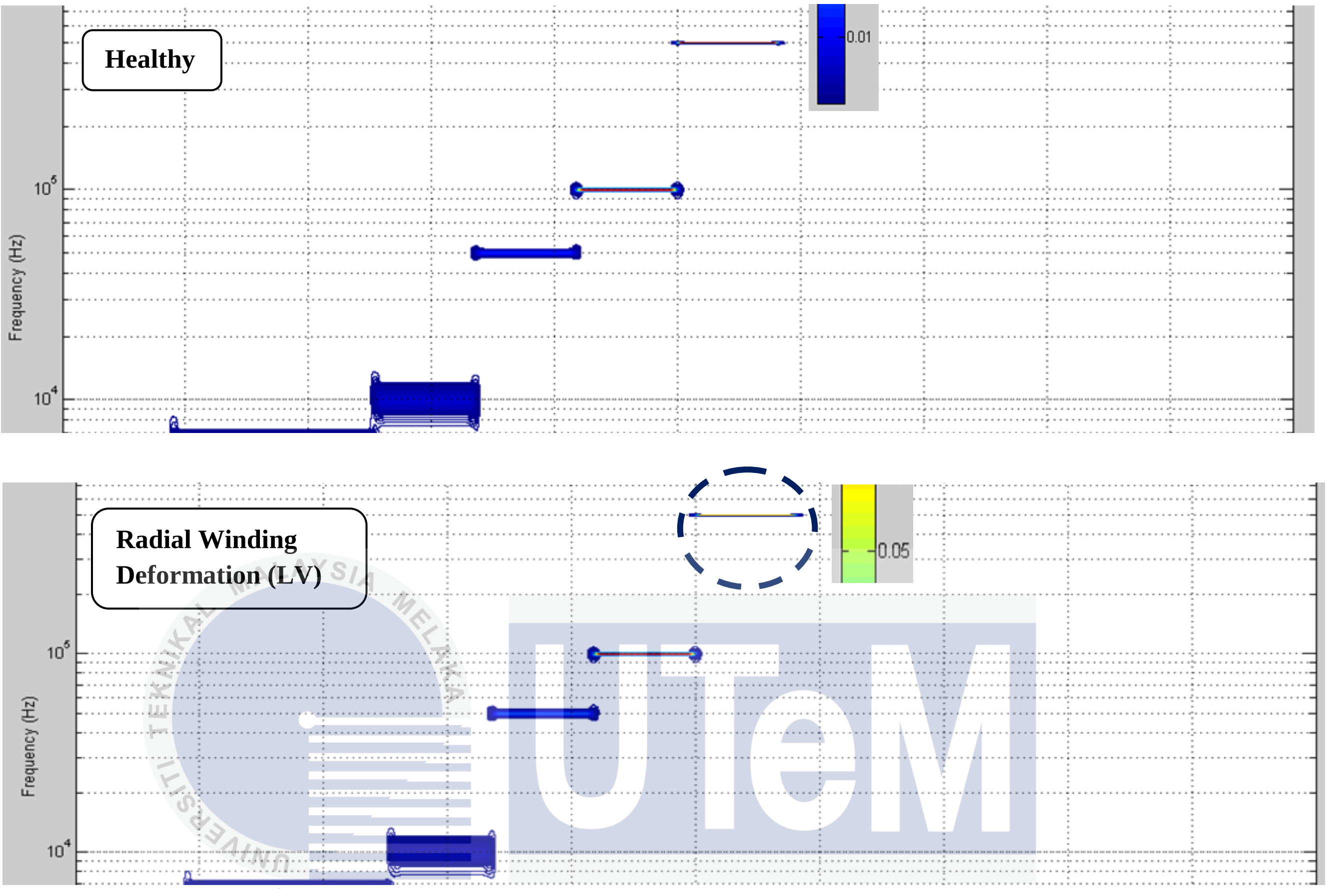


Figure 4.17: Comparison between healthy transformer and radial winding deformation (LV)

Figure 4.17 indicates the difference between healthy and radial winding deformation in LV side. From this comparison, there is only one difference which is at 500 kHz the peak component of healthy transformer located at point 0.01 energy level while the radial winding deformation (LV) located at point 0.05 of energy level. This large difference occur at the middle sub band and prove that TFD also capable to detect the radial winding deformation on the LV side.

c) Axial Winding Deformation (HV)

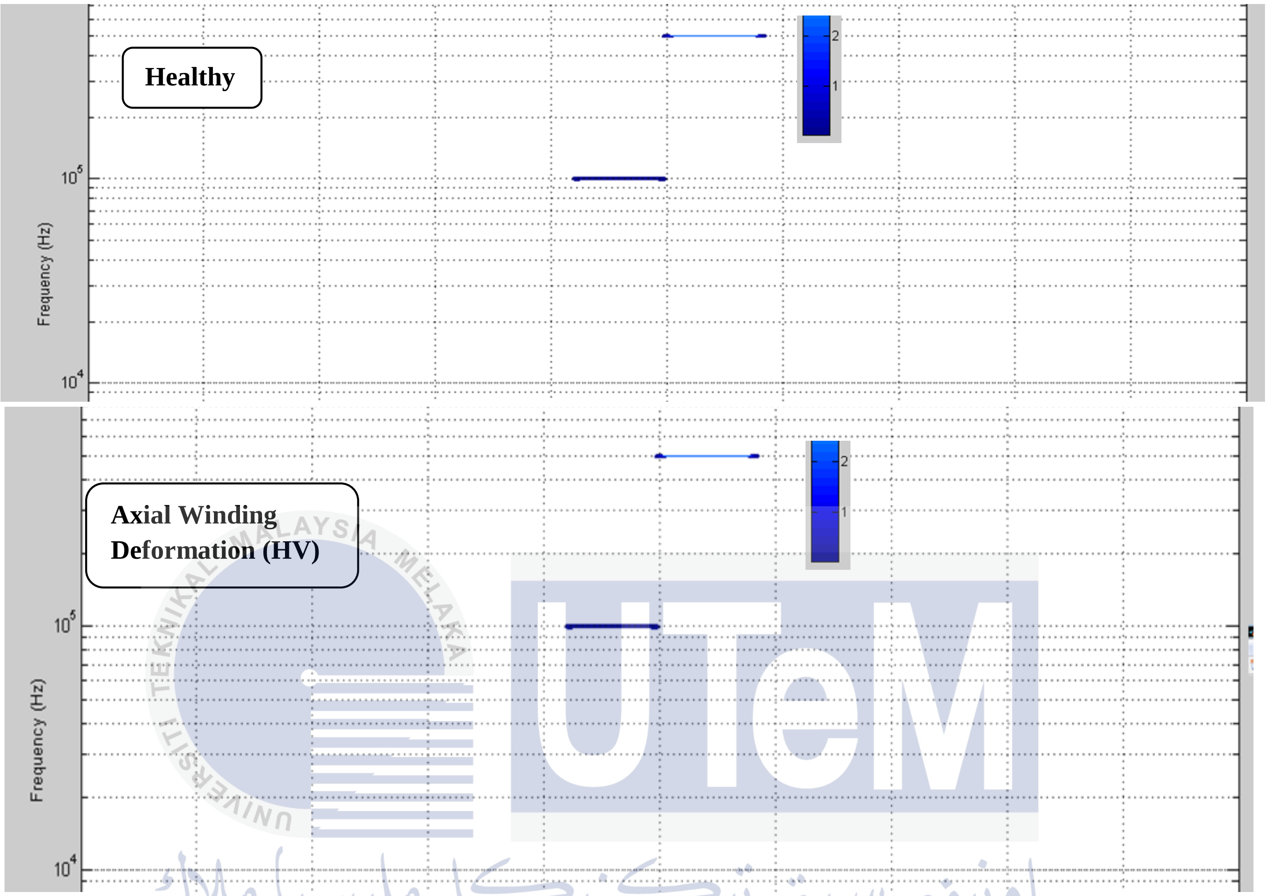


Figure 4.18: Comparison between healthy transformer and axial winding deformation (HV)

Figure 4.18 indicates there is no differences can be traced from healthy and axial winding deformation (HV). From this understanding, clarify that is axial winding deformation cannot be traced on the HV side and TFD unsuccessful to detect the axial winding deformation for HV sides. Both of the peak components at 500 kHz located at point two of energy level $(2x10^3)$.

d) Axial Winding Deformation (LV)

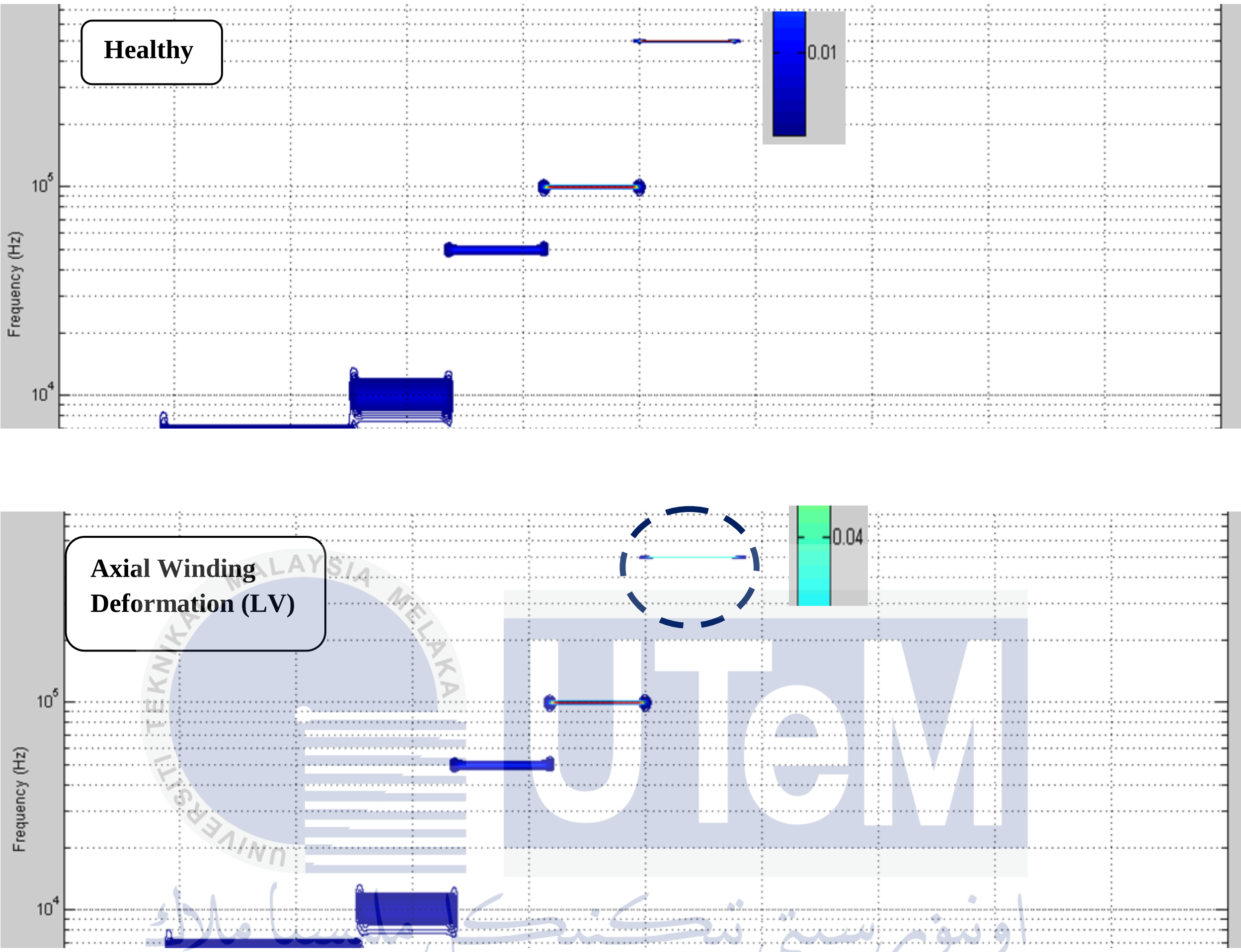


Figure 4.19: Comparison between healthy transformer and axial winding deformation (LV)

Figure 4.19 indicates the difference between healthy and axial winding deformation in LV side. From this comparison, there is only one difference which is at 500 kHz the peak component of healthy transformer located at point 0.01 energy level while the axial winding deformation (LV) located at point 0.04 of energy level. This large difference occur at the high sub band (more than 400 kHz) and prove that even though TFD unsuccessful to detect the axial winding deformation at the HV side but TFD capable to detect the radial winding deformation on the LV side. In other words, TFD is remains useful in order to detect the radial winding deformation.

e) Shorten Turn Fault (HV)

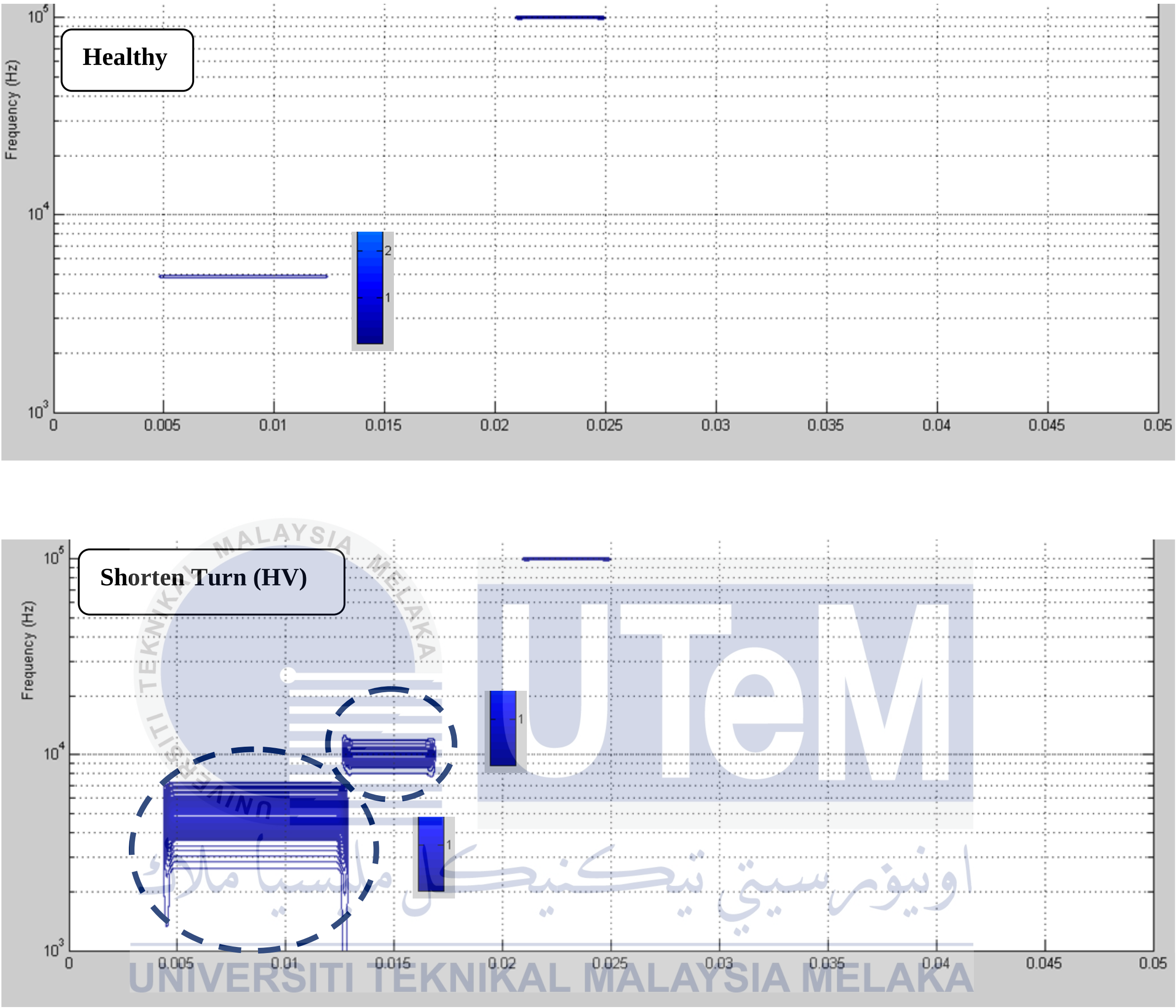


Figure 4.20: Comparison between healthy transformer and shorten turn (HV)

Figure 4.20 indicates the difference between healthy and shorten turn in HV side. From this comparison, there a consists of several significant differences which are firstly at 5 kHz the peak component for healthy transformer located at the point of two energy level ($2x10^3$) while the shorten turn (HV) located at point one energy level ($1x10^3$). Next, the peak component for healthy transformer only occurs at 5 kHz while at peak component at shorten turn (HV) occurs from 1 kHz up to 5 kHz. Furthermore, another difference occurs at 10 kHz where the peak component located at the point of one energy level ($1x10^3$) for shorten turn however there is no peak component at healthy response.

f) Shorten Turn (LV)

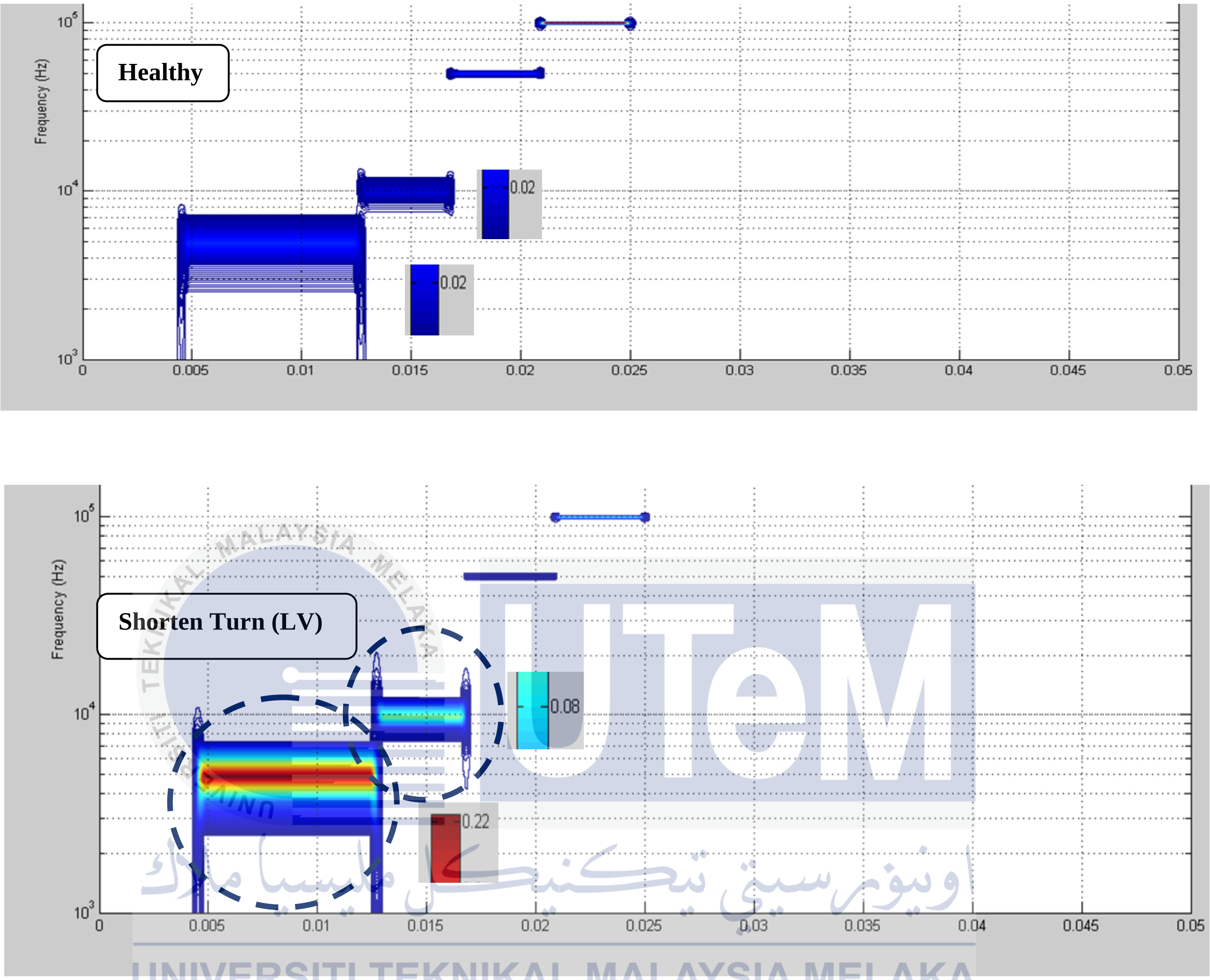


Figure 4.21: Comparison between healthy transformer and shorten turn (LV)

Figure 4.21 indicates the difference between healthy and shorten turn in LV side. From this comparison, consists of several significant differences which are firstly at 5 kHz the peak component for healthy transformer located at the point 0.02 energy level while the shorten turn (HV) located at point 0.22 energy level. From this observation, indicates the peak component of shorten turn is highest peak component compared to the healthy transformer. The entire result proved that TFD able to detect traced shorten turn effectively. Next, there is also occur one difference at 10 kHz where the peak component located at the point of 0.08energy level for shorten turn however the peak component for healthy transformer located at 0.02 energy level.

4.5 The magnetic field effect to the fault transformer

The mechanical faults occur within the transformer will cause the magnetic field in the transformer undergo changes. By using software Maxwell, the effect of the magnetic field can be clearly identified. Figure 4.22 shows the comparison in terms of magnetic field effect between healthy transformer and axial fault transformer. All the tested transformer using Maxwell was set through 10 Ampere of current and the core were set as steel. According from the simulation, the magnetic field of the healthy transformer is 1.9651 Tesla. From this analysis, axial fault can be occurs when the magnetic field increase to become 2.0 Tesla for the steel core. The maximum magnetic field density for axial faults transformer able increase up to 2.1795 Tesla and the resultant for the winding will cause 43 winding turns corrupted. From the theoretical, if an axial fault occurs in the windings of a single phase transformer that is energized from a suitable source of alternating current, a shifting field will be generated because of the phase displaced currents flowing in the turns of the winding. The current in the main part of the winding generates a flux in phase therewith. The resultant from these effects will produce out-of-phase fluxes, and when space displaced it will produce a shifting field.

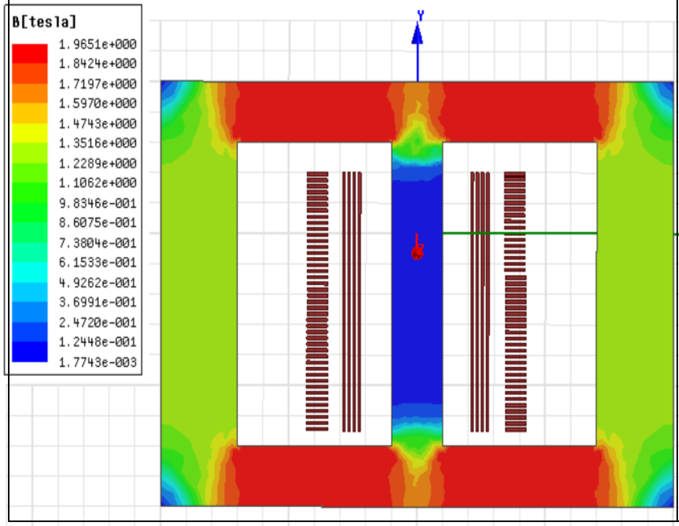
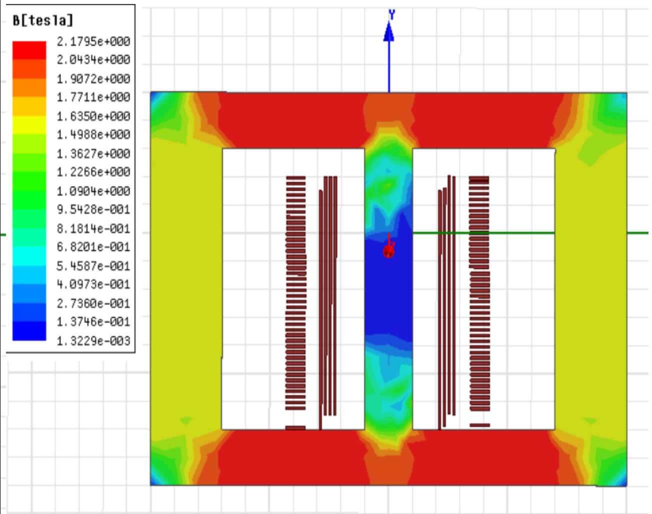
Healthy transformer	Axial faults transformer
	

Figure 4.22: The comparison magnetic field effect in the healthy and unhealthy transformer

4.5 Power losses between healthy and axial faults transformer

Figure 4.23 illustrated the measurement on the transformer healthy and unhealthy transformer which is axial fault transformer. From the measurement, all the result shows in the Table 4.0. Basically, a transformer is designed that may a little energy is possible to lost. There are many ways that a transformer can lose energy like:

a) Power losses occur due to the induce currents (Eddy current) in the iron core that will produce heat and reduce the transformer's efficiency.
b) Current flow through the primary and secondary coils will produce heat.
c) The core is magnetized and demagnetized alternately when AC current flows through the primary coil or known as hysteresis.
d) Leakage of magnetic flux in the primary coil

However, mechanical fault cannot be detected by measure the losses in the transformer. Table 4.0 shows that there are no power changes in the input transformer for both healthy and unhealthy transformer and only a little changes or it can be assume as no changes in the output transformer for both healthy and unhealthy transformer. From this understanding, it proved that only SFRA method will able to detect the mechanical fault in the transformer.

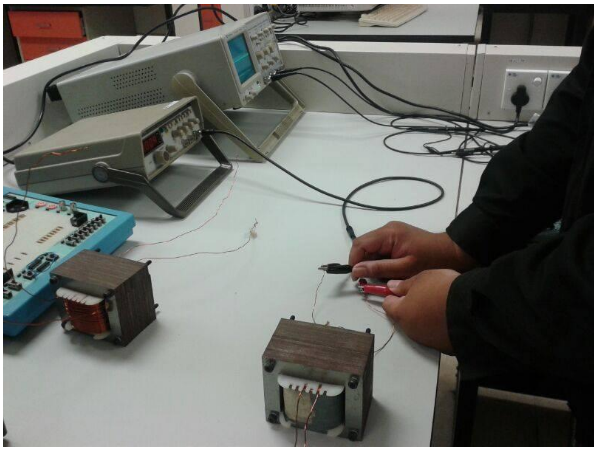


Figure 4.23: Measuring the power losses in the transformer

Table 4.0: The measurement result for the non defect transformer and axial fault transformer

Type of transformer	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}
Non defect transformer	13.00 V	1.89mA	0.024W	2.30	0.02mA	0.046mW
Axial fault transformer	13.00 V	1.88mA	0.024W	2.26	0.02mA	0.045mW

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As the conclusion, Sweep Frequency Response Analysis (SFRA) that has been used in this project should succeed in proving the effectiveness in detecting the mechanical fault in the transformer used. From paper [3] until [14] has expressed fully that the TFD methods able to detect or trace the mechanical faults in the transformer. The SFRA measurement was implemented for all ranges of frequency which are low sub bands, middle sub bands and high sub bands and each of this sub bands represent their distinctive faults. However, the only result from TFD is deeply viewed because TFD is simple and affordable to implement with only using MATLAB. The transformer have also been identified which is healthy and unhealthy in order to compare the output through using Omicron Bode 100. Moreover, the single phase transformer modeled with simulated mechanical faults is design successfully. From this experiment proved that TFD success to discover the presence of mechanical fault in the transformer precisely and very accurate based on the frequency ranges, particularly and the entire objective for this project is accomplished successfully.

For the recommendation, in future work implementation it could be suggested to use TFD from SFRA methods in order to detect other than mechanical fault such as electrical fault. There are several type electrical faults canned been investigated and it is capable to implement such as open circuit in the single phase transformer.

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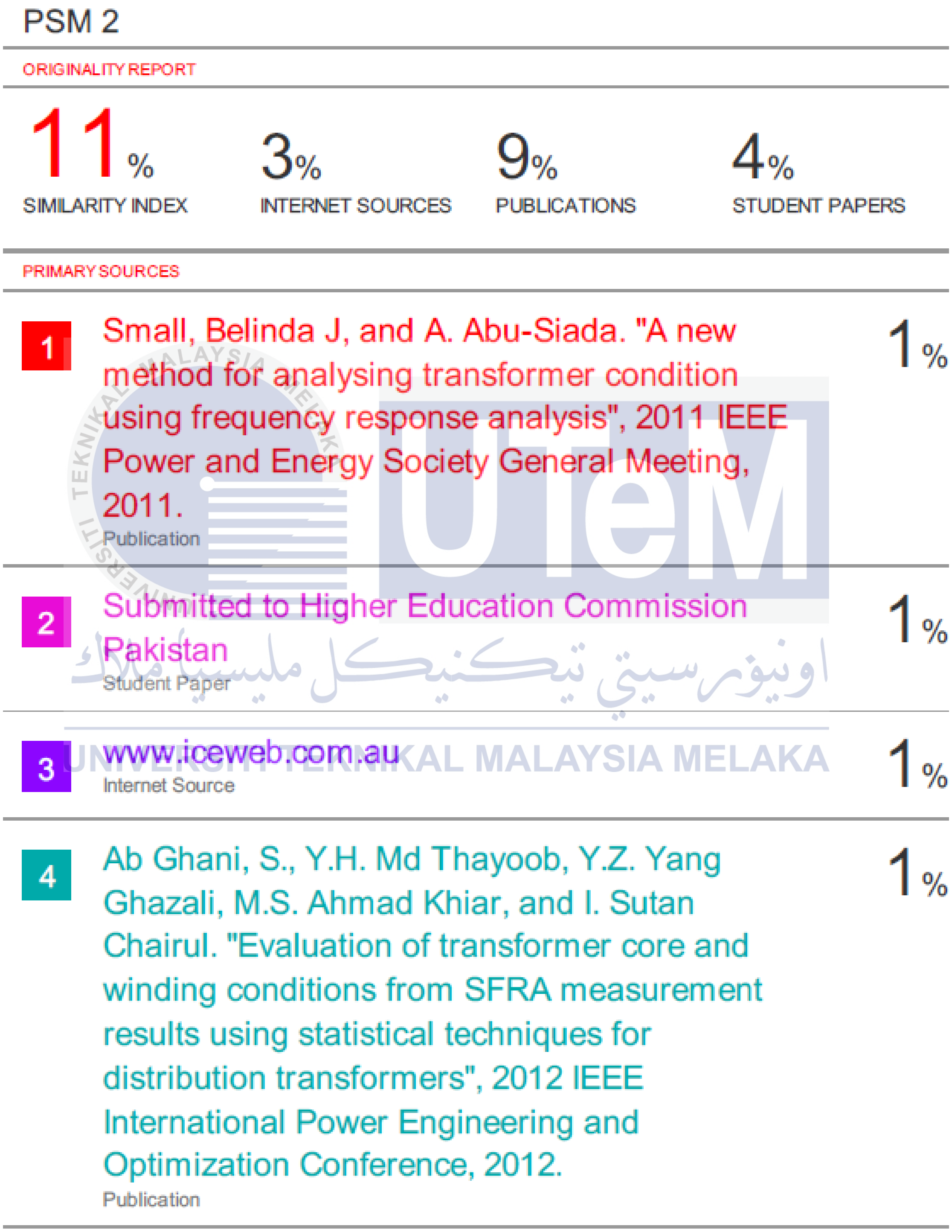
APPENDICE

Turnitin Result



PSM 2

ORIGINALITY REPORT

11%	3%	9%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Small, Belinda J, and A. Abu-Siada. "A new method for analysing transformer condition using frequency response analysis", 2011 IEEE Power and Energy Society General Meeting, 2011. Publication	1%
2	Submitted to Higher Education Commission Pakistan Student Paper	1%
3	www.iceweb.com.au Internet Source	1%
4	Ab Ghani, S., Y.H. Md Thayoob, Y.Z. Yang Ghazali, M.S. Ahmad Khiar, and I. Sutan Chairul. "Evaluation of transformer core and winding conditions from SFRA measurement results using statistical techniques for distribution transformers", 2012 IEEE International Power Engineering and Optimization Conference, 2012. Publication	1%

Coding MATLAB

```
clear all;clc;
close all;
Nw=2^11;
N=50*Nw;
f1=50;
fs=2500000;
ts=1/fs;

t1 = 0:ts:(N-1)*ts;
% f=[1:fr:(N*fr)];
% Nf1=(round(f1/fr)+1);

%%%% Generate signal  %%%%%


 x=0*sin(2*pi*0*(1:N)/fs);


%  x(5*Nw:15*Nw)=0.0189*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.0134*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.0169*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=0.0378*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=0.2128*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=0.4247*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);


%  x(5*Nw:15*Nw)=0.4766*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.3374*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.4766*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=1.1972*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=1.3432*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=1.0670*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);

%   x(5*Nw:15*Nw)=0.0190*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.0120*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.0213*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=0.0477*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=0.2680*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=0.4248*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);

%   x(5*Nw:15*Nw)=0.4248*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.3007*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.6000*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=1.3432*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=1.1972*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=0.9509*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%

%  x(5*Nw:15*Nw)=0.0151*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.0107*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.0151*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=0.0337*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=0.1897*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=0.3786*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);

%  x(5*Nw:15*Nw)=0.4248*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.3007*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.5348*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=1.3432*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=0.9509*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=0.6732*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);

%   x(5*Nw:15*Nw)=0.0951*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=0.0600*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=0.0095*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=0.0337*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=0.2129*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=0.3786*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);

  x(5*Nw:15*Nw)=1.8974*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
 x(15*Nw:20*Nw)=1.3432*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
 x(20*Nw:25*Nw)=0.2680*sin(2*pi*50000*(20*Nw:25*Nw)/fs);

 x(25*Nw:30*Nw)=1.0670*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
 x(30*Nw:35*Nw)=1.1972*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
 x(35*Nw:40*Nw)=1.0670*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%
%  x(Nw:5*Nw)=3*sin(2*pi*2000*(Nw:5*Nw)/fs);

%  x(5*Nw:15*Nw)=3*sin(2*pi*5000*(5*Nw:15*Nw)/fs);
%  x(15*Nw:20*Nw)=3*sin(2*pi*10000*(15*Nw:20*Nw)/fs);
%  x(20*Nw:25*Nw)=3*sin(2*pi*50000*(20*Nw:25*Nw)/fs);
%
%  x(25*Nw:30*Nw)=3*sin(2*pi*100000*(25*Nw:30*Nw)/fs);
%  x(30*Nw:35*Nw)=3*sin(2*pi*500000*(30*Nw:35*Nw)/fs);
%  x(35*Nw:40*Nw)=3*sin(2*pi*1000000*(35*Nw:40*Nw)/fs);

 figure(1);
plot(t1,x);
```

```
for n = 1:N-Nw
   v2 (1:Nw) = x(1+n-1 : Nw+n-1);
   win = hann (Nw)';
   v1 = v2.*win;
   V1 =fft(v1);
   E = V1.*conj(V1); % energy form
   Pv = E/Nw/Nw;      % power form
   TFR(1:Nw/2,n)= (Pv(1:Nw/2));
end


 figure(5);
fr2=fs/Nw;
[Ny,Nx] = size (TFR);
t2= (Nw)*ts:ts:((Nx-1)/fs)+Nw*ts;
freq2 = 0: fr2 :(Ny-1)*fr2;


grid;

contour(t2,freq2,(abs(TFR)),500);grid on;  % 60 refer to the display for contour
 set(gca,'yscale','log')
%  set(gca,'Color','black')
axis([0 0.05 1000 1200000]);
% axis([0 0.003 0.10 10000]);
colorbar;

ylabel ('Frequency (Hz)');title ('Contour TFD');
```