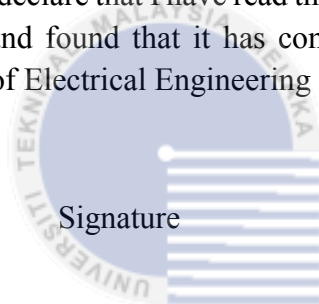
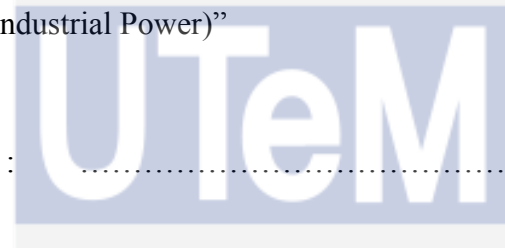


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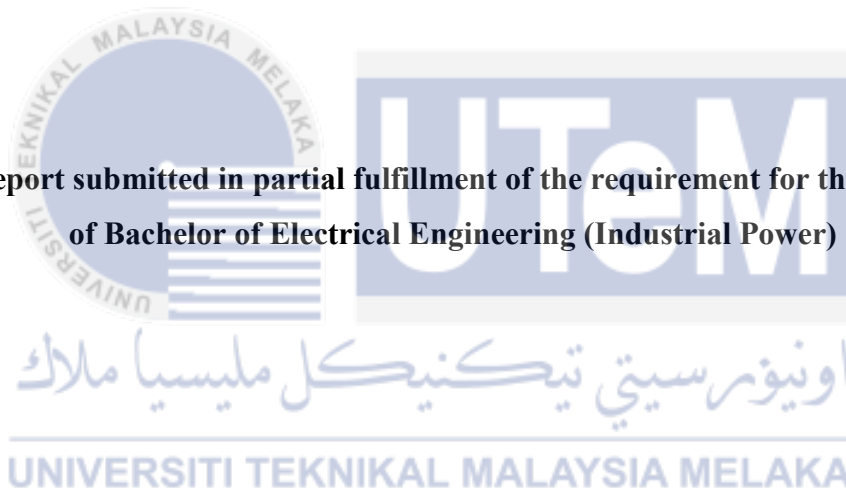
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HARMONIC SOURCE IDENTIFICATION SYSTEM

MUHAMMAD SUFYAN SAFWAN BIN MOHAMAD BASIR

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

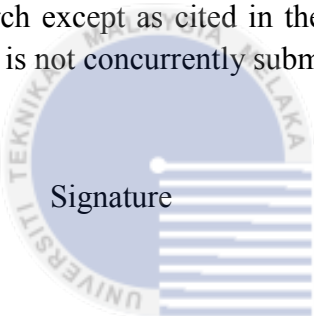


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2015

I declare that this report entitle “*Harmonic Source Identification System*” 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.

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To my beloved mother and father



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ABSTRACT

The impact of harmonic distortion in modern power system became a great concern in the last decade. The problem associated with the increase usage of appliances for non-linear load allows harmonic to presence in electric power system. Harmonic distortion is not only lead to poor power quality but also can cause malfunction to sensitive electronic equipments. In order to reduce the amount of harmonic, identifying the harmonic source location between utilities and customer is an effective way for harmonic signature recognition. To evaluate the quality of the source, measurement for the single phase 240VAC source should be proposed with the capability to identify the harmonic source. Harmonic Source Identification System (HSIS) is developed to analyze the harmonic source by identifying the total harmonic distortion for voltage and current used by using both direction of active power flow and Fast Fourier Transform (FFT) method. Different load identification due to different level of harmonic distortion can be classified by conditions includes 'Excellent', 'Caution' or 'Danger' that recommended by IEEE 519-2014. The signal measured by voltage and current transducers will be converted in the form of digital signals for signal processing by using NI 6000 DAQ card. The effectiveness of HSIS is emphasized through simulation results from MATLAB. A performance test is conducted with different type of loads namely incandescent lamp, CFL lamp and synchronous motor. The notch area that occurs at the distorted waveform is presented by power spectrum. Waveform measured is identified to be less distorted for non-power electronic components and is fully distorted for power electronic components through performance test. The expected value for total harmonic distortion for voltage (THDv) and current (THDi) will be shown on monitors and users can identify the performance of the system through HSIS and safety precaution can be made if the value of harmonic exceed dangerous level.

ABSTRAK

Kesan dari herotan harmonik dalam sistem kuasa moden menjadi kebimbangan pada dekad yang lalu. Masalah ini berpunca dari peningkatan penggunaan peralatan bukan linear membenarkan kehadiran harmonik dalam sistem kuasa elektrik. Herotan harmonik bukan sahaja membawa kepada kelemahan kualiti tenaga malah boleh menyebabkan kerosakan kepada peralatan elektronik yang sensitif. Dalam usaha untuk mengurangkan jumlah harmonik, pengenalpastian lokasi punca harmonik antara utiliti dan pengguna adalah cara terbaik bagi perolehan harmonik. Bagi menilai kualiti sumber, pengukuran berdasarkan sumber fasa 240VAU perlu dicadangkan dengan keupayaan untuk mengenal pasti sumber harmonik. Harmonic Source Identification System (HSIS) dibangunkan untuk menganalisa punca harmonik dengan mengenal pasti jumlah herotan harmonik untuk voltan dan arus yang digunakan dengan menggunakan kaedah arah aliran kuasa aktif dan Fast Fourier Transform (FFT). Pengenalpastian beban yang berbeza disebabkan kelainan tahap herotan harmonik boleh diklasifikasikan pada kondisi 'Sangat Baik', 'Amaran' atau 'Bahaya' yang disarankan oleh IEEE 519-2014. Isyarat yang diukur dengan pengesan voltan dan arus akan ditukar dalam bentuk isyarat digital bagi pemprosesan signal menggunakan kad NI 6000 DAQ. Keberkesanan HSIS diukur melalui keputusan simulasi dari MATLAB. Ujian prestasi dilaksanakan dengan pelbagai jenis beban iaitu lampu pijar, lampu CFL dan motor segerak. Kawasan takuk yang berlaku pada gelombang terherot dikemukakan dalam bentuk spektrum kuasa. Bentuk gelombang yang diukur kurang terherot apabila tiada komponen elektronik kuasa dan mengalami herotan yang tinggi pada komponen elektronik kuasa melalui ujian prestasi. Nilai jangkaan harmonik bagi jumlah herotan harmonik untuk voltan (THD_v) dan arus (THD_i) akan dipaparkan pada monitor dan pengguna boleh mengenal pasti prestasi sistem melalui HSIS dan langkah pencegahan boleh dilaksanakan sekiranya nilai harmonik melepasi tahap bahaya.

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LIST OF ABBREVIATIONS

A/D	-	Analog to digital
AC	-	Alternating current
ANSI	-	American National Standards Institute
CFL	-	Compact fluorescent lamp
CPU	-	Central processing unit
CT	-	Current transducer
DAQ	-	Data acquisition
DTFT	-	Discrete Time Fourier Transform
DWPT	-	Discrete Wavelet Packet Transform
FFT	-	Fast Fourier Transform
GND	-	Ground
GUI	-	Graphical User Interface
HSIS	-	Harmonic Source Identification System
Hz	-	Hertz
IEEE	-	Institute of Electrical and Electronics Engineers
LED	-	Light emitting diode
LV	-	Low voltage
MATLAB	-	Matric laboratory
NI	-	National Instrument
PC	-	Personal computer

PCC	-	Point of common coupling
PQ	-	Power Quality
rms	-	Root mean square
TDD	-	Total Demand Distortion
THD	-	Total harmonic distortion
THDi	-	Total current harmonic distortion
THDv	-	Total voltage harmonic distortion
USB	-	Universal Serial Bus
VS2015	-	Visual Studio 2015
VT	-	Voltage transducer
WPT	-	Wavelet Packet Transform



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CHAPTER 1

INTRODUCTION

1.1 Research Background / Motivations

In present days, power distribution system became highlighted in the growth of technology for availability, reliability and quality of a system. Power electronic components that apply in digital circuitry such as computer and television create power line disturbance namely harmonic distortion [1]. Harmonic distortion became the major contributor to poor power quality due to excessive draw of reactive power from non-linear loads such as nonlinearity of transformer, arcing device, rotating machines, and inverter fed AC drives [2]. Non-linear loads are caused by a drawn of non-sinusoidal current, thus inducing voltage distortion and affecting on consumer equipment. Based on the IEEE 519 - 2014 Task Force on the Effect of Harmonic on Equipment, the harmonic can lead to problem in central processing unit (CPU) frequency problem and can change the size and brightness for television. Hence, this justifies that modern electronic devices in electrical systems are sensitive to harmonic issues than those from the olden days.

Harmonic source problems need to be monitored to identify the locations of distortion of voltage and current between non-linear loads (customer) and the network (utility). This is important to ensure the safety of the equipment in term of lifespan, malfunctioning and error. The maximum allowable for total harmonic distortion (THD) recommends by IEEE Standard 519-2014 where %THD_v must be not be greater than 8%, while %THD_i must not be greater than 50% of the rated current [3]. This project is capable to identify the source of harmonic for the single phase 240VAC system by taking a reference point known as point of common coupling (PCC). Through the classification of harmonic source at PCC, the source of harmonic

can be traced by minimizing the area where PCC is located. Figure 1.1 shows the location of the harmonic source at Area 3 that can be identified by placing the voltage transducers (VT) and current transducers (CT) at each PCC. HSIS is capable to identify the harmonic source by taking the parameters of rms voltage, current, real power, reactive power and apparent power of the measured system. Hence, the detection of harmonic source at Area 3 is classified as a customer fault and the word “Customer” will be displayed in the graphical user interface (GUI).

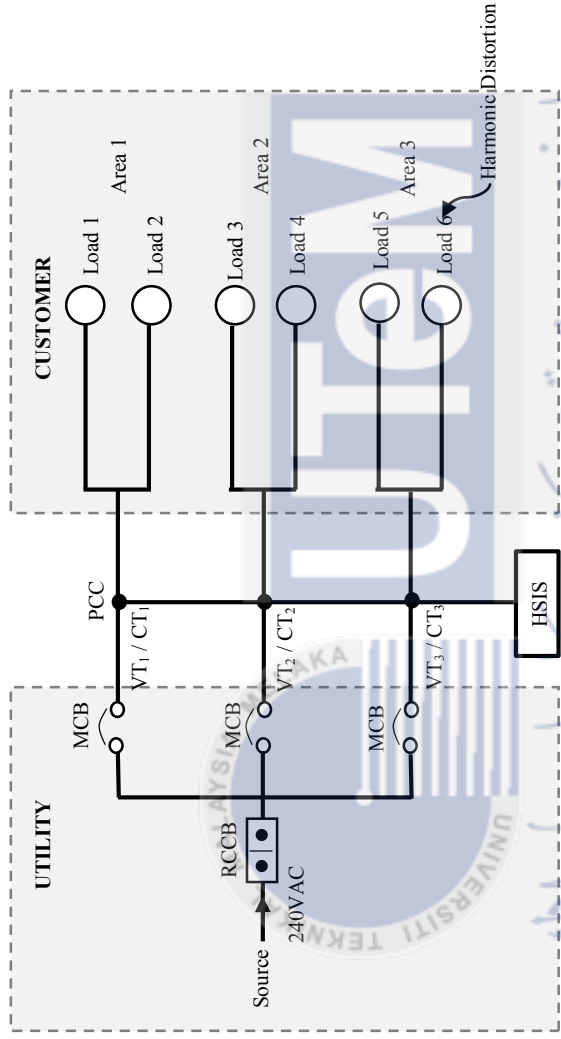


Figure 1.1: Identification of Harmonic Source Using HSIS

Mainly, the harmonics have varied with time according to the load conditions. From such point of view, a method based on time varying signal in an option to monitor the harmonic distortion [4]. HSIS is developed based on time domain where the value of voltage due to the time is measured by using FFT. Through the load measured in single phase system, the expected waveform with harmonic is as shown in Figure 1.2 (a). The harmonic occur in a single phase system for voltage and current is not a clean sinusoidal waveform due to non-linear loads. This signal will be analyzed and converted in term of FFT spectrum as shown in Figure 1.2 (b).

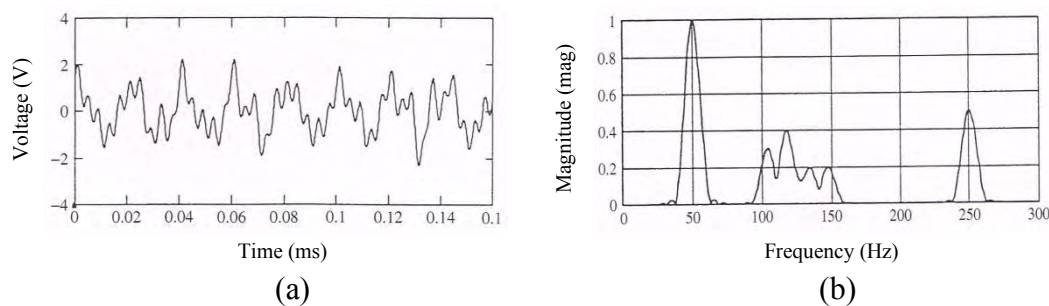


Figure 1.2: (a) Waveform with Harmonic Components
(b) FFT Spectrum [4]

HSIS is proposed to serve as an alternative to the pricy monitoring systems available, so the performance test is conducted to ensure the capability of HSIS. Different type of loads is measured for the system performance verification due to different level of harmonic. In addition, it is well known that harmonic source detection popularity is increased because of the amount of harmonic has gained. Thus, the significant way is to monitor the level of harmonic distortion so that immediate action can be taken such as installing the filter to reduce the amount of harmonic.

1.2 Problem Statement

Harmonic distortion is mainly caused by non-linear loads supplied from the electrical appliances. This condition will form large oscillatory currents and voltage that can damage the equipment and insulation from the single phase 240VAC system. User having problems to identify the locations of the load that produced large amounts of harmonic. The capability of HSIS is able to monitor the harmonic distortion of current and voltage supplied. If the large amount of harmonic occur in a supply source, an action can be taken by the user. Different level of harmonic can be identified with different load identification in the system due to the different load demand by the user. This project is made as a safety purpose for the user to avoid using appliances than can be damaged by harmonic distortion.

1.3 Objective

This project embarks on the following objectives:

1. To simulate the voltage and current for harmonic distortion using MATLAB based on Fast Fourier Transform (FFT).
2. To develop Harmonic Source Identification System to identify the harmonic distortion from single phase 240VAC source supply.
3. To analyze the performance of the system with different load identification from single phase 240VAC source supply.

1.4 Scope of Work

Harmonic Source Identification System is developed to identify the total harmonic distortion for voltage (THD_v) and current (THD_i) from single phase 240VAC source supply using Fast Fourier Transform (FFT) method. Voltage and current transducer will be used to measure the harmonic distortion from single phase system with different load identification. Simulation based on voltage and current will be conducted using MATLAB and level of harmonic distortion will be presented in form of FFT spectrum. VS2015 will be used to measure the performance of the system with different load identification.

1.5 Report Outlines

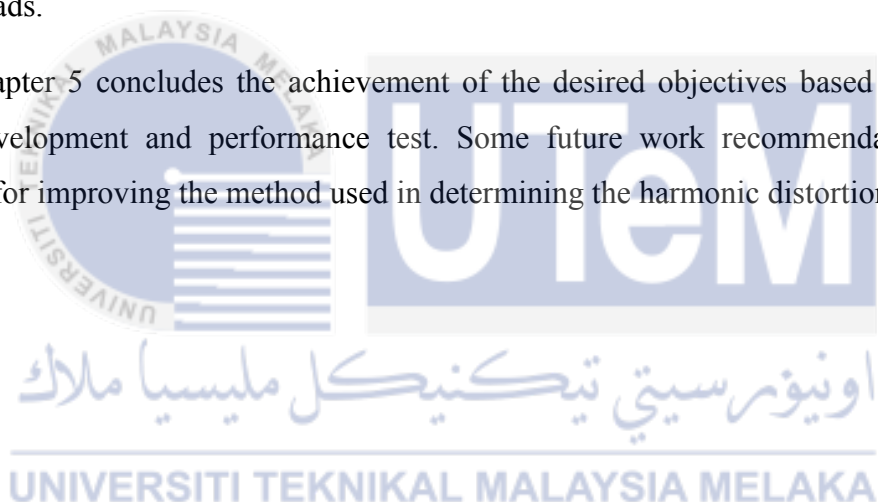
The outline of this report represent by 5 chapters. Brief explanation for the cause of harmonic distortion and how these harmonic can harm the equipment are discussed in introduction part. In this chapter, it has been stated that HSIS is developed to identify the location harmonic source. The objectives and scope are clearly stated for a project guidelines. Other chapters in this report are summarized as follows:

Chapter 2 presents the background theories related to the project. This includes the explanation of basic method used to measure the THD and harmonic source locations. The summary and discussion of the proposed methods of HSIS have also explained in this chapter.

Chapter 3 discusses the project methodology used in developing HSIS. Acceptable methods used in accomplishing this project are explained in details. With the help of a particular figure and block diagram, the hardware and software implementation in developing HSIS are shown. Three different loads are considered for performance test of the system.

Chapter 4 shows the results of simulations from MATLAB based on the method proposed. The effectiveness of HSIS in measurement and harmonic source identification are discussed in accordance with the results recorded by the performance test for three different types of loads.

Chapter 5 concludes the achievement of the desired objectives based on simulation, project development and performance test. Some future work recommendations are also suggested for improving the method used in determining the harmonic distortion.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to gain enough information to recommend the appropriate method that can be used to complete the research, comparison between certain techniques is required to measure the harmonic distortion in single phase system. The outlines in this chapter related to the theory and basic principles, review of previous related work, and summary of this project. In the first section of the research covered the definition from Institute of Electrical and Electronics Engineers (IEEE) where PCC, Total Demand Distortion (TDD), harmonic measurement methods, and voltage and current distortion limits. Besides, this section reviews on harmonic distortion occur in the single phase power system by analyzing different types of waveform for different harmonic order in the following sequence.

Reviews of previous related works on harmonic distortion focused on certain methods such as Wavelet Packet Transform (WPT), direction of active power flow and FFT designed by respective researchers. Each method is explained based on three sections, i.e. the analog input and signal conversion, signal processing and computational calculation, and GUI. The performance is verified for improvising the existing harmonic distortion monitoring system for the convenience of users.

2.2 Theory and Basic Principles

Institute of Electrical and Electronics Engineers (IEEE) 519-2014 stated that the measurement of harmonic distortion is recommended at PCC whereby the point is on the LV side of the distribution transformer [5]. As stated in [6], the loads contain harmonic can be pure resistive, inductive, capacitive or single phase rectifier. Nowadays, measurement of harmonic is proposed where the harmonic source is located between the utility and costumer using several methods. There will be disadvantage in measuring the harmonic at PCC for single point due to lack in accuracy. In terms of economics, PCC can increase the level of investment for harmonic measurement in power system for optimization [7].

In PCC measurement, TDD is considered as a percentage of average maximum voltage or current over a demand interval for certain time [8]. IEEE 519 stated that the demand interval in [9] is typically between 15 to 30 minutes and larger voltage or current demand will produce large distortion and vice versa. As mentioned above, TDD is not covered for interharmonics component as the main objective focused on harmonic distortion as mentioned in [6]. Based on consideration stated in [10], data taken for harmonic distortion represent best in average values for the performance of the system.

Harmonic distortion becomes the main culprit in power quality (PQ) system now. Under certain condition stated in [11] where nonlinear loads such as rectifier and arc furnace increases with the increases uses of power electronic component. This condition leads to the disturbance in a system allow appliances to operate under loss condition and increases maintenance cost. Harmonic distortion that occurs in single phase will become influenced to other appliances and leads to further damages. For example, a device like a computer that sensitive to disturbance can cause data error. The supplier will become the victim due to the loss interested in customer for their utilities. Due to this issue, researchers come with certain method that will be discussed later.

Voltage and current distortion limit measured is recommended based on rated value between 120V to 69kV. Through this recommendation, harmonic distortion at PCC can be measured and proper solution can be made if the value exceeds the limits. In terms of harmonic distortion, there may be a problem due to the increased use of the capacitor banks that can

increase power factor, but may lead to the worst scenario such as harmonic [12]. In accordance, proper measuring system is the best option to monitor the performance of a system and hypothesis can be made based on the situation occur where HSIS is proposed.

2.2.1 Total Harmonic Distortion

Harmonic distortion is one of the main indices that affect the power quality. Harmonic distortion is represented in a complex time and frequency domain [12] and expressed in rms values. As mentioned in [13], due to the increases use of power electronic components, new type of harmonic source is traced. Harmonic effect can be measured either voltage or current and this distortion may lead to the increases of frequencies in the waveform [14]. Figure 2.1 presents the harmonic waveform for single phase systems.

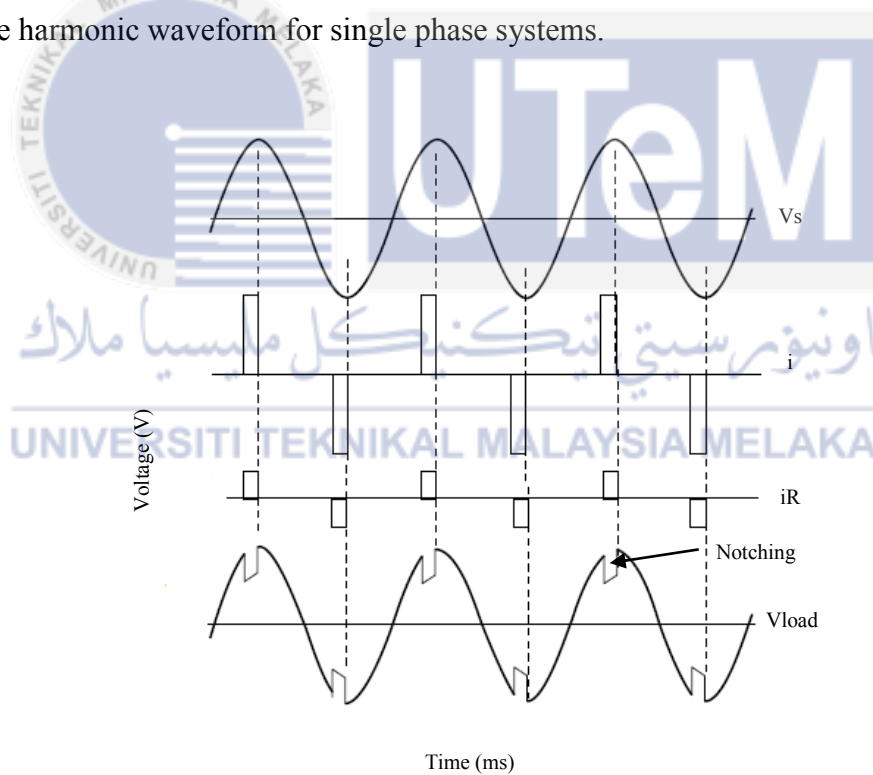


Figure 2.1: Harmonic Signal Occur Inside Sinusoidal Signal [12]

As shown in Figure 2.1, the distortion occurs at the pure sinusoidal waveform is called notching. Notch area may affect the quality of the system. The percentage of notch depth is

measured to monitor the distortion in a source. The ratio between non-fundamental frequencies to fundamental frequency is called total harmonic distortion and can be expressed as given below [15].

$$THD = \frac{\sqrt{\sum_{n=2}^N V_n^2}}{V_1} \quad (2.1)$$

Where V_n = Single frequency r.m.s

n = Harmonic voltage

N = Maximum harmonic

V_1 = Fundamental line to neutral r.m.s

Based on recommendation of American National Standards Institute (ANSI) standard in [16], the THD truncation is at 5kHz, but in practical application, the value will not exceed that much due sensitivity on hardware implementation. THD may come to simple in term of measurement based on equation (2.1) but the detailed information in the power spectrum analysis for every harmonic order became the main issue.

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2.2.2 Harmonic Level

Different harmonic level gives a different shape of harmonic waveform. Harmonic level can be classified into 3 different sequences which are positive, negative and zero. As mentioned above, a harmonic is measured at PCC where the studies include the modelling of two winding transformers. As stated in [17], most distribution transformer cannot propagate and leads to zero sequence harmonics. As the result, the low voltage system will suffer greater damage if small unbalances happen as the zero sequence harmonic involve at neutral wire. Table 2.1 indicates the level of harmonic for positive, negative and zero sequence.

Table 2.1: Sequence of Harmonic

Harmonic Order	1	2	3	4	5	6	7	8	9
Positive Sequence	+			+			+		
Negative Sequence		-			-			-	
Zero Sequence			0			0			0

Based on Table 2.1, third harmonic, which is zero sequence harmonic is the highest among other levels of harmonic. Without proper prevention may lead other effect such as overheating, losses in the neutral line due to zero sequence harmonic and reduction in energy efficiency.

2.3 Review of Previous Related Work

Several methods had been proposed to identify the harmonic for the performance of the system. The harmonic measuring system includes different methods in classifying the harmonic source between the utility and the customer which standardized by IEEE 519-2014 based on the values and percentage THD calculated. All of these methods include time varying whereby the analog signal detected by transducer will be converted in the form of discrete signal for system analysis. Quantities such as the magnitude against frequency of voltage or current are measured over timer for a short or long period of time depend on the number of samples captured. On the other hand, digital rms quantities provide accurate measurement which offers stability that highly recommended for measuring level of harmonics as stated in [18]. The measurement of harmonic can be divided into 3 main stages includes analog input and signal conversion, signal processing and computational calculation, and graphical user interface. The system proposed consists of voltage or current transducer as sensing tools to measure the quantities at PCC.

DAQ system is based on microprocessing that integrate with VS2015 provide the interface for the whole system. The NI 6000 DAQ card is the hardware used to convert the

analog signal produced by the transducer to digital signal whereby Measurement Studio is used to analyze the signal using a certain method such as WPT, direction of active power flow and FFT. Rms value measured by WPT method will be converted to discrete wavelet packet transform (DWPT) using a DAQ card and the signal is divided into several bands of frequency [19]. Computational analysis of DWPT algorithm is performed where each frequency band is decomposed into uniform frequency bands results the capabilities to measure the harmonic components for rms voltage and current as stated in [20] based on IEEE 1459-2000. WPT will give accurate values if the frequency band taken is lower and small frequency bands may help in reducing the error [21]. Through WPT method, the results can be obtained by determining the reasonable number of decomposition layers include harmonic distortion signal based on several samples. Performance of WPT algorithm can be tested by selecting the frequency band at level 2 which covers 32 nodes and each node contains four coefficients. However, the small leakage as mentioned in [22] may occur between nodes can be a disadvantage for WPT algorithm.

Nevertheless, direction of active power flow indicates the widely method used in the harmonic measurement system. One point is taken as a reference for source detector between utility and customer side. Through this method, the magnitude of voltage and current with corresponding to phase angle is measured depends on which side the magnitude flows [23]. Based on DAQ determination, if the active power measured at PCC gives the value greater than zero ($P_h > 0$), the harmonic occurs at the utility side whereby if the active power measured at PCC is less than zero ($P_h < 0$), customer side is the main contributor of harmonic [24]. This method involves mathematical and computational analysis to measure the harmonic. MATLAB is used to generate based on the instantaneous power stated in [25]. Based on the result obtained in [24], the direction of active power flow gives incorrect result if the measurement of harmonic is for three phase system. On the other hand, HSIS based on direction of active power flow can be used in presuming the harmonic source locations.

FFT algorithm is proposed for harmonic distortion measurement based on real-time analysis where the continuous time signal is converted into a discrete time signal using the DAQ card called Discrete Time Fourier Transform (DTFT). FFT method involves when sampling frequency and period is two times higher than fundamental frequency and signal period [26].

This method is highly recommended due to its availability and simplicity in determining the harmonic distortion. The magnitude of the sampling signal is analyzing where FFT exponential equation involves through computation.

FFT method is helpful due to its advantages which gives high precision results and absent in spectrum leakage. The measuring process include where the sampling data produced by DAQ card using Measurement Studio are processed using FFT algorithm and simulation based on this method is made. Based on results obtained in [27], [28], the FFT method seems to give a more accurate value and suitable for measuring harmonic for single phase systems. Table 2.2 shows the advantage and disadvantage of these methods [22], [27], [29], [30].

Table 2.2: Advantage and Disadvantage of WPT, Direction of Active Power Flow, and FFT

Method	Advantage	Disadvantage
Wavelet Packet Transform	Gives accurate values and flexible for harmonic distortion measuring and more efficient in measuring based on frequency bands separation.	Small leakage occurs due to the separation of frequency bands.
Direction of Active Power Flow	Widely use and simple to construct.	This method cannot solve complex task in 3 phase source.
Fast Fourier Transform	Gives accurate values, no spectral leakage, and is the best method for DAQ system using discrete signal.	Leads to incorrect result if the sample sequence based on fundamental frequency is not fixed.

Reference [18] – [30] focuses on the digital processing unit where certain algorithm involve is measuring the harmonic distortion for single phase system. Each of this algorithm has its own advantages and disadvantages and results based on previous experiment is used as a reference for HSIS. For the user interface, the value generates by Measurement Studio is

converted into friendly interface for simplicity. Performance test includes linear and nonlinear loads will take place as to fulfill the condition in measuring the THD and detecting harmonic source locations.

2.4 Summary and Discussion of the Review

There are certain methods can be used for harmonic monitoring system such as WPT, direction of active power flow, and FFT as discussed in [18] – [30]. The technique such as WPT used signal is divided into several bands of frequency for data processing. WPT is known to be the most accurate value compare to other 2 method proposed in [23], [26]. However, HSIS is based on DAQ analysis where analog signal produced by a transducer is converted in the form of digital signal for processing and FFT algorithm known to be the best option as mentioned in [26]. FFT is known to be the best and measurement based on IEEE 519-2014 and fulfilling the standard of the harmonic distortion monitoring system. Although method discussed in [23] – [25] is widely used and known to be the customer choice, due to the increases use of power electronic component will cancel the accuracy of this algorithm. But still the ability of direction of active power flow in determining the harmonic source locations between utility and customer is implemented in HSIS for source detection.

Based on the result obtained from researchers in [27], [28], the FFT method gives the relevant value in measuring the harmonic for single phase systems as HSIS is developed to identify harmonic distortion in single phase system at PCC. HSIS is only focused on measuring harmonic distortion with the exception of transient response, sag and swell and etc. The performance of the system can be measure based on linear and nonlinear loads as stated in [11]. Based on the data gathered, HSIS will be designed based on the FFT algorithm for THD measurement and direction of active power flow for source detection due to its compatibility.

CHAPTER 3

METHODOLOGY

3.1 Principles of the Methods Used In the Previous Work

HSIS will be carried out based on the investigation about a certain level of harmonic due to voltage and current. The signal produced by the voltage and current transducer will be analyzed by the VS2015 using FFT technique. For this technique, A/D converter will be used to change the analog signal in digital form that required by digital instruments as shown in Figure 3.1. Generally, digital instrument uses microprocessor for signal processing captured by data acquisition card. The microprocessor will calculate the harmonic level based on FFT technique. Parameters such as real-time waveform and real-time harmonic analysis will be displayed on a screen [31].

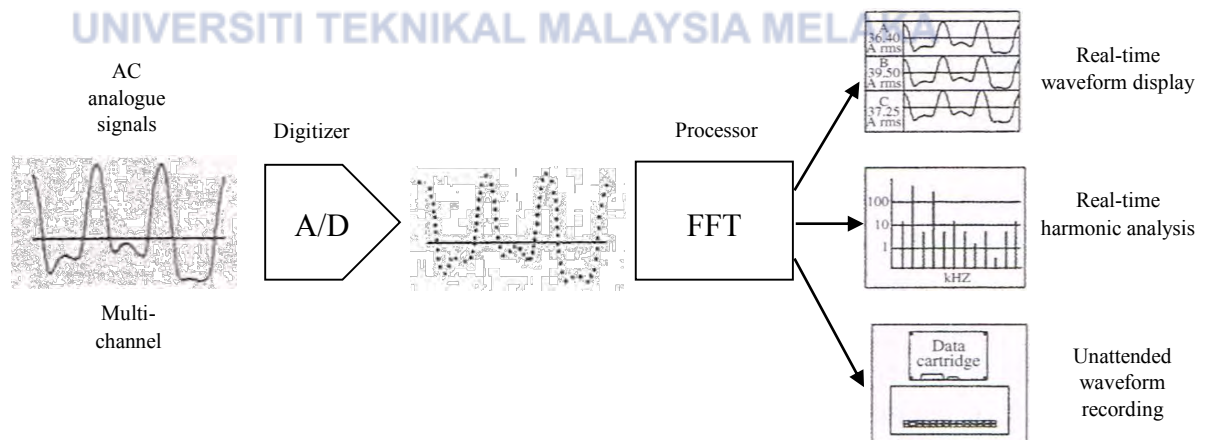


Figure 3.1: Components of a Multiwave Monitoring System

3.2 Project Development Workflow

For the first stage in project development, literature review of previous project is important to verify the advantage, disadvantage and the development of harmonic distortion in terms of voltage and current. From the literature review, the method of FFT to identify harmonic from a single phase system will be done based on research. This method is highly recommended due to its availability and simplicity in determining the harmonic distortion. Voltage and current transducers are used to capture the signal. The analog signal produced by a sensor is converted in the form of digital signal for processing. Each circuit for the sensor is designed based on its capability to capture the harmonic through the signal produced. Project interface is designed by using VS2015 resulting total harmonic distortion for voltage and current by the process of analyzing and calculating the voltage and current measured as shown in Figure 3.2. All the values based on THD level are displayed in the form of frequency spectrum and the reading is shown through computer display. The main purpose of hardware and software implementation is to ensure that all the sensors chosen satisfied the requirement condition for identifying total harmonic distortion. If the value of reading is not satisfied, troubleshooting will be done by calibrating the reading of the sensor.

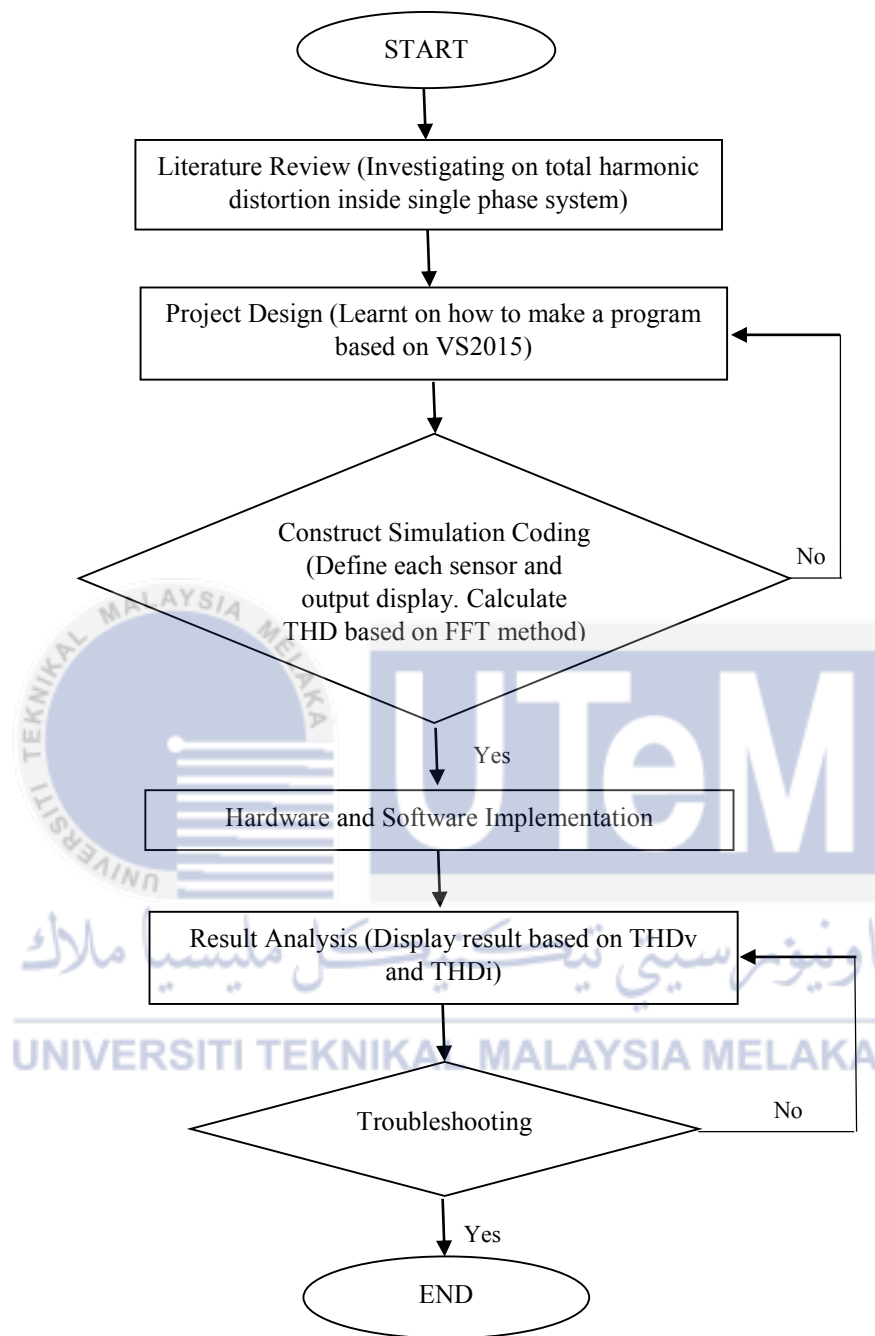


Figure 3.2: Project Workflow

3.2.1 Software Implementation

In the development of HSIS for single phase systems, simulation based on VS2015 is required. Measurement Studio 2013 library is integrated with VS2015 as the requirement of the National Instrument DAQ card for acquiring the signal measured. Figure 3.3 shows the flowchart of HSIS construction. Ports for voltage transducer and current transducer are initialized for signal acquiring based on DAQ card in VS2015. Initializing of voltage and current transducers are required for ratio calibration for both transducers to ensure the system stability.

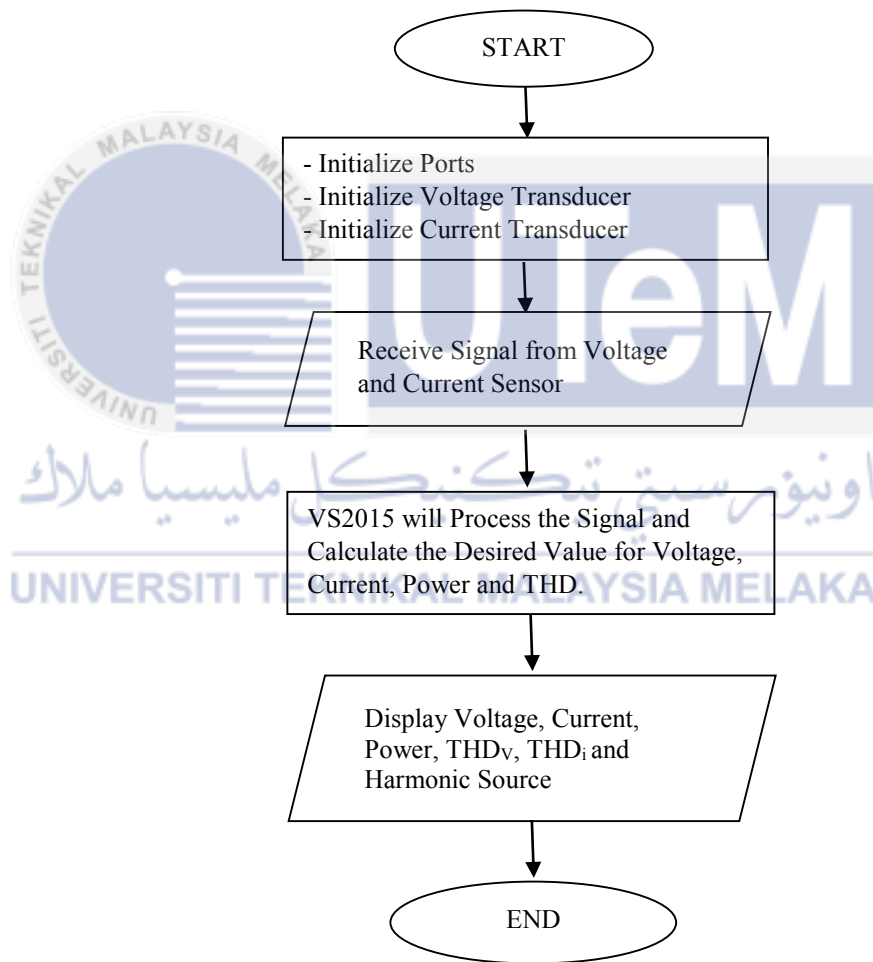


Figure 3.3 Flowchart of Harmonic Source Identification System

The signal received will be processed by using PC-based processing unit in term of digital data to obtain the desired value of voltage, current, power and THD. VS2015 will do the calculation for harmonic signal based on FFT method. This method is highly recommended due to simplicity in determining the harmonic distortion. The formula of FFT exponential equation is used to analyze the magnitude of the sampling signal through computation as shown in equation 3.1.

$$x(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft} dt \quad (3.1)$$

The system is approached by displaying the data obtained graphic and text form. An appropriate monitoring display in GUI for HSIS is shown on Figure 3.4. The overall system development consists of parameters such as voltage (V), current (I), active power (P), reactive power (Q), apparent power (S), power factor (pf), THD and harmonic source are presented.

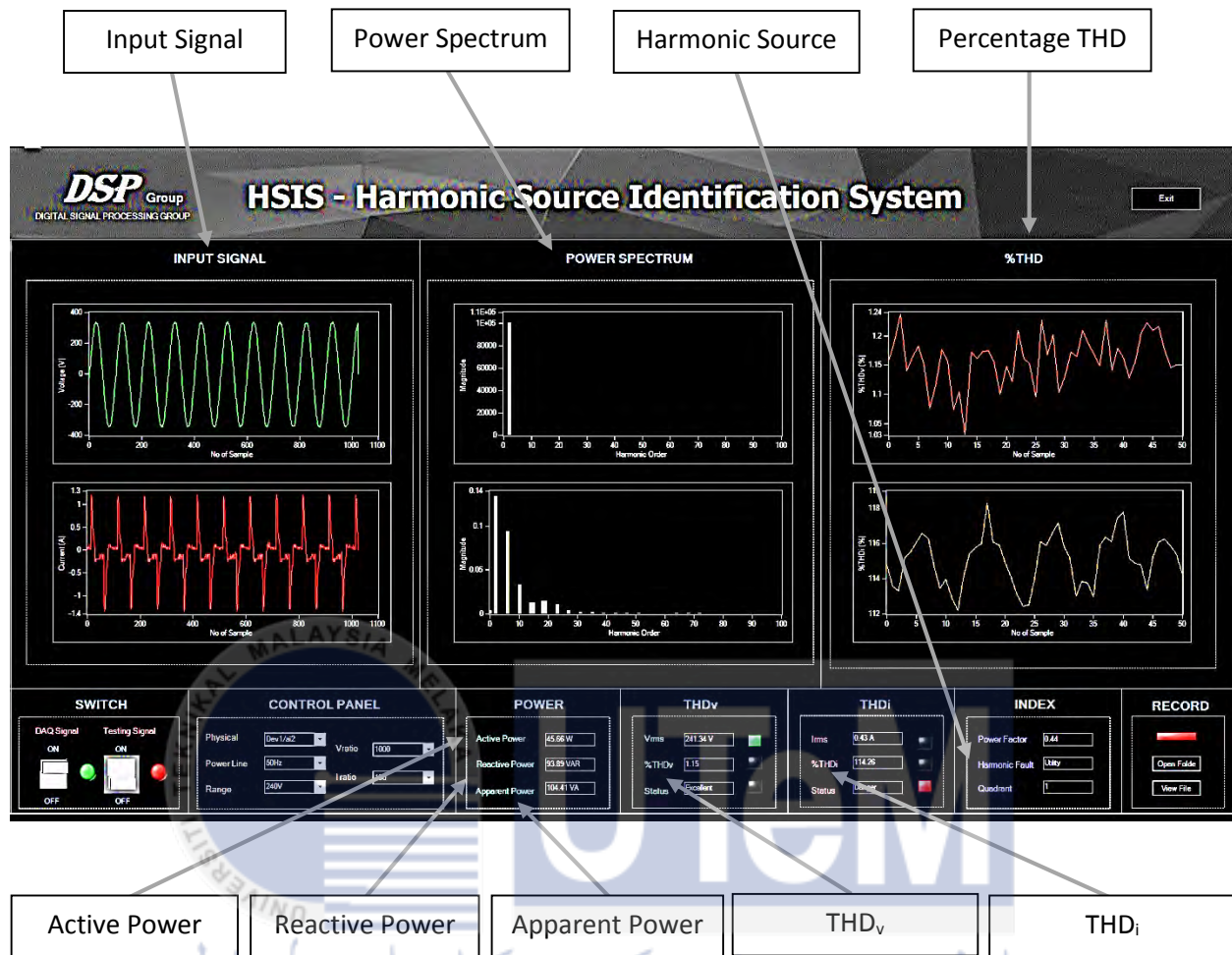


Figure 3.4: HSIS GUI

HSIS is built with user friendly as the LED indicates the status of the system. The level of %THD allow for the system are %THD_v must be not be greater than 8%, while %THD_i must not be greater than 50% of the rated current. Different colors show up such as green indicated excellent, yellow indicated caution and red indicated danger. The data is recorded in real time monitoring and automatically save in the destination folder.

3.2.2 Hardware Implementation

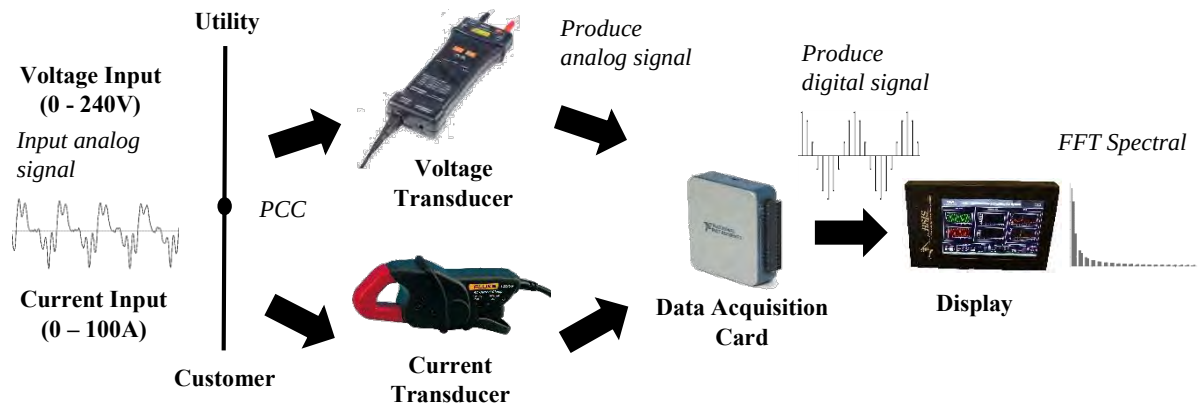


Figure 3.5: General Diagram for the System

Figure 3.5 shows a general diagram for this system. 240VAC is supplied through voltage and current transducer and displayed as the output. Analog signal measured at PCC by a transducer contains harmonic distortion from the utility and customer side will be analyzed. Both voltage and current transducer measured are ranging from 240VAC for voltage and 100A for current. As the limitation of data acquisition (DAQ) card that can read the analog signal up to 10V for voltage, the output analog signal for transducer is between -10V to 10V in range.

DAQ card is the device that measure analog signal produced by the transducer for voltage and current and convert it into a digital signal as required by digital instrument. NI DAQ 6000 is used as the compatibility of this DAQ card to link with many digital instruments. A digital instrument that uses microprocessor for the processing will process the signal produced by the DAQ card using the FFT method. Based on Figure 3.6, voltage transducer is connected to port A2 and GND while the current transducer is connected to pin A3 and GND in NI DAQ 6000.

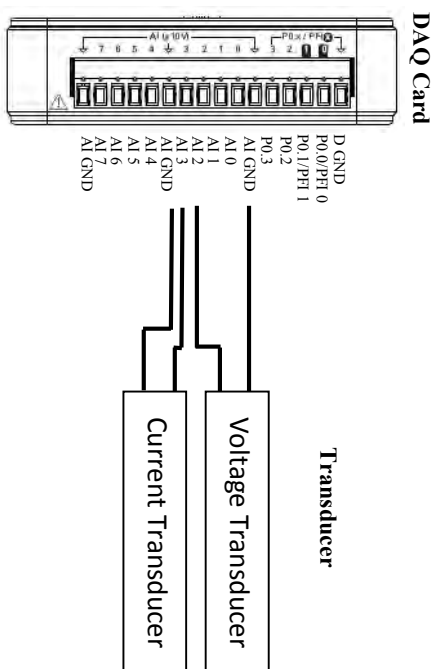


Figure 3.6: Connection Diagram for NI DAQ 6000

For the communication medium between the DAQ card and PC-based hardware, USB 2.0 cable is used. The continuous data sampling is analyzed using VS2015 where all the parameter calculated will be shown for the user interface. All parameters stated are displayed in digital forms as well as in waveforms. In addition, this system also provides voltage and current spectrum information for both THD_v and THD_i. In the preface to the Appendix A containing the hardware development of HSIS.

3.3 Description of the Work to Be Undertaken

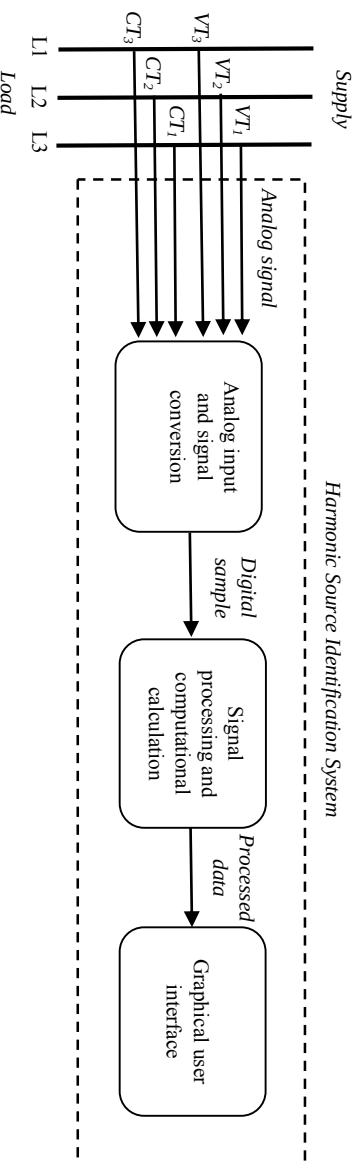


Figure 3.7: Schematic Diagram for HSIS

As shown in Figure 3.7, the analog signal captured by voltage and current transducer will be sent into the analog input and signal conversion. The function of this unit is to convert the analog signal into a digital signal. This unit will provide greater flexibility for altering the algorithms to be used for data sample processing. The digital sample will be transferred into signal processing and computational calculation unit. FFT method is used to calculate the signal and convert it in the form of harmonic distortion using VS2015. The measured data for THD_v and THD_i can be accessible from the HSIS GUI so that user can take an action for the data displayed. Harmonic source can be determined by identifying the direction of active power flow. If the harmonic occur at utility side, the value of power would be positive and if the harmonic occur that customer side, the value of power would be negative.

3.4 Performance Testing

The test is set up to analyze the performance of the system by taking the parameter for different type of loads namely incandescent lamp, CFL lamp and synchronous motor. These tests are conducted to determine the single phase harmonic distortion based on energy efficiency and non-energy efficient loads. The parameters measured are presented in the HSIS GUI to verify the capability of the system in determining the harmonic source location.

Case 1: Incandescent Lamp

In order to obtain the harmonic signal, incandescent lamp is used for the performance test as shown in Figure 3.8. Different variety of load need to be analyzed for the performance of HSIS due to different level of harmonic produced. The aim of the test is to verify that HSIS is able to monitor the parameter of voltage, current, active power, reactive power, apparent power, power factor, THD and harmonic source location for different type of loads. For this test, 36W of incandescence lamp is used for each unit of lamps.

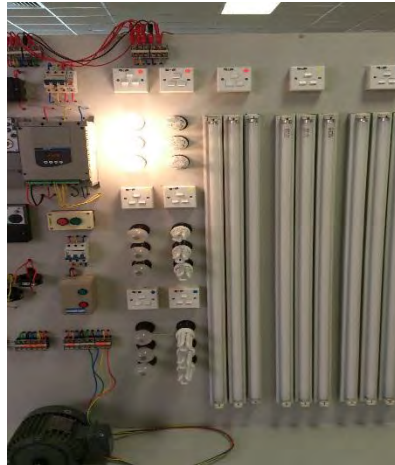


Figure 3.8: Incandescent Lamp Test

Case 2: CFL Lamp

Figure 3.9 reveals the CFL lamp test for 1, 2 and 3 units of the lamps for single phase systems. The expected result of this test is the value of voltage and current drawn must be lower than incandescence lamp while the value of THD is higher due to the presents of power electronic component. Each lamp used are operated under 10W of rated power.

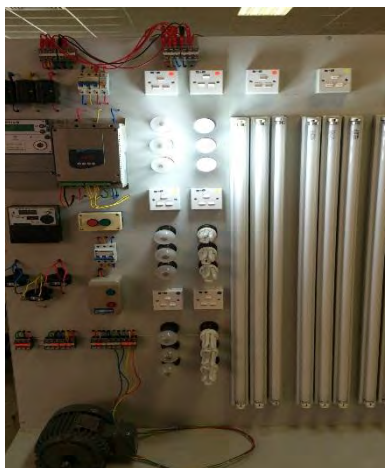


Figure 3.9: CFL Lamp Test

Case 3: Synchronous Motor

The test is repeated for motoring unit whereby three phase synchronous motor is measured by using HSIS as indicated in Figure 3.10. Per phase analysis is conducted with red phase is taken as the reference point. The main concern of this test is to monitor the performance of the system whereby the parameter such as voltage, current, active power, reactive power, apparent power, power factor THD and harmonic source location that produced by the synchronous motor is taken.



Figure 3.10: Synchronous Motor Test

3.5 Project Gantt Chart and Key Milestones

Before the project starts, the planning should be done to ensure the project is developed according to the time given. Table 3.1 shows a Gantt chart of overall planning for this project within 28 weeks. The purpose of this Gantt chart is as a guideline for this project so that the project is structured and organized properly. Two weeks are provided to develop the hardware based on NI USB 6000. Next, four weeks are proposed to develop the software of HSIS using VS2015 along with program testing from Matlab. Testing and troubleshooting is done on Final Year Project 2 includes the verification of connection of HSIS. Requirement of three week for performance testing with different load identification is done. The report writing is conducted along the way of the project process and no fix time is provided.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Simulation Results and Discussion

MATLAB is used to simulate the voltage and current for harmonic distortion based on the FFT method to fulfill the objective. The result must be verified to ensure the stability of the system with different level of harmonic. The coding is constructed based on FFT method where the input signal declared is analyzed in terms of a power spectrum graph. The percentage of harmonic is measured by taking the maximum value of magnitude for each level of harmonic depend on the type of load used.

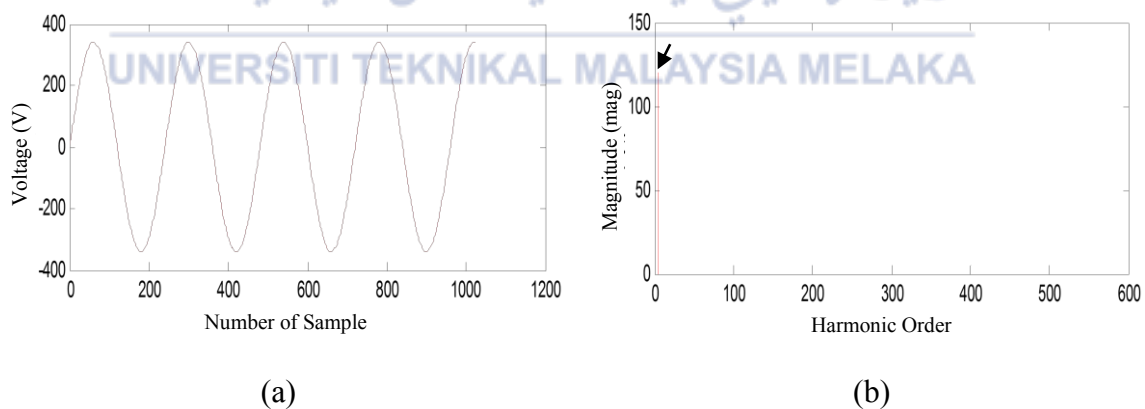


Figure 4.1: No Harmonic Condition (a) Input Waveform (b) Power Spectrum

Figure 4.1 (a) shows a pure sinusoidal waveform for voltage against number of sample in Matlab. For non-harmonic condition, there is no notching occurring at the magnitude of the

400 waveform measured at PCC. Single phase 240VAC source, 50Hz for 1024 samples is taken as reference point of frequency for THD calculation. The signal is analyzed by using the FFT method and each level of harmonic is represented in the power spectrum as shown in Figure 4.1 (b).

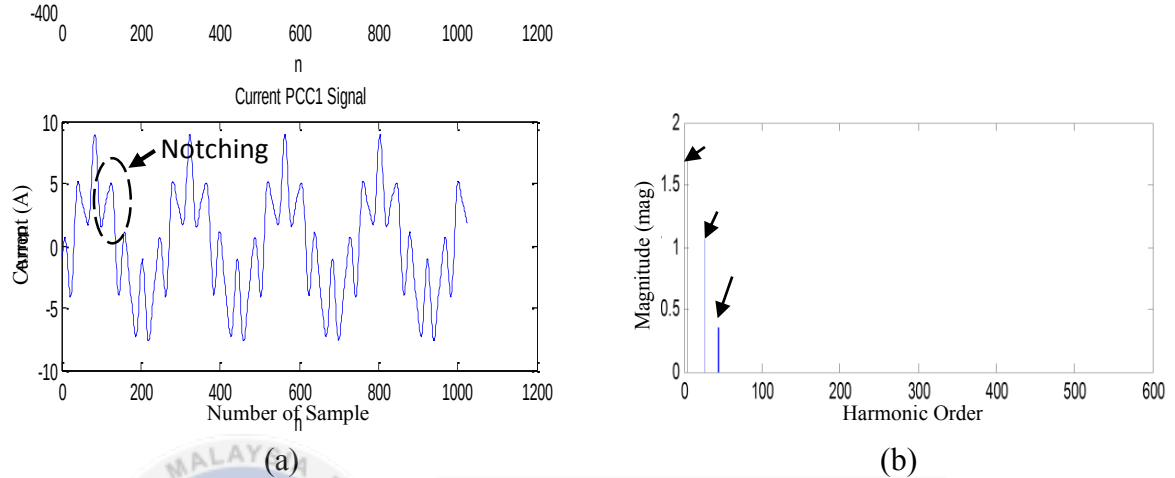


Figure 4.2: Harmonic Condition (a) Input Waveform (b) Power Spectrum

The representation of harmonic waveform for current over the number of samples is as shown in Figure 4.2 (a). The waveform is fully distorted where there is notching present at the magnitude of the waveform. Current harmonic spectrum in Figure 4.2 (b) represents the fundamental frequency component and harmonic components that have been analyzed by using the FFT method. The harmonic components include 300Hz for 6th order of harmonic and 500Hz for 10th harmonic. THD can be determined by taking a ratio of harmonic component magnitude to the fundamental frequency component magnitude.

4.2 Performance Tests and Discussion

The performance of HSIS is analyzed with the results collected from different type of loads such as incandescent lamp, CFL lamp and synchronous motor. Voltage, current, active power, reactive power, apparent power, THD and harmonic source parameters are taken to identify the location of harmonic that can lead harm to the source. Other than that, the results from this test need to be analyzed and compare in terms of the THD level for both voltage and current due to recommendation of IEEE 519-2014. The LED status that indicates the system condition is as shown in Table 4.1 below. Green LED shows that the value of THD_v is below than 5%, while THD_i is less than 10%. For the value of THD_v in between 5% to 8%, yellow LED is shown. If the THD_v value is greater than 8% and THD_i greater than 50%, LED status is in red.

Table 4.1: LED Status for System Condition

THD _v		THD _i	
THD Level Recommendation	LED Status	THD Level Recommendation	LED Status
THD _v < 5%	Green	THD _i < 10%	Green
5% < THD _v < 8%	Yellow	10% < THD _i < 50%	Yellow
THD _v > 8%	Red	THD _i > 50%	Red

Case 1: Incandescent Lamp

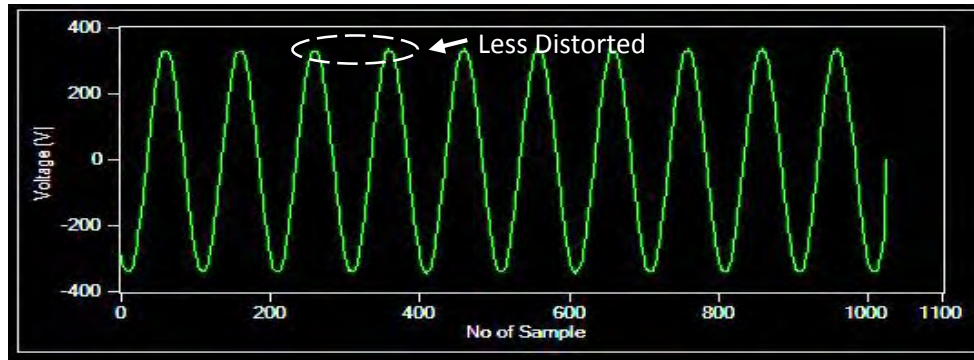
The parameters from the test is tabulated in Table 4.2. The measurement is taken from 1, 2 and 3 units of the lamps for single phase systems. The voltage is seen to be at a constant value ranging from 239.14V to 240.42V while the representation of current for each unit exhibits an ascending progression. Similar to other 4 parameters, namely active power, reactive power, apparent power and power factor values are kept increasing as the load value is added. The THD_v is seem to give almost the same value for every unit of lamps and THD_i has kept descending. Increase use of an incandescent lamp is considered good in reducing the amount of

THDi. However, large amounts of power consumption can cause loss in term of financial due to high amount of current drawn by a load.

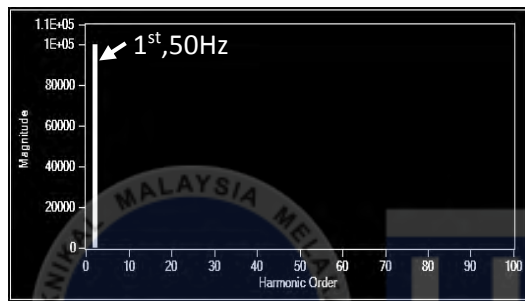
Table 4.2: Results of Incandescent Lamp Test

Parameter	1 Unit	2 Units	3 Units
Voltage (V)	239.14	239.82	240.42
Current (A)	0.15	0.26	0.36
Active Power (kW)	0.02763	0.05110	0.07582
Reactive Power (kVAR)	0.02449	0.03449	0.04273
Apparent Power (kVA)	0.03691	0.06165	0.08703
THDv (%)	1.14	1.14	1.18
THDi (%)	37.39	20.78	14.32
Power Factor	0.75	0.83	0.87

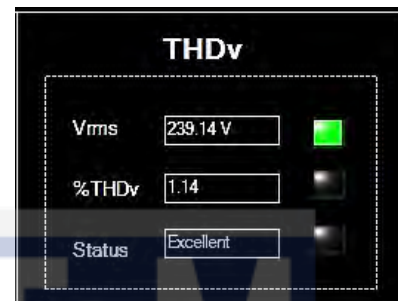
Figure 4.3 (a) shows the waveform of voltage versus number of samples recorded from HSIS GUI. The continuous time waveform for every 1024 samples is taken as reference for harmonic distortion measurement. The waveform shown cannot be assumed to be purely sinusoidal due to THDv present in the system. The fundamental frequency component with the frequency of 50Hz has occurred in the region marked in Figure 4.3 (b). As shown in Figure 4.3 (c), the value for THDv for 1 unit of incandescent lamp indicated 1.14% and the system is stated to be operated under 'Excellent' condition. Ideally, incandescent lamp operates under a high amount of heat because of electromagnetic radiation resulting larger power consumption. The THDv measured is considered low means that the input sinusoidal voltage waveform is less distorted.



(a)



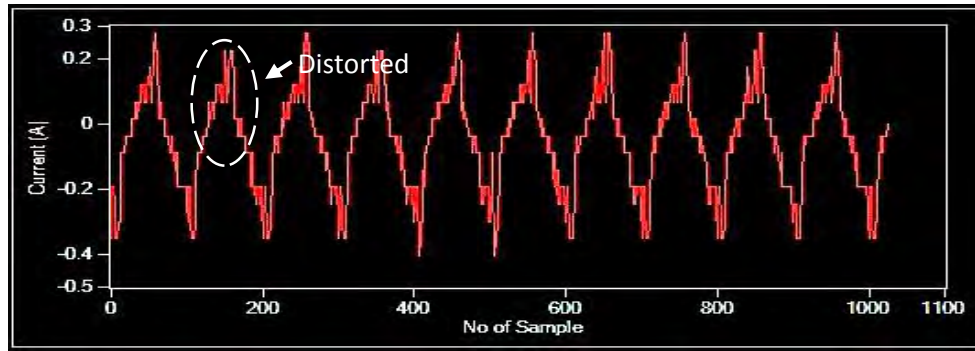
(b)



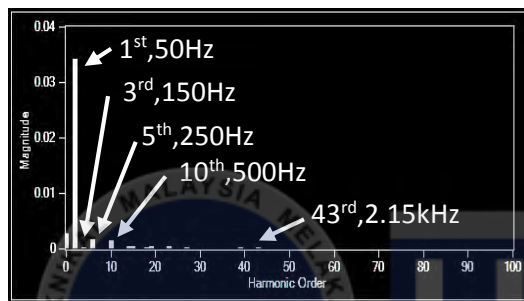
(c)

Figure 4.3: (a) Input Voltage Waveform (b) Power Spectrum (c) THDv Parameter

The results for the current waveform versus a number of samples measured is shown in Figure 4.4 (a). The waveform seems to be distorted and produce non-sinusoidal waveform. Figure 4.4 (b) shows the current power spectrum for both fundamental frequency component and harmonic components. As observed in Figure 4.4 (b), first harmonic order is the highest compared to the other level of harmonic components. The harmonic components measured is from 3rd order for 150Hz to 43rd order for 2.15 kHz. By dividing non-sinusoidal current between fundamental frequency component and harmonic components, the value of THDi can be obtained as indicated in Figure 4.4 (c). The system known to be in 'Caution' condition due to the value of THDi obtained gives 37.39% value in measurement. This condition can be described as normal because the value of THDi is still below the range recommended by IEEE 519-2014, thus indicating the system proposed is indeed efficient. The value of THDi that occur in the source gives a large effect on the input current waveform. Therefore the waveform is considered non-sinusoidal and can lead to damage for the equipments.



(a)



(b)



(c)

Figure 4.4: (a) Input Current Waveform (b) Power Spectrum (c) THDi Parameter

Significantly, harmonic source can be identified by taking the direction of active power flow between positive and negative at PCC. In Figure 4.5, harmonic source is located at customer side where the value of active power measured gives negative sign. Although the value of both THDv and THDi are still below dangerous levels, the location of harmonic can still be identified.

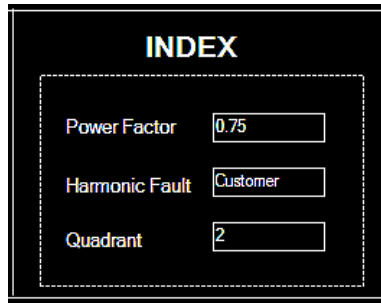


Figure 4.5: GUI for Harmonic Source

Case 2: CFL Lamp

Table 4.3 presents the results of CFL lamp tests for 1, 2 and 3 units of the lamp. The value of voltage of 1 units of CFL lamp indicated 243.8V and keep descending slightly. The value of current, active power, reactive power and apparent eventually increased as the loads increase. There is no large gap between the value of THD_v measured for every unit of lamps and the value of THD_i is above 100%. CFL lamps indicates worst power factor where both 2 units and 3 units of lamps represent 0.44. 3 units of CFL lamp produce higher amounts of THD_i which is 8.49% more than 1 unit of CFL lamp. Increased use of CFL lamp can lead to the worst distortion level.

Table 4.3: Results of CFL Lamp Test

Parameter	1 Unit	2 Units	3 Units
Voltage (V)	243.8	242.95	241.34
Current (A)	0.17	0.29	0.43
Active Power (kW)	0.01901	0.03151	0.04566
Reactive Power (kVAR)	0.03602	0.06365	0.09389
Apparent Power (kVA)	0.04073	0.07102	0.10441
THD _v (%)	1.19	1.2	1.15
THD _i (%)	105.77	113.12	114.26
Power Factor	0.47	0.44	0.44

Figure 4.6 (a) depicts the waveform of voltage versus number of samples recorded by HSIS whereas Figure 4.6 (b) shows the value of THD_v measured for 1 unit of the lamp. The waveform in Figure 4.6 (a) clearly shown there is less distortion occur in the system. The system for voltage is considered ‘Excellent’ based on the percentage of THD_v is only 1.19%. Low level of THD is indicated by green LED as shown. Unexpectedly, results for THD_v is still considered small, although the switching circuit is used in CFL lamp. When the loads are increased, THD_v produced are still below 1.2%.

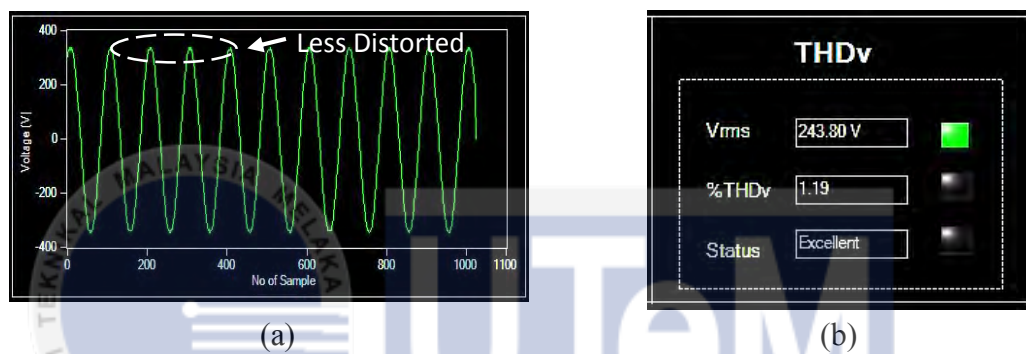
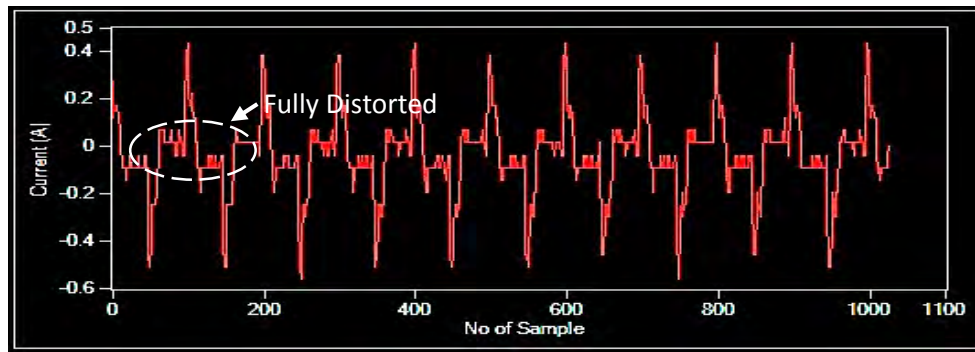
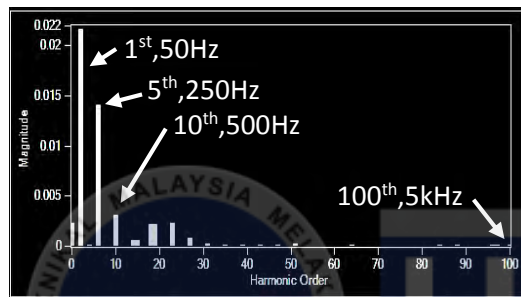


Figure 4.6: (a) Input Voltage Waveform (b) THD_v Parameter

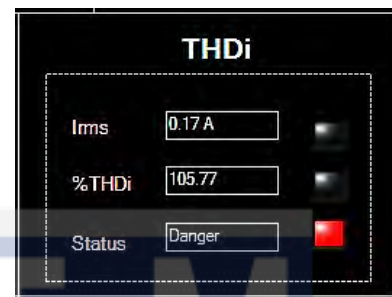
The waveform of current against number of samples measured as shown in Figure 4.7 (a) represents the higher distortion level. In Figure 4.7 (b), current power spectrum indicates that the harmonic components obtain is up to 5kHz that represent by 100th order. Contrarily, the magnitude of harmonic components measured is appears to have expressive enlargement compared to case 1 for 5th and 10th order. Figure 4.7 (c) shows the measurement of THD_i is 105.77%, which indicates the system is under ‘Danger’ condition. If none of an action is taken, the source contains high level of harmonic that may harm other sensitive equipments. For user friendliness, red LED will light up to show the source is fully distorted. THD_i for CFL lamp suffered a significant increase due to the presents of power electronic component used for the lamp operation. The accuracy of HSIS is considered high due to the ability to measure harmonic component up to 100th order. Subsequently, low power factor in a system induced the harmonic. On one side, the energy efficient lamp required less amount of power consumption, but on the other hand, using CFL lamp will increase the distortion level to the waveform.



(a)



(b)



(c)

Figure 4.7: (a) Input Current Waveform (b) Power Spectrum (c) THDi Parameter

Similar to case 1, the harmonic is located at 'Customer' side of the system as illustrated in Figure 4.8. Inductive load fault can be recognized from power flow quadrant located at '2'. From the index status for both case 1 and case 2, the location of harmonic source is still identified for all conditions includes 'Excellent', 'Caution' or 'Danger'.

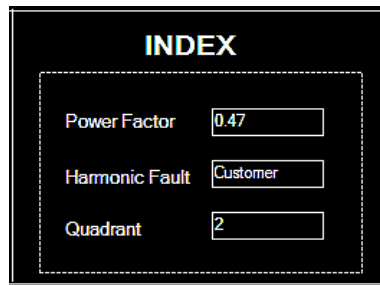


Figure 4.8: GUI for Harmonic Source

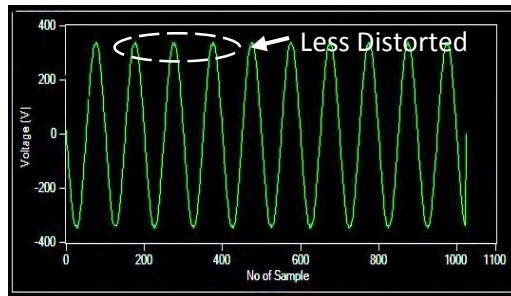
Case 3: Synchronous Motor

The results of the synchronous motor test are summarized in Table 4.4. Every parameter recorded is per phase measurement where red phase is taken as a reference point for PCC. The outcome for voltage measurement is 242.03V and the value of current is 2.02A. Synchronous motor seems to draw the higher amount of power compared to other 2 cases under operating condition which indicates 0.18031kW for active power, 0.45516kVAR for reactive power and 0.48957kVA for apparent power.

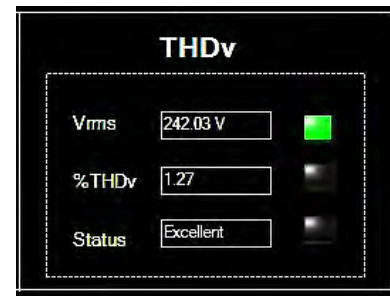
Table 4.4: Results of Synchronous Motor Test

Parameter	1 Unit
Voltage (V)	242.03
Current (A)	2.02
Active Power (kW)	0.18031
Reactive Power (kVAR)	0.45516
Apparent Power (kVA)	0.48957
THDv (%)	1.27
THDi (%)	7.13
Power Factor	0.37

Figure 4.9 (a) implies that the input waveform for voltage is less distorted resulting low percentage of THDv in the source. The value of THDv in Figure 4.9 (b) represents 1.27% and the status is stated to be 'Excellent'. Green LED shows the condition of the source that recommended by the IEEE standard. Motoring unit is considered low in producing the harmonic, but still can be interfered because of the source voltage supply is full of harmonics.



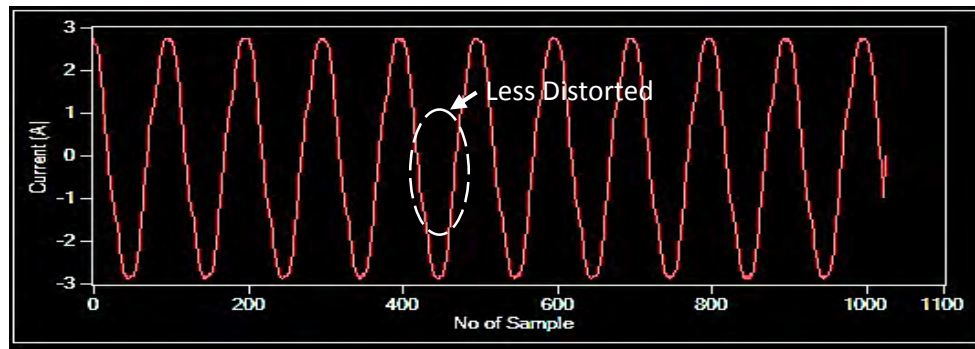
(a)



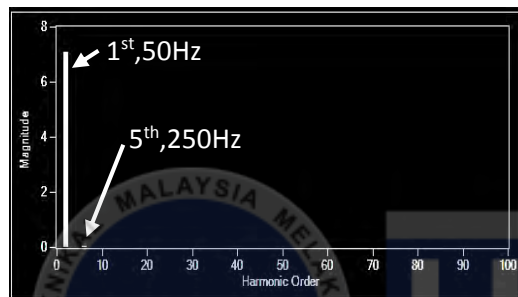
(b)

Figure 4.9: (a) Input Voltage Waveform (b) THDv Parameter

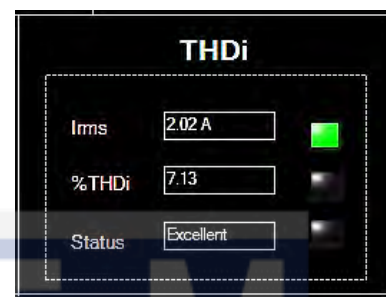
Current versus number of sample waveform for the synchronous motor test is illustrated in Figure 4.10 (a). The waveform is less distorted compared to other cases and the value of THDi as shown in Figure 4.10 (c) is only 7.13%. The current power spectrum in Figure 4.9 (b) shows the harmonic component is only occurring at 250Hz resulting low level of harmonics. The measurement of THDi that less than 8% is considered 'Excellent', so the green LED will light up. Therefore, it can be concluded that harmonic source produce by motoring unit is low. Synchronous motor does not create harmonics when the motor is running at constant speed. Mostly, the 5th order harmonic will occur in motoring unit due to increases impedance during starting condition. Thus, the value of THDi will decays to much lower values when the motor run at invariant speed.



(a)



(b)



(c)

Figure 4.10: (a) Input Current Waveform (b) Power Spectrum (c) THDi Parameter

The location of harmonic for synchronous motor as shown in Figure 4.11 is 'customer'. As discussed earlier, HSIS will identify the harmonic source due to the direction of active power flow. If the harmonic distortion at utility side is lower than customer side, the harmonic source shown below is unchanged.

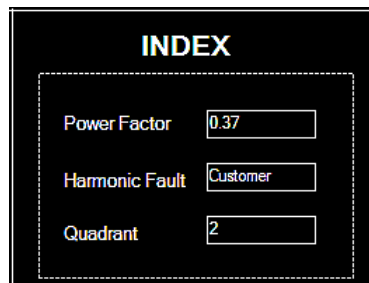


Figure 4.11: GUI for Harmonic Source

4.2.1 Overview of Performance Test Analysis

The graph in Figure 4.12 clearly shows the measurement of THD_v for different type of load. The results of THD_v for incandescent lamp recorded is 1.14%, which is the lowest compared to CFL lamp and synchronous motor. The maximum value of THD_v recorded by HSIS is 1.27% for synchronous motor. This value is still lower in term of harmonic distortion in a source. Based on the data gathered for three different cases, THD_v for 240VAC source is not the main contributor to the harmonic, but still proper monitoring equipment should be placed due to non-expected outcome that can lead to distortion in a supply source. Normally, main contributor for THD_v is caused by a utility side and will affect the supply source. Saturation of transformer and non-ideal sinusoidal waveform produced by generator contain a certain amount of harmonic. Thus, the temperature of the loads will rise and shortened service life.

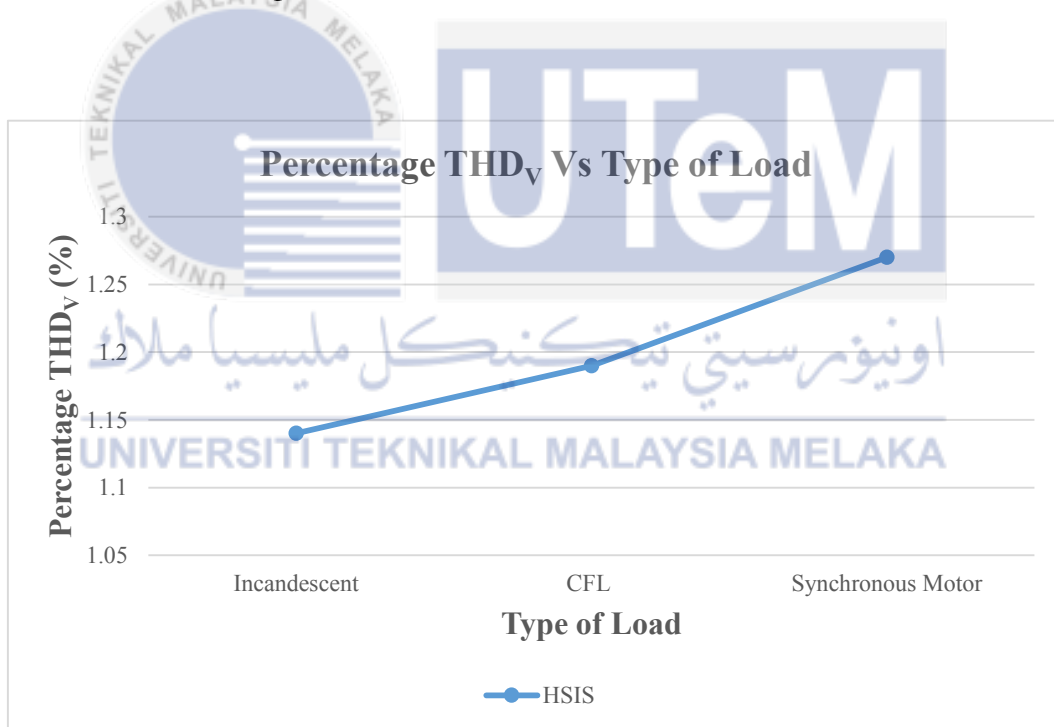


Figure 4.12: Graph of Percentage THD_v versus Type of Load

Graphs for percentage THDi versus type of load is depicted in Figure 4.13. CFL lamp produces a larger amount of harmonic compare to other two. Synchronous motor shows low level of THDi produced for only 7.13%. Second goes to incandescent lamp indicated 37.39% and the highest value that represent by CFL lamp indicates 105.77%. Equipment such as a CFL lamp that use power electronic component can lead to a high distortion level in a source. Incandescent lamp and synchronous are minor harmonic contributor and the value of THD is still below the dangerous range. Power electronic components in CFL lamp cause the harmonic to produce at (2nd, 3rd, 5th, 6th, 8th) order.

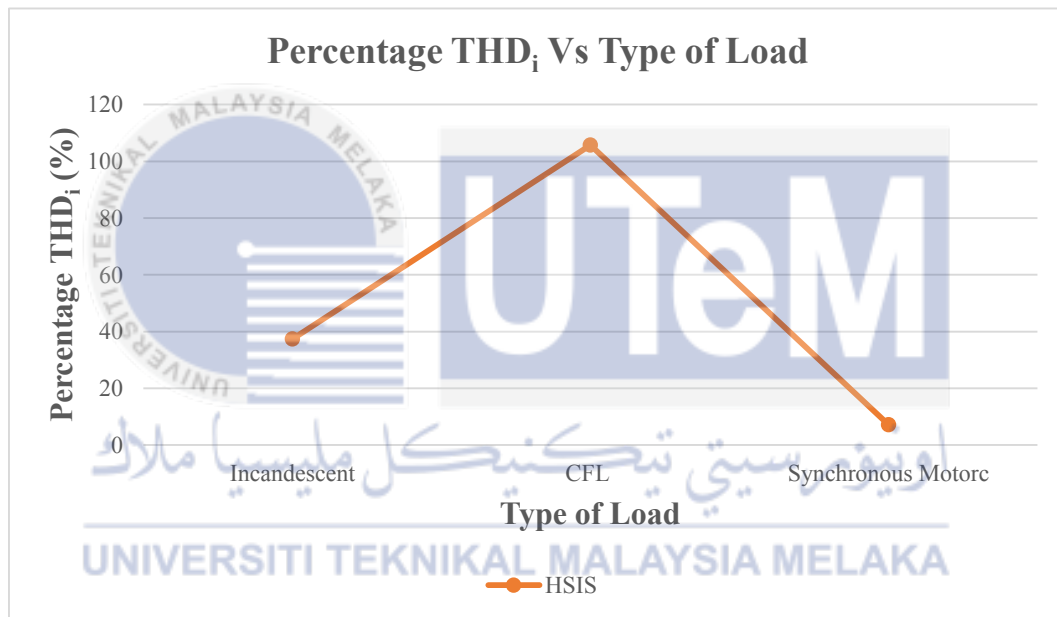


Figure 4.13: Graph of Percentage THDi versus Type of Load

CHAPTER 5

CONCLUSION AND RECCOMENDATION

5.1 Conclusion

It is concluded that the desired objectives are successfully achieved in terms of developing a system to identify the harmonic distortion of single phase 240VAC source supply. The capability of HSIS for monitoring the harmonic source whereby the source detection is between the customer and the utility. The simulation results from MATLAB is verified by simulating the voltage and current based on FFT method. Thus, an output power spectrum is presented in the power spectrum graph for each level of harmonic up to 100th.

Development of HSIS using VS2015 where the analog signal measured by voltage transducer and current transducer is being converted into digital signal using NI USB 6000 DAQ card. The ability to access the different parameters such as voltage (V), current (I), active power (P), reactive power (Q), apparent power (S), power factor (pf), THD and harmonic source for user through designed system GUI allow user to monitor the source condition. The status of the harmonic source can be monitored by HSIS includes 'Excellent', 'Caution' or 'Danger' for the different THD level of the detection based on IEEE 519-2014 standard with user-friendly interface.

The performance of the system is verified by taking different type of loads such as incandescence lamp, CFL lamp and synchronous motor. Likewise HSIS succeeded in identifying the harmonic source located at the source supplied through the test conducted. Based on the value of THD_v and THD_i displayed, proper filter can be designed for safety precaution and the lifetime for certain sensitive devices can be increased.

5.2 Recommendations

For future development, different type of method such as WPT can be implemented on HSIS to improve system stability and efficiency. The accuracy in harmonic distortion measurement can be increased by using WPT compared to FFT method. Improvement in the test results obtained in this project can also be considered. For example, the detection of harmonic source by using direction of active power flow at PCC. Two PCC is an alternative approaches can be used as a reference for better harmonic source detection. Instead of monitoring the harmonic level, recommendation for harmonic reduction using a filter can be applied in this system.



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APPENDIX A

Hardware Development of Harmonic Source Identification System



Figure 1: HSIS Front View

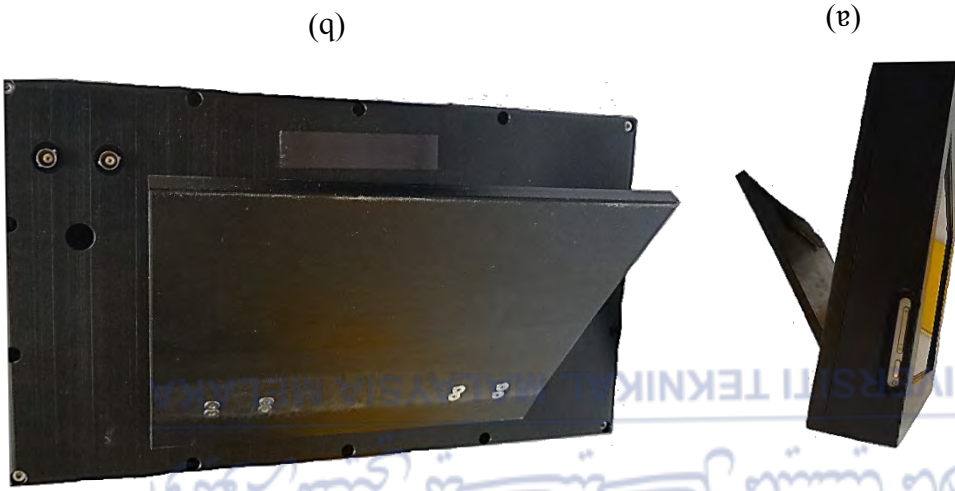


Figure 2: HSIS (a) Side View (b) Back View