DEVELOPMENT OF FAULT DETECTION SYSTEM FOR THREE--PHASE VOLTAGE SOURCE INVERTER (VSI)

Sa’adah Binti Daud

Bachelor of Electrical Engineering (Industrial Power)

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"I hereby declare that I have read through this report entitle "Development of Fault Detection System for Three-phase Voltage Source Inverter (VSI)" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : ……………………………………………

Supervisor's Name : DR. ABDUL RAHIM BIN ABDULLAH

Date : ……………………………………………

DEVELOPMENT OF FAULT DETECTION SYSTEM IN THREE-PHASE VOLTAGE SOURCE INVERTER (VSI)

SA'ADAH BINTI DAUD

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

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitle "*Development of Fault Detection System for Three-phase Voltage Source Inverter (VSI)"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………………………

Name : SA'ADAH BINTI DAUD

Date : ………………………………………………

To my beloved family

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ABSTRACT

Voltage Source Inverter (VSI) is widely used in larger electronics areas, portable devices and in power generation systems. Lately, this device is highly demand in applications using renewable energy such as Solar Photovoltaic (PV) System and Smart Grid System. As time move on, the development of technologies using renewable energy is needed for future demand since this resource helps in protecting the surrounding. In industry, the performance and effects of the devices are such important factors that must be taken into account in order to ensure the continuity of the applications. Normally, the faults occur on the switching device that is very sensitive. A small electric disturbance may cause destruction at high cost and sudden system failure. The development of fault detection system for Voltage Source Inverter (VSI) is to monitor and detect fault at the early stage. This fault can be detected by the behavior of current waveform. This project aims are to analyze the system based on RMS and average current as the parameters, to develop the system with accurate value measurement and to classify the types of fault occurs. Analysis is conducted in order to identify the fault pattern or behavior by using MATLAB. This analysis will first undergo the circuit design process using Simulink, a tool in MATLAB. The simulation will result in the classification of faults' type. The project designed is focused on applications using three-phase VSI. This system is design using Microsoft Visual Basic 2010 and is known as "VSI Fault Detection System" that can detect and classify only two types of fault which are short-circuit fault and open-circuit fault. The use of NI USB-6009 DAQ Card is to capture signal source or data and interface it with Visual Basic 10.0. The monitor can display the parameters reading and waveform which are RMS current and average current. The type of fault is mention in the system once fault is detected. This system provides precaution and early identification of fault thus reduces high maintenance cost and prevent critical fault from happen.

ABSTRAK

Voltan sumber inverter (VSI) digunakan secara meluas dalam sistem penjanaan kuasa, bidang elektronik dan digunakan untuk peranti mudah alih. Penggunaan peranti ini mendapat permintaan yang luas dalam aplikasi yang menggunakan sumber tenaga yang boleh diperbaharui seperti Sistem Solar Photovoltaic (PV) dan sistem Grid Pintar. Justeru itu, penggunaan sumber yang boleh diperbaharui sangat berguna dalam memenuhi keperluan masa depan disamping dapat melindungi alam sekitar. Keberkesanan dan prestasi sesebuah peranti merupakan salah satu faktor penting untuk memastikan kelancaran sesuatu aplikasi atau sistem. Kebiasaannya, kerosakan berlaku pada suis di dalam litar VSI. Suis-suis yang terdedah kepada gangguan kecil elektrik boleh menyebabkan peranti rosak serta kegagalan sistem beroperasi secara tiba-tiba. Penghasilan sistem pengesan gangguan untuk Voltan sumber inverter (VSI) boleh mengesan dan memantau kerosakan pada peringkat awal. Kerosakan ini dapat dikesan melaui bentuk dan corak gelombang arus. Tujuan projek ini adalah untuk menganalisis sistem berdasarkan arus RMS dan arus purata, untuk menghasilkan sistem yang dapat beroperasi dengan tepat dan untuk mengenalpasti jenis kerosakan yang berlaku. Analisis dijalankan untuk mengenal pasti corak gangguan dengan menggunakan MATLAB. Reka bentuk litar dihasilkan dengan menggunakan Simulink dan jenis kerosakan atau kesalahan dapat dikesan dan dikategorikan melalui proses simulasi. Projek ini direka untuk aplikasi *three-phase VSI*. Sistem ini dihasilkan menggunakan Microsoft Visual Basic 2010 dan dikenali sebagai "VSI Fault Detection System" yang boleh mengesan dan mengelaskan dua jenis kerosakan sahaja iaitu litar pintas atau litar terbuka. NI USB-6009 digunakan sebagai perantara yang dapat merakam isyarat signal dan menterjemahkannya kepada bahasa yang difahami oleh Visual Basic 10. Monitor memaparkan bacaan parameter dan corak gelombang iaitu arus RMS (RMS current) dan arus purata (average current). Jenis-jenis kerosakan VSI akan dipaparkan apabila sistem mengesannya. Sistem ini dapat mengurangkan kos penyelenggaraan yang tinggi dan mencegah kerosakan yang lebih kritikal daripada berlaku.

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CHAPTER 1

INTRODUCTION

1.1 Research Background / Motivations

Recently, in industrial processes, automation has lead to comprehensive electromechanical systems. The cost of production and operation are high, thus can cause a rise in planned and unplanned standstill. Standstill or breakdown of a single of dozens of drives usually leads to the complete malfunction of the system. Thus, a short standstill times and high utilization over time are required for an economic operation. In case of inevitable maintenance, only short interruption times are allowed and unplanned faults have to be kept minimize [1]. Therefore, it is necessary to assure the safety and continuous operation for application using this equipment since they can improve the productivity [2].

The most common drive in industry is inverters. Inverters are basically used to transfer power from a DC source power to an AC load, such as an AC motor. In power electronics context, the word "inverter" denotes a power conversion circuits that runs from a DC voltage or current source and converts it into AC voltage or current as illustrated in Figure 1.1. Examples of DC voltage source are battery bank, solar photovoltaic cells and an AC voltage supply that undergo rectification into DC.

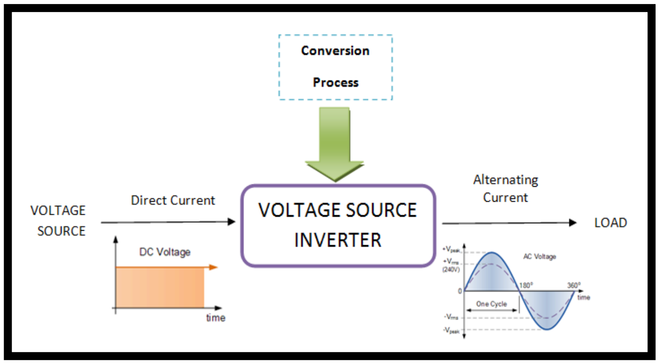


Figure 1.1: Illustration of voltage source inverter

These devices are widely used in power generation systems such as in solar generating systems, electric utility companies that need the conversion of DC power source to AC loads, in power grid and also in High Voltage Direct Current (HVDC) power transmission. They are also widely used in larger electronics systems. Inverter circuits are being applied in industry such as uninterruptable power supply (UPS) unit, electronic frequency charger, and adjustable speed drives (ASD) for ac motors [3]. An example of application using inverters in a grid-connected solar PV system is shown in Figure 1.2 while in HVDC power transmission is shown in Figure 1.3.

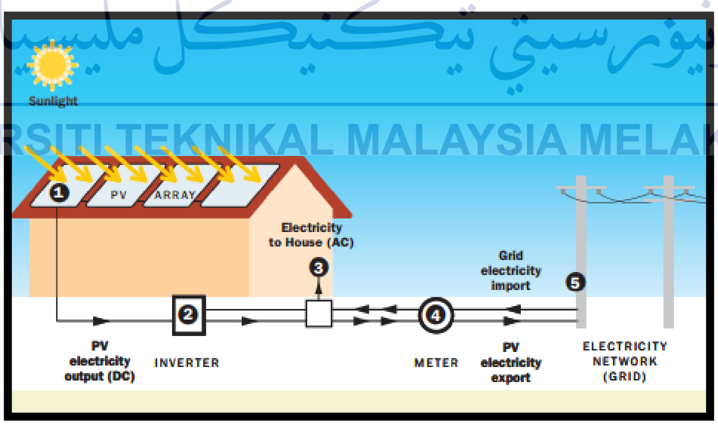


Figure 1.2: A grid-connected solar PV system. [4]

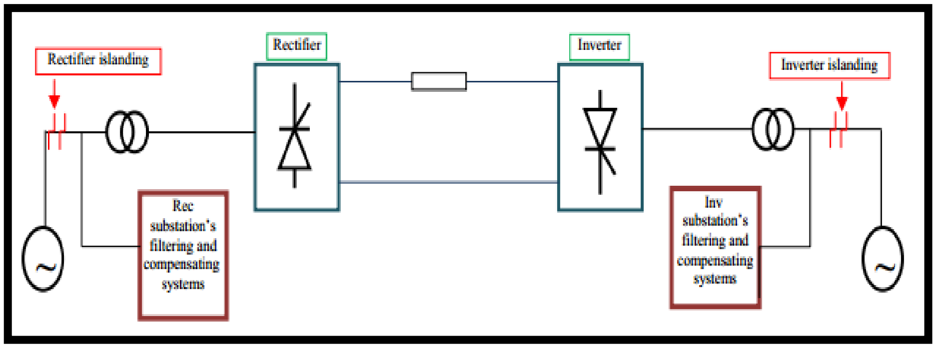


Figure 1.3: A HVDC power transmission. [5]

Apart from solar panels, inverters also play role in transmitting power from batteries and fuel cells. Grid-tied inverters are used in solar electricity system. These inverters have the ability to feed back energy into the utility grid since it produces alternating current with the amplitude and frequency as the energy provided by the utility distribution network. Thus, these help during blackout since they can be shut off. Therefore, inverters play a big role in order to achieve or to make a system to be possibly operated. As time move on, the development of technologies using renewable energy is needed for future generation to fulfill their demand as well as to protect the environment and make it greener. So the inverters are important device and their efficiency must be taken into account.

Inverters are divided into two types which are Current Source Inverter (CSI) and Voltage Source Inverter (VSI). For Voltage Source Inverter (VSI), a DC voltage source is converted to be fed to AC voltage load. Usually, the fault occurs at the switching device of the circuit. There are several types of fault may appear in VSI namely DC link capacitor short-circuit fault, Open-circuit fault, and short-circuit fault [6]. When these faults occur, the associated system need to be stopped for a maintenance schedule. The main idea and information about the waveform behavior of these faults are one of the important key for protection and tolerant control for this equipment. This behavior must be analyzed in order to detect the type of fault occur on the switching device.

This project presents the design and development of fault detection system to detect and measure faults occur in Voltage Source Inverter (VSI) at the early stage. The system can also differentiate between two types of faults that are open-circuit fault and short-circuit fault.

The parameter will be measured are current in RMS value and average value. The data will be recorded and stored efficiently thus, the fault of VSI can be monitored.

1.2 Problem Statements

Most of power electronic devices such as Voltage Source Inverter (VSI) run in an environment requiring rapid speed variation, frequent starting or stopping and constant overloading. This circuit is subject to many failures such as constant abuse of voltage overswings and the surge of over-current. Even though the devices come with protection such as snubber circuits, switching devices are thermally fragile and physically small.

In Voltage Source Inverter (VSI), the faults normally occur on the switching device that is very sensitive. Even a small electric disturbance can lead to the exceeding of thermal rating resulting in rapid destruction. In case of expensive, high power systems, safety critical system and multi-converter integrated automation systems, the presence of faults will result in sudden system failure.

The occurrence of fault such as open-circuit fault and short-circuit fault will affect the efficiency of a system or application. Prevention should be taken first to avoid much worst damage. Thus, to prevent damages at a high cost, the fault occurrence must be monitored earlier. The faults can be detected by the behavior of current waveform. Analysis must be done to ease in identifying and classifying the types of fault occurs at the switches.

1.3 Objectives

The objectives of the proposed project are:

1. To analyze VSI fault detection system based on average current and RMS current using MATLAB Simulink.

2. To develop VSI fault detection system that will provide accurate value for the measurement parameters that is the average value and RMS value of current in each phase of the system using Visual Basic 2010.
3. To classify types of fault occur in VSI whether it is open-circuit or short-circuit faults.

1.4 Scopes

The scopes of this project are:

1. This project detects and classify fault in three-phase VSI whether it is open-circuit fault or short-circuit fault.
2. This system utilizes the Microsoft Visual Basic 2010 software to display the waveform behavior as well as measurement parameters and NI USB-6009 Data Acquisition Card (DAQ card) to capture source signal and interface it with Visual Basic 2010 software.
3. This project detects the occurrence of fault by the average and RMS current value.
4. The system designed display the RMS and average value of current.
5. The current signal used is not more than 50Ampere.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and Basic Principles

2.1.1 Voltage Source Inverter (VSI)

Inverters are designed to provide either single-phase or three-phase output. Usually, three-phase ac is required in larger industrial applications. Inverter is also classified into two that is offline and online inverter. An inverter is called offline inverter or autonomous inverter if it is the only source of the load ac line. If an inverter is a part of the common power supply line, it is known as a line-fed inverter or online inverter. Voltage source inverter (VSI) and current source inverter (CSI) are distinguished in accordance with the circuit arrangement classification.

A Voltage source inverter (VSI) or voltage stiff inverter is the most commonly used type of inverter which forms voltage with properties. The properties are magnitude, frequency and phase. This inverter comes with low internal impedance. Basically, VSI has a capacitor of high capacity connected across the supply source that keeps input voltage to be constant. The switches of VSI are constructed on the base of the full controlled devices such as transistors, GTO thyristor or MCT. If bidirectional current is required, the freewheeling diodes are connected across the switches [7].

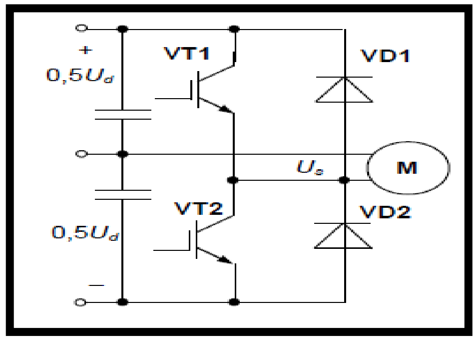


Figure 2.1: Half-bridge Single-phase VSI [7]

Figure 2.1 represent a half-bride midpoint configuration of the single-phase VSI. Usually the role of switches VT1 and VT2 are played by BJTs, IGBTs, MOSFETs, GTO thyristors or force-commutational SCRs. VT1 and VT2 will arrange the DC source with the common terminal to supply the load, M. During the positive half cycle, switch VT1 is turned on which gives the positive supply. On the other hand, during the negative cycle, switch VT2 is turned on and giving negative supply. If VT1 and VT2 are turned on at the same time, both switches will operate and short the DC supply. Freewheeling diode in the circuit that is VD1 and VD2 feed the reactive energy of the load back to supply. The feedback diodes will start conducting when the current and voltage are of opposite polarities [7].

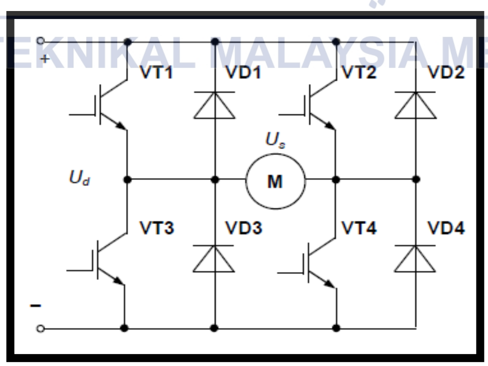


Figure 2.2: Single-phase Full-bridge VSI [7]

Figure 2.2 shows the full-bride configuration of single-phase VSI. Each of its legs includes a pair of transistors with anti-parallel discharge circuits of reverse current built on the freewheeling diodes [7]. Each feedback diodes provide an alternate path for the inductive current, which continues to flow when its switch is turned off. The feedback diodes will return the generated power back to the supply whereas the switches carry the reactive voltage.

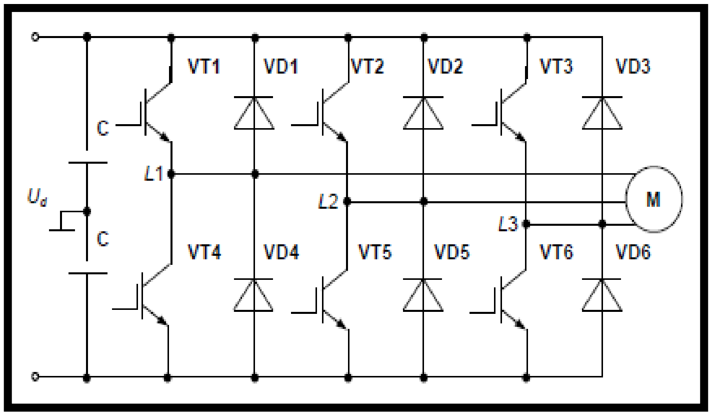


Figure 2.3: Three-phase VSI [7]

A three-phase VSI consists of three equal legs as shown in Figure 2.3. Each leg is for each phase. The output of each leg is depending on the dc supply load and the switching status while the output voltage is independent of the load current magnitude. An example of switching sequence for Figure 2.3 is VT1-VT6-VT2-VT4-VT3-VT5-VT1-VT6…[7] Theoretically, only one switch for each pair will be in closed position, while the other pair will be open. The switching scheme and its voltage output are summarized in Table 2.1.

Table 2.1: Switching scheme of three-phase inverter

VT1	VT2	VT3	VL1	VL2	VL3
0	0	0	0	0	0
0	0	1	0	-Vdc	+Vdc
0	1	0	-Vdc	+Vdc	0
0	1	1	-Vdc	0	-Vdc
1	0	0	+Vdc	0	-Vdc
1	0	1	+Vdc	-Vdc	0
1	1	0	0	+Vdc	-Vdc
1	1	1	0	0	0

Two transistors are together in on state each time span and the producing a rectangle shape output voltage as shown in Figure 2.4. The three legs are phase-shifted by 120°. When VT1 is turned on, point Li is connected to the positive terminal of the DC supply, meanwhile, when VT4 is switched on point L1 is connected to the negative DC supply terminal. The waveform L1, L2 and L3 shown are shifted by 120° [7].

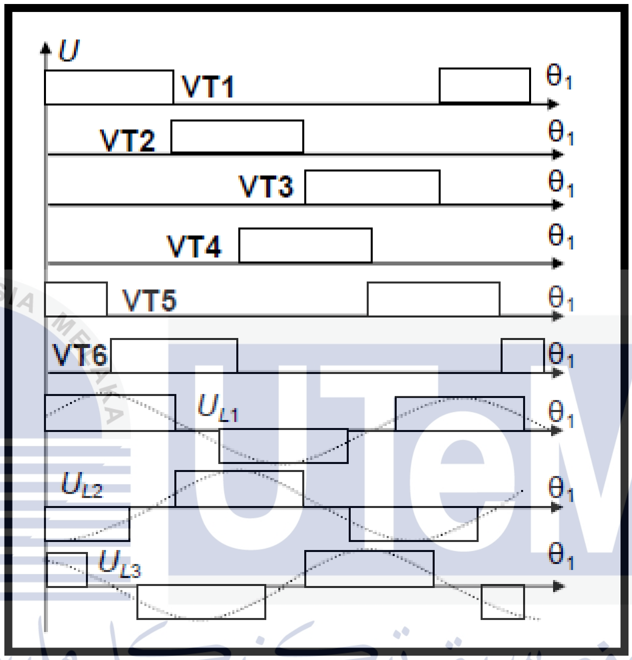


Figure 2.4: Waveform of the switching sequence of three-phase VSI [7]

2.1.2 Fault Detection in VSI

Inverters are widely used in application of ac motor such as air conditioning, uninterruptable power supplies and others. About 38% failures that found in the application of power inverter and mostly the failure come from power switches [8]. The design and performance of inverter can result in a better electrical apparatus usage in life. If failure occurs within the application, the effect to the human life is high cost for maintenance [9]. Thus, knowledge to identify the parameters of fault behavior of an inverter is necessary from the standpoint of improving the system design and protection. There could be a quite high possibility of failure in the switching device due to high electrical [10].

The information of behavior of fault in voltage source inverter is vital for the protection and fault tolerant control [11]. One of the main reason of faults is related to semiconductor [12][13]. Usually, the common faults modes of the power converters is the short circuit. Short circuit detection becomes a feature of several drives ICs. Another main cause of inverter fault is open circuit that led to overstresses on the healthy transistor and pulsating current [14]. To improve the reliability and efficiency, several fault-tolerant strategies are adopted in the inverters.

2.1.3 Visual Basic

Visual Basic created by Microsoft is the third-generation event-driven programming language and integrated development environment (IDE). Visual Basic which derived from BASIC, enables the rapid application development (RAD) of graphical user interface (GUI) applications, Remote Data Objects, ActiveX Data Objects, access to database using Data Access Objects, and creation of ActiveX control and objects. Visual basic is an easy and fast way to create programs for Microsoft Window since it contains a complete set of tools to simplify development. An application can be created by a programmer using the components available in the Visual Basic program itself [15].

The word "visual" refers to the way used to create the user sees that is the Graphical User Interface or GUI. "Basic" refers to Beginner All-purpose Symbolic Instruction Code (BASIC) programming language. This language had been used by more programmers compared to any other language in the history of computing. Basically, a programming language acts as a translator between users and their computers [15].

The use of programming language is to instruct the computer in a simpler and easier way to learn and understand. The instructions given by the language will then be converted to machine language by a program known as compiler. A program written in Visual Basic will have structure that is consisting of modules, procedures and line of code. There are also rules that define the way to categories words, known as programming elements. Programming elements include statements, declarations, methods, operators and keywords. Visual basic is very simple and easy to learn. It is easy to develop graphical user interface (GUI) and to connect to handler functions provided by the applications [15].

2.1.4 Data Acquisition (DAQ)

Data acquisition (DAQ) is a process of sampling signals that measure electrical or physical conditions such as current, voltage, pressure, temperature or sound and resulted by converting these samples into digital numeric values. The resulting samples can be manipulated by a computer. Typically, DAQ system converts analog waveforms into digital values for processing purpose. A DAQ system is comprises of sensor, DAQ measurement hardware and programmable software in computer. Briefly, the sensor will convert the physical parameters to electrical signals. The output sensor can be in many forms such as current, voltage, resistance and others electrical attribute that varies over time [16].

Depending on the sensors' type, some of them may require additional components or circuitry to properly produce an accurate signal that can be read by DAQ device. Thus, DAQ hardware acts as the interface between a computer and electrical signals from sensors. It functions as a device that digitizes incoming analog signals in order to ease the computer to interpret them. Three components of a DAQ device are the signal conditioning circuitry, analog-to-digital converter and computer bus [16].

A signal conditioning circuitry manipulates the electrical signal in such way that meets the requirement form of digital since the output sensor might be noisy or too dangerous to measure directly. This circuitry includes amplification, attenuation, filtering and isolation. Analog-to-Digital converter (ADC) converts the conditioned sensor signals to digital form. An ADC provides a digital representation of an analog signal at an instant in time. It takes periodic samples of the signal at a predefined rate. These samples are transferred to a computer via computer bus. The original signal will then reconstructed from the samples. DAQ device are connected to a computer through a slot or port. The computer bus interfaces them for passing instruction and measured data [16].

DAQ are regulated by software programs developed using a variety of general purpose programming languages such as visual basic, visual C++, Java and LabVIEW. It is used for processing, visualizing and storing measurement data. There are two types of software component in a DAQ system, namely driver software and application software. Application software eases the interaction between the computer and user for obtaining, analyzing and presenting measurement data. It is either a programming environment for building applications with custom functionality or a prebuilt application with predefined functionality. Custom application is often used to perform signal-processing algorithms, automate multiple functions of a DAQ device and display custom user interfaces [16].

Driver software provides application software the ability to connect with a DAQ device. This software eases communication with the DAQ device by abstracting register-level programming and low-level hardware commands. DAQ driver software is typically exposes an application programming interface (API) uses in a programming environment to construct application software.

2.1.5 NI USB- 6009 DAQ Card.

Figure 2.5: NI USB-6009 DAQ card [17]

Providing the basic DAQ functionality, NI USB-6009 as shown in Figure 2.5, can be used for applications such as data logging, academic lab experiments and portable measurement. It is affordable and sophisticated for measurement applications. It is suitable for faster sampling, more accurate measurement, calibration support and higher channel count. USB DAQ modules are compatible with NI application software such as LABVIEW7.x, LabWindows/CV17.x or Measurement Studio7.x, Visual Studion.NET, C/C++ and Visual Basic 6 [17].

2.2 Review of Previous Related Works.

Many researches had been analyzed the methods and techniques in detection and diagnosis of fault in VSI. In article by D.Faito et al. (2009), an eigenvalue or eigenvector 3D current reference method is proposed. In this article, the new fault detection and diagnosis system is proposed for voltage source inverter fed variable speed drives. Variable Frequency Drives (VFDs) normally operate in an environment requiring rapid speed variation, frequent start or stop and constant overloading.

The approach is based on the eigenvalues or eigenvectors of the 3D current referential. It uses an automatic three step algorithm. First and foremost, the output currents of the inverter are measured. It will result in typical patterns that can be used to identify fault. Then the eigenvectors of the 3D current referential will be computed and the proposed algorithm will differentiate if there is any fault and detect the faulty switch. The performance is verified on various types of working conditions. Throughout the research, simulation and experimental results are presented to show the effectiveness of the method [18].

Another simple method was also being approached as in an article written by S.M Jung et al. (2009). This paper proposed a new simple fault detection method for permanent magnet synchronous motor (PMSM). It is stated that in the PMSM drives, the switching device of VSI have the electrical and thermal stresses due to high current and voltages. The high switching frequency by the pulse width modulation (PWM) increase the stresses on switching devices and increase the probability of faulty risk compare to the other components. This technique diagnoses the open-switch damage in VSI. The terminal voltage is the sum of neutral to center voltage and phase voltage. Thus, the fault is identified by comparing the reference voltage with the terminal voltage [6].

The method proposed by V. Fernao Pires, et al. (2010) for the detection and identification is subjected to the transistor open circuit fault. This method uses a 3D representation of the inverter three-phase currents with a pattern recognition algorithm. In their article, the current trajectory mass center is the first step to be obtained. Then, the symmetry of the image projection around the mass center is analyzed. The effectiveness of the proposed method is shown by the simulation results [14].

M.Trabelsi et al. (2012) in their article deals an approach for single and multiple open-circuit fault in VSI fed induction motor. This method is based on the information of the inverter currents output distribution in $\alpha - \beta$ frame combined with additional diagnosis variables which use their mean values. The approach for single and multiple open-circuit faults diagnoses in VSI consists of two steps. Twenty-seven patterns are built with output inverter current in $\alpha - \beta$ axis functions to detect the faulty legs. In this first step, six of the patterns are dedicated to single-fault modes while the others are to multiple open switch modes. Second step is achieved by normalizing the average line currents. The use of normalized current-average values allow the fast identification of the single fault and make it possible to distinguish several multiple-fault cases having the same signature in $\alpha - \beta$ frame [2].

In the detection and diagnosis faults of 3-Phase Inverter System, an article by M.S Khanniche et al. (2001), the detection mechanism is based on a technique of wavelet transform. This method is applied to a three phase VSI feeding a fuzzy logic controlled motor. This approach identifies the transistor base drive open- circuit fault [19]. S.Karimi et al. (2007) highlight the method of detection fault implemented using field programmable gate array (FPGA). In their article, method of minimization the time interval between the fault occurrence and its diagnosis are introduced. Throughout this research, a ‘time criterion’ and ‘voltage criterion’ is demonstrated [20].

A.R Abdullah et al. (2013) used spectrogram method in analyzing Open Switch Faults in VSI. The spectrogram technique is used to represent the signal in time frequency representation (TFR). The detection and identification of open circuit fault in application using

VSI are introduced by time frequency distribution (TFD) [9]. A.R Abdullah et al. (2013) had also proposed spectrogram technique as a method in analyzing short circuit switches fault in another article [21].

A.O Di Tommaso et al. (2012) present a method of fault detection algorithm based on a simple geometrical approach. In this method, the proposed fault detection algorithm is characterized by simplicity, low computational and implementation effort with a consequent enough fast execution, easy control integration with the possibility to use it both in hardware in the loop systems and Microprocessor of common industrial usage. This approach is distinguished by two cases. First, an entire leg of the inverter is disconnected following the fault. This may happen if the fault rapidly propagates to the second leg device, as in the case of a packaged module or for the intervention of fast fuses or other protections. Secondly, an open circuit fault regards a single device and the current in the faulted phase can circulate for a half wave closing its pattern through the freewheeling diodes and in the second device of the leg [22].

J.O Estima et al. (2011) proposed a new method for real-time diagnostics feeding AC machines. In this method, the average absolute values are used as principle quantities in order to formulate the diagnostic variables. These prove to be more robust against the issue of false alarms, carrying information about multiple open-circuit failures [23]. The method is normally being feed to induction motor or permanent magnet synchronous motor (PMSM). The detection is usually focused on the switching device of the VSI in its application.

2.3 Summary of the Review.

There are many methods and techniques presented for the detection of fault in VSI. The previous techniques for the detection are tabulated in Table 2.2.

Table 2.2: Summary of the review

No.	Method or Technique	Proposed by	Descriptions
1	Eigenvalues or eigenvectors 3D current reference	D. Faito, J.F. Martins, V.Fernao Pires and J.Maia	• Eigenvalues analysis able to obtain the main directions of the inverter output currents in a 3D current state space. • Represent in a geometrical interpretation of the principal component space. • Current trajectory method causes time delay for the fault detection.
2	Simple switch open fault	S.M Jung, J.S Park, H.S Kim, H.W Kim and M.J Youn	• Fault is determined by comparing the reference voltage with the terminal voltage. • Obtained by sum of neutral to center voltage and phase voltage. • Use Kirchhoff's voltage law.
3	3D representation of three phase current inverter with a pattern recognition algorithm	V. Fernao Pires, Tito G. Amaral, Duarte Sousa and G.D. Marques	• Obtaining specific pattern using 3D representation method. • Pattern recognition used to identify the faulty switch. • Current trajectory method causes time delay for the fault detection.
4	Information of inverter currents output distribution in $\alpha - \beta$ frame.	M.Trabelsi, M.Boussak, and A.Chaari	• Fault detection concerning on the direct evaluation of the slope value of the output inverter currents' trajectory in $\alpha - \beta$ frame. • Uses the normalized mean values of the line current. • Slope method might not be well suited for IGBT open-circuit fault detection. • Under transient state shows high robustness and fast detection and identification.
5	Wavelet transform	M.S Khanniche and M.R Mamat-Ibrahim	• This method allows the components of a non-stationary signal to be analyzed.

			• Can be constructed for stationary as well as non-stationary signals. • Localized in both time and frequency domain.
6	Spectrogram technique on open circuit fault	A.R Abdullah, N.S Ahmad, E.F Shair and A.Jidin	• Suitable for non-stationary signal depending on the cause of fault. • Used simpler formula. • Presents a 3D plot of signal in magnitude, time and frequency.
7	Spectrogram technique on short circuit fault	A.R Abdullah, N.S Ahmad, A.Jidin, N.Bahari, M.Manap, and M.H Jopri	• Suitable for non-stationary signal depending on the cause of fault. • Used simpler formula. • Presents a 3D plot of signal in magnitude, time and frequency.
8	Fault detection algorithm based on simple geometrical approach	A.O Di Tommaso, F.Genduso, and R.Micceli	• Presented algorithm is a valid and suitable alternative to the actual state of the art in the field of inverter fault detection. • Easy integration in the control system of fault-tolerant inverters.

Based on Table 2.2, the chosen technique for the fault detection is proposed by A.R Abdullah et al. (2013) that are spectrogram technique. This is because other methods use more complex algorithm formula and cause time delay. In detecting fault, method for analyzing non-stationary signals is necessary because when fault occurs, the pattern will change obviously. Thus, wavelet transform and spectrogram are suitable method but for accurate value, spectrogram is more reliable since the analysis represents a 3D plot of signal in magnitude, time and frequency whereas, wavelet transform can only monitor analysis in time and frequency only.

2.4 Discussion on Chosen Technique.

Open switch fault analysis in VSI using spectrogram method highlighted by A.R Abdullah et al. (2013) focuses on open-circuit fault of upper and lower switches. Firstly, the gating signal is identified whether fault behavior presents or absents. The performance of parameter in VSI by using time frequency analysis techniques present a three-dimensional plot of a signal in terms of the signal energy or magnitude with respect to time and frequency. It is focused on spectrogram to perform time frequency for the evaluation performance of the open-circuit fault VSI signal. The performance parameters are based on the spectrogram which is the calculation results of frequency spectrum of windowed frames of a compound signal, the instantaneous RMS voltage, instantaneous RMS fundamental voltage, instantaneous total waveform distortion, total harmonic distortion and total non-harmonic distortion. The performances of the highlighted technique are evaluated using simulations subjected to an induction motor [9].

A similar technique is also used in defining the short-circuit switches fault. This fault can be detected using spectrogram as proposed by A.R Abdullah et al. (2013). The analysis of the short-circuit fault of VSI is analyzed using time frequency distribution (TFD). TFD represents current signal of VSI in time frequency representation (TFR). TFR provides temporary and spectrum information signal. As being approached by open-circuit fault technique, the gating signal and the fault behavior is being clearly determined before estimating parameters of the signal. The performance parameter are based on the instantaneous RMS current, instantaneous RMS Fundamental current, total waveform distortion, total harmonic and non-harmonic distortion and also the instantaneous average current. The performances of the highlighted technique are evaluated using simulations subjected to a three-phase induction motor [21].

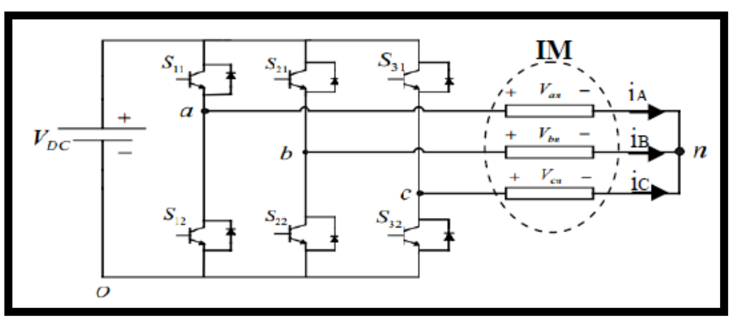


Figure 2.6: VSI three-phase ac drive structure [21].

Figure 2.6 shows the standard structure of three-phase VSI structure. The circuit consists of a classical three-leg inverter. A suitable gate voltage must be applied to drive transistor into the saturation mode for low on-state voltage. The gate drive circuit that generates control voltage should be applied between the gate and source terminal. A gating signal of the inverter in an ideal case is represented in Figure 2.7. In the switching functions, the phase is represented by "j" where j= {a, b, c} and variable "p" and "n" represents upper and lower phase component. Usually in application inverter, the occurrence of fault is in one of the power switches (S_{11} to S_{32}). The fault occurs will be detected and the faulty leg will be isolated. The switch is closed whenever current flow through the anti-parallel diode (D_1 to D_6) and open when in an ideal case showing the signal in Figure 2.4.2. The status of the switch are represent by the term "0" when it is opened, and "1" when it is closed.

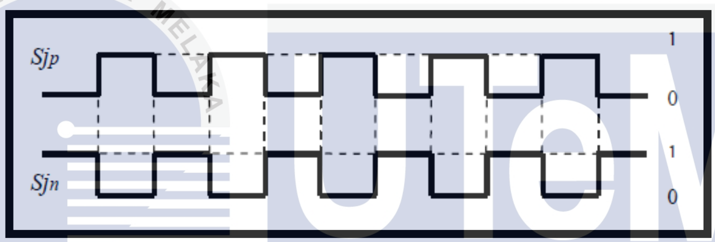


Figure 2.7: An ideal gating signal [21]

In VSI, open-circuit faults make the phase current to be zero either for positive or negative half-cycle. It also depends on the location of the fault occurrence whether at the upper or lower switch. This type of fault is represents in Figure 2.8 below. From the gating signal, the fault occurs in lower switch S_{12}. The short-circuit fault occurred when both the upper switch and lower switch is closed at the same time. Figure 2.9 shows the example's signal of short-circuit fault.

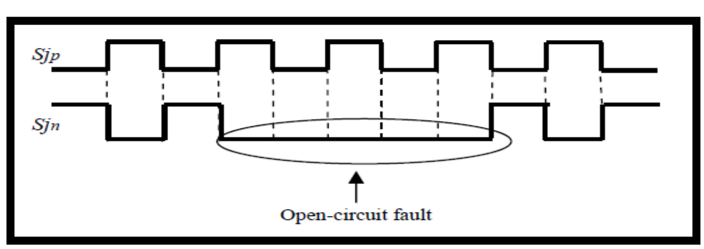


Figure 2.8: Open circuit fault [9]

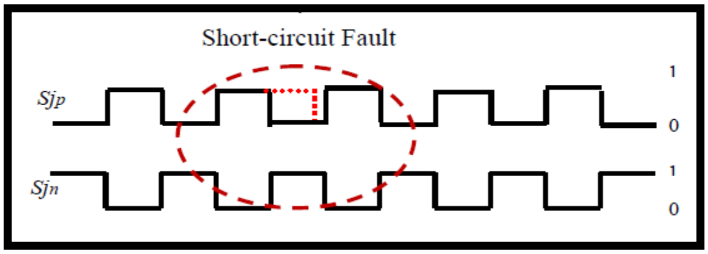


Figure 2.9: Short circuit fault [21]

The formulas needed for fault analysis are stated in equation 2.1:

1) Squared magnitude of the Short Time Fourier Transform (STFT)

$$s(t,f) = \left|\int_{-\infty}^{\infty} x(\tau)w(\tau - t)e^{-j2\pi ft}\, d\tau\right|^2 \quad (2.1)$$

$x(\tau)$= input signal

$w(t)$=window function

Hanning window is used since it is useful for noise measurement where a better frequency resolution is produced than other windows' function. It is also used in digital signal processing in order to select a subset of a series of samples in order to perform a Fourier transform or other calculations. Furthermore, Hanning window is very low aliasing and the tradeoff is slightly decrease resolution (widening of the main lobe). The formula of instantaneous RMS and average currents to measure the parameters are shown in equation 2.2 and equation 2.3.

2) Instantaneous RMS current

$$I_{RMS}(t) = \sqrt{2\int_{0}^{fmax} S(t,f)df} \quad (2.2)$$

$s(t,f)$ = TFR of signal

f_{max} = maximum frequency of interest

3) Instantaneous Average Current

$$I_{ave}(t) = \frac{1}{T}\int_{0}^{T} x(\tau)w(\tau - t)d\tau \qquad (2.3)$$

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Proposed System

The system is designed to measure current respectively. Current transducer will convert its signal to the input value of DAQ card. In this system, NI USB 6009 DAQ card is being used. The signal will be captured by DAQ card and will be sent to the monitor. The operating input of NI USB 6009 is 5V with 50mA. This equipment can measure signals and convert the results into data or signal that can be manipulated using Visual Basic 2010. Figure 3.1 shows the illustration of the project while the block diagram is shown in Figure 3.2

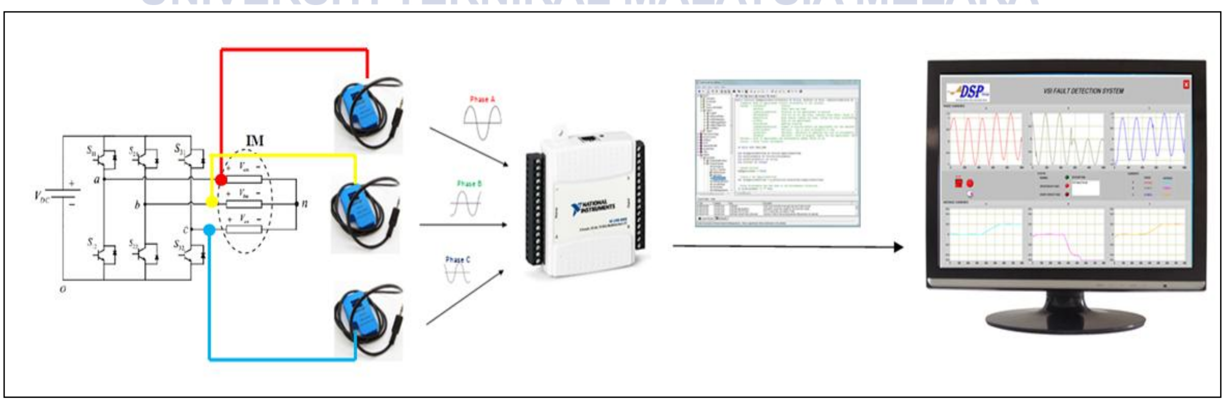


Figure 3.1: Illustration of the project

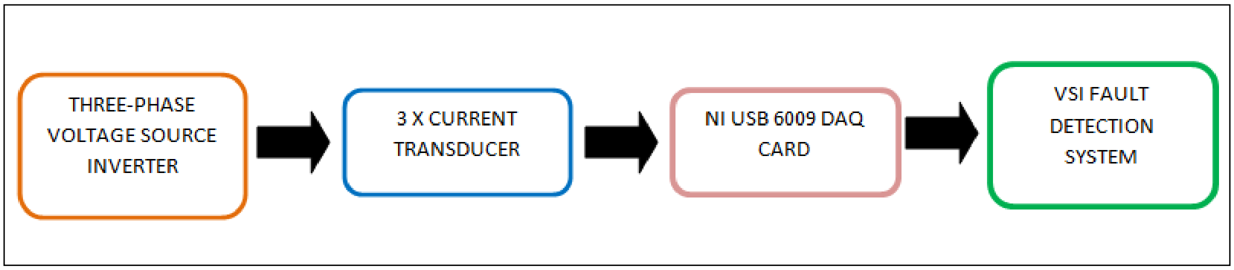


Figure 3.2: Block diagram of the project

3.2 Flowchart of Research Methodology

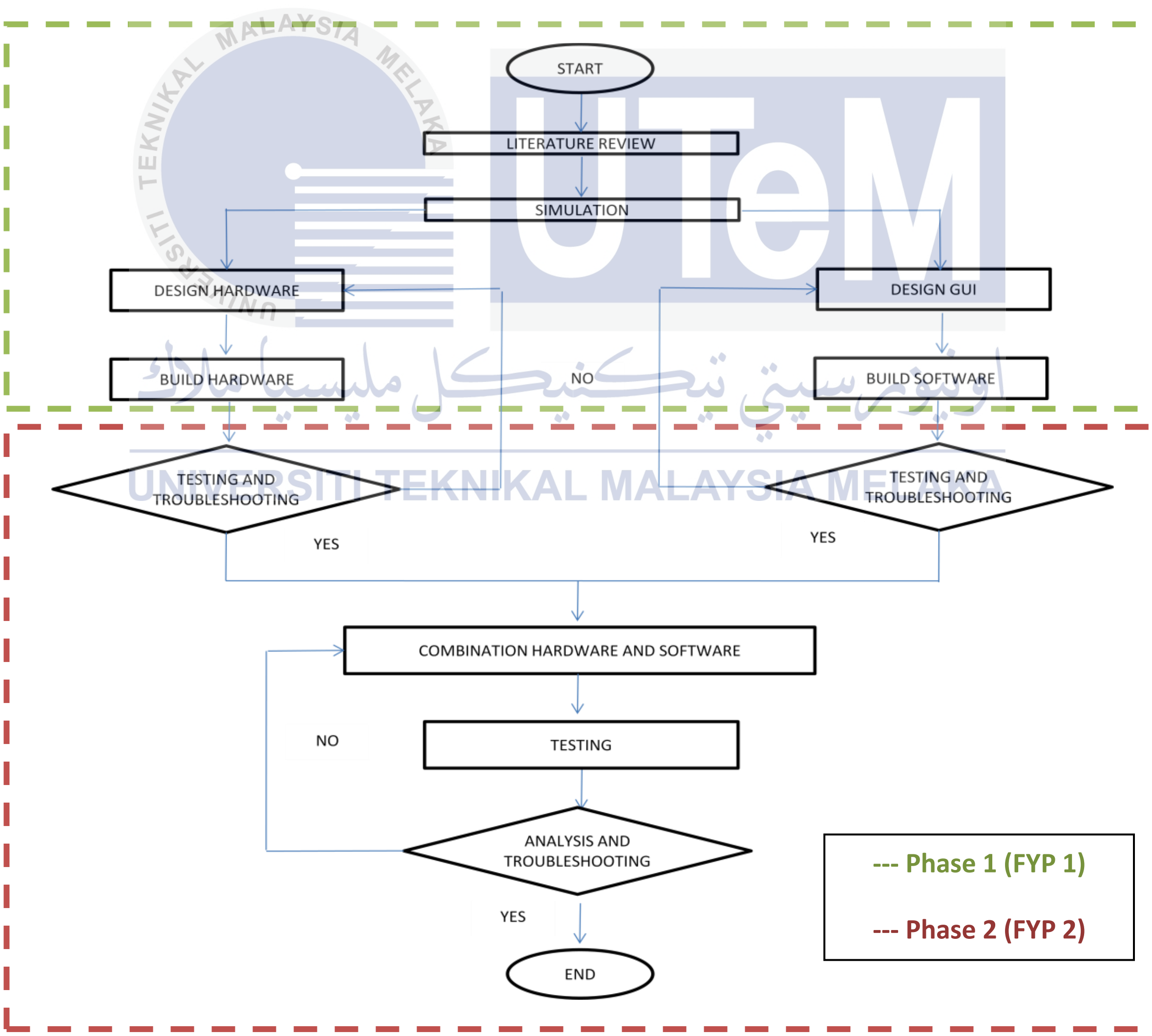


Figure 3.3: Flowchart of research methodology

The methodology of this project is shown in Figure 3.3. This project is divided into two parts that are hardware and software. Firstly, this project is started with literature review that gives idea and better understanding about the system need to be developed. In order to complete the first stage, researches have been done through internet, journals, articles and its relation to the system is analyzed. The next step is simulation using MATLAB Simulink in order to design and analyze the fault behavior.

Then, the project is proceeds with designing the program of fault detection system using Visual Basic 2010 software. The process of designing the program is the part of this project that will produced the output and measures the parameters values of the system. The software must be suitable with the implementation that will be communicated with the hardware.

At the same time, the hardware development is started by designing the actual system. The hardware design are created and modified regarding the desired system. The components include are NI USB-6009 DAQ Card and three current transducers. The designed system for every implementation stages of hardware and software will undergo testing and troubleshooting to ensure the achievement of this project.

After the above stages have been achieved, the following task is to ensure that the combination between hardware and software will fulfill all the specification and achieve the project objectives and scopes. The resulted data must be relevant with the system designed. The last stage is carrying out testing and troubleshooting of the interfacing between hardware and software. This stage is to ensure that the system works perfectly.

3.2.1 Literature Review

Spectrogram technique or also known as time-frequency analysis technique as proposed by A.R Abdullah et al. (2013) is used to analyze the faults signal in time-frequency representation (TFR). TFR consists of the magnitude of signal with respect to time and frequency. As being mentioned by the equation 2.1 in chapter 2, the spectrogram formula is squared of Short Time Fourier Transform (STFT). From the equation, $x(\tau)$ represent the input signals while w(t) is the window function. For this technique, Hanning window is used to perform the analysis. To measure the parameters such as RMS and average current, equation 2.2 and equation 2.3 will be used. Spectrogram is reliable since the analysis represents a 3D plot of signal in magnitude, time and frequency which is more accurate.

3.2.2 Simulation using MATLAB Simulink

Fault detection for VSI is simulated using MATLAB Simulink software, a high-level language and interactive environment for visualization, numerical computation and programming. Developed by MathWorks, this software enables analysis of data, create models, matrix manipulations, plotting of functions, development and implementation of algorithms. Simulink, a programming tool in MATLAB is a data flow graphical programming language for modeling, analyzing and simulating multi-domain dynamic systems [24].

A circuit consists of three-phase inverter connected to an induction motor, pulse width modulation (PWM) as shown in Figure 2.6 in Chapter 2, equipped with fault generation is designed and modeled using Simulink. Using spectrogram technique, the model is designed as presented in Figure 3.1. Three-phase inverter switches are controlled in pairs which are S_{11} and S_{12}, S_{21} and S_{22}, and S_{31} and S_{32}. In the operation, only one switch will open for each pair. The voltage at the output will be +Vdc, -Vdc or zero depending on the switching scheme as shown in Table 2.1 in previous chapter.

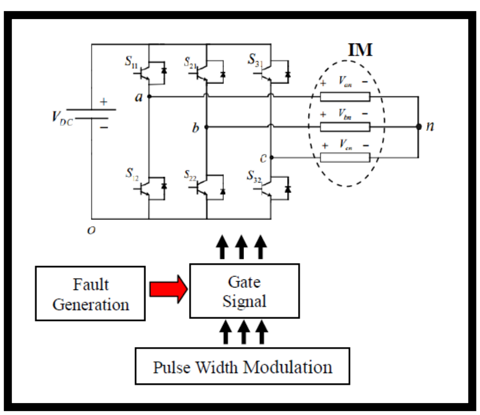


Figure 3.4: Model of VSI switches [21]

Triangular waveform establishes the switching frequency of the three-phase inverter. In this analysis, the switching scheme is controlled by the comparison of PWM and sinusoidal control which is setting by the desired fundamental frequency of the inverter output. The fault is analyzed using equation 2.1 using hanning function build in MATLAB Simulink. Short-circuit fault and open-circuit fault are analyzed for upper and lower switch. The behavior and the pattern of fault current for short-circuit and open-circuit is identified and determined.

MATLAB enable faster analysis and quick development of new algorithms, while Simulink provide accurate system-level multi-domain analysis. This software ensures a better performance of the entire designed system (mathwork). Moreover, it is suitable for real-time implementation thus making it reliable to be used in detecting fault since accurate result can be obtained [25].

3.2.3 Implementation of Microsoft Visual Basic 2010 Software.

The system designed is implemented with Microsoft Visual Basic 2010 to display the pattern of waveforms as well as RMS and average current value as the measurement parameters in GUI form. Visual Basic (VB) is chosen since the structure of the Basic programming language is simpler and easier. Since VB is an event driven, it is easy to program and write logic to the respective events. It is built in with controls and container interface and the executions of code are based on user actions. Therefore, it helps user to trace their coding problem unlike other programming software that need sequential of tracking code from the beginning to the end of source [26].

VB is user friendly and interactive because there is only a few complain about its user friendliness. VB is provided with various window sections like Immediate Window and Watch Window to help in programming, testing and debugging during the entire phase of development. VB can handle software development in speedy manner as it consists of ready-made controls, user friendly IDE, tools and utilities to crate project in less timeframe. Furthermore, any pending issues can be analyze and resolve very quickly [27]. The advantages of VB are illustrated in Figure 3.5.

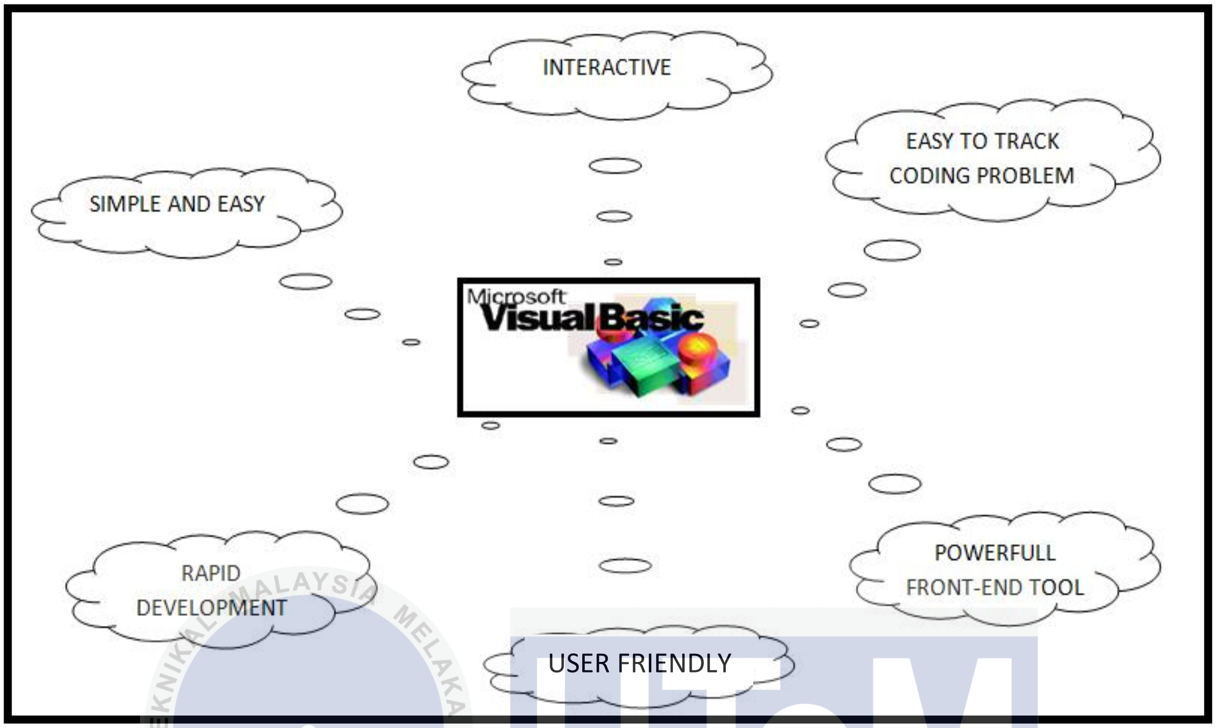


Figure 3.5: Advantages of Visual Basic

VB comes with many versions such as Visual Basic.NET (2002) also known as VB7.0, Visual Basic.NET 2003 (VB 7.1), Visual Basic 2005 (VB 8.0), Visual Basic 2008 (VB 9.0), Visual Basic 2010 (VB 10.0) and Visual Basic 2012 (VB 11.0). These VB versions are the upgrade version of VB6. The basic syntax of the language has not change much but there are new additions to support new features. The data type has been doubled in length from 16 bits to 32 bits, and the Long data type is double to 32 bits to 64 bits. For this project, VB 10.0 is being implemented. VB 10.0 is more time-saving that help developers done with fewer lines of code. This version is the merged of VB and C# language which enables auto-implemented properties and collection initializers. This feature is not included in VB before. The main point for the usage of VB 10.0 is fewer line codes since a lot of tedious coding will be done by the compiler instead. Figure 3.6 and Figure 3.7 shows the VB 10.0 Logo and it workspace.

Figure 3.6: Visual Basic 2010 logo [27]

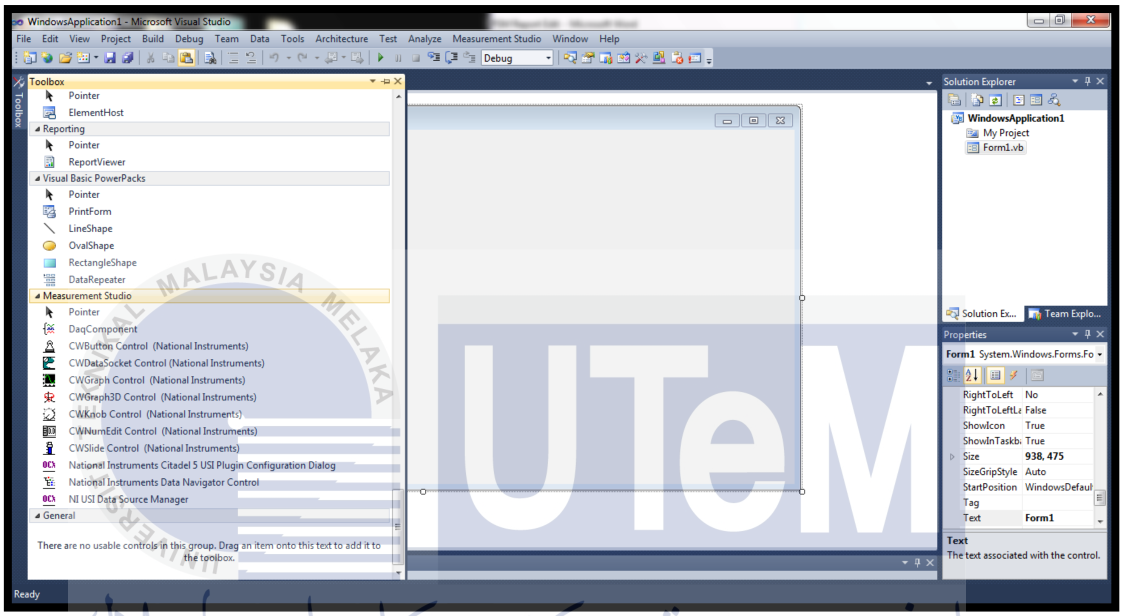


Figure 3.7: Visual Basic 2010 workspace

In designing the GUI, all parameters need to determine the fault currents' types must be included. The system is designed to display three-phase current inverter waveform, that shows the pattern of normal and during both short-circuit and open-circuit fault occur. The system also designed to display the value of RMS and average current value. The status of the current also must be shown to users whether it is normal or facing some faults. Therefore, the fault can be detected and monitored.

3.2.4 Hardware Implementation.

The system designed to have three input of current transducer. The first current transducer is connected to pin AI 0+ and AI 0- , the second current transducer is connected to pin AI 1+ and AI 1- and the third will be connected to pin AI 2+ and AI 2- in NI USB-6009. The pin assignment of NI USB-6009 is shown in Figure 3.8 and the descriptions of each pin are tabulated in Table 3.1. The three current transducers will be connected isolate for differential measurement. In other word, the signal is pairs for each current transducer. This device can receive up to 8 analog inputs for single-ended measurement by using eight channels AI (0 to 7) and grounded the signals at GND pin. The datasheet for NI USB-6009 is attached in appendices.

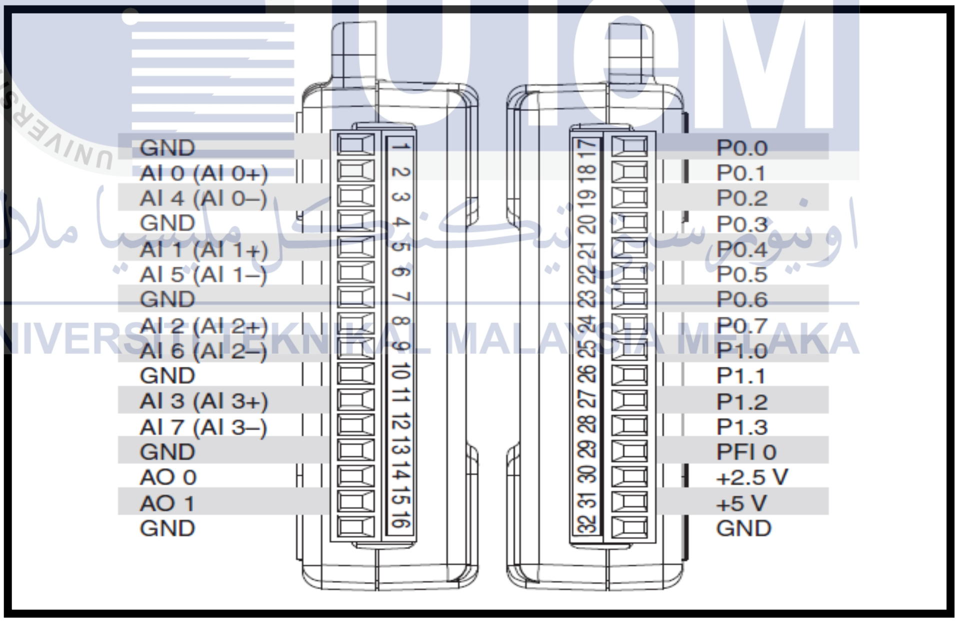


Figure 3.8: NI USB-6009 pinout [28]

Table 3.1: Pin descriptions [28]

Signal Name	Reference	Direction	Description
GND	-	-	The reference point for : - single-ended analog input measurements - analog output voltages -digital signals - +5VDC supply - +2.5 VDC at the I/O connector - Bias current return point for differential mode measurements.
AI <0…7>	Varies	Input	Analog input channels 0 to 7 - Single-ended measurements: each signal is an analog input voltage channel. - differential measurement: positive and negative inputs pair; AI<0,4>, AI<1,5>, AI<2,6>, AI<3,7>
AO<0…1>	GND	Output	Analog output channels o and 1
PO<0…7>	GND	Input or Output	Port 0 Digital I/O channels 0 to 7
P1<0…3>	GND	Input or Output	Port 1 Digital I/O channels 0 to 3
PFI 0	GND	Input	Configurable as either a digital trigger or an event counter input.
+2.5 V	GND	Output	+2.5 V external reference
+5 V	GND	Output	+5 V Power supply

The current transducer will be used in accomplishing this project is SCT013, 100A:50mA Non invasive AC current sensor split core current transformer by YHDC as shown in Figure 3.9. This current transducer is based on the magnetic transformer working principle and suitable for power grid, power energy measurement, or measuring real-time domestic appliances. The datasheet for this product is attached in appendices. Other applications is in measuring current, monitoring and protection of AC motor, air compressor and lighting equipment. For this project, the current transducer is suitable since it act as clamp meter that can be used for other applications using inverter. Thus, the system designed can monitor and detect fault in many inverter applications. [29].

Figure 3.9: SCT013, 100A:50mA current sensor [29]

The specifications are:

- Non-linearity = ±3%
- Turn Ratio = 100A:50mA
- Resistance Grade= Grade B
- Work Temperature= -25^{o} C to +70^{o} C
- Dielectric Strength (between shell and output) = 1000 V AC/1min 5mA
- Leading wire in Length = 1m
- Open size = 13mm X 13mm
- Input Current (100A AC Version) = 0 to 100AC / Output Mode = 0 to 5mA
- Input Current (30 AC Version) = 0 to 30A AC / Output Mode = 0 to 1V

Figure 3.10 shows the schematic diagram of current transducer. From the diagram, transient-voltage suppressor (TVS) diode is used as a protection of the transducer from voltage spikes induced in wires. These diagrams will guide the connection and wiring process of the system thus ensuring the system works as planned. The design of the hardware is presented in Chapter 4.

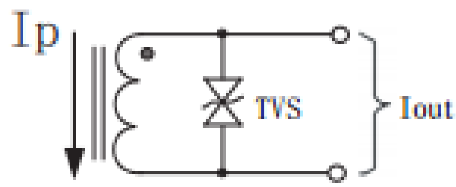


Figure 3.10: SCT013, 100A:50mA schematic diagram [29]

3.2.5 Combination of Hardware and Software

The last division of the project is the combination of hardware and software. Signal or data from three current transducers will be captured and recorded by NI USB-6009 DAQ Card. The DAQ Card will interface with GUI in VB 10.0 to display the signals. The interfacing process will be enabled by the code programmed in VB 10.0 in order for the software to recognize and analyze the hardware.

3.2.6 Testing and Troubleshooting

In order to determine the reliability of the system, a performance testing must be conducted. The system's performance is analyzed by the applications of inverter in laboratory. This test includes the use of the MOSFET three-phase inverter. The inverter will be injected by direct current (D.C) power supply range from zero to 240V. The circuit is connected as shown in Figure 3.11. The current waveform produce by the inverter is monitored by oscilloscope and the classifications fault is determined by the fault detection system designed. The test is conducted in three conditions which are no fault condition, short circuit fault condition and open-circuit fault condition. The fault is created at upper or lower switch of an inverter phase or leg.

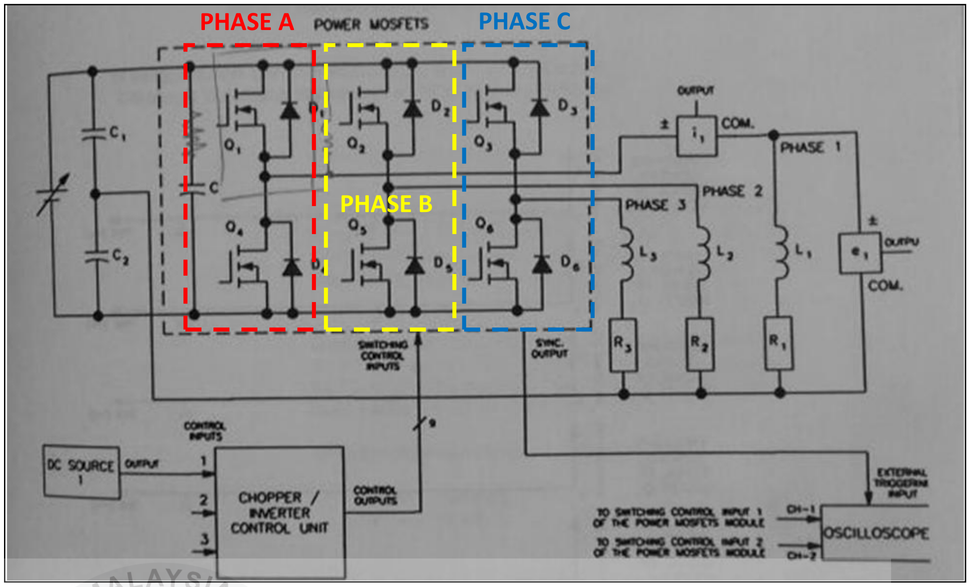


Figure 3.11: Inverter circuit connection

3.3 Project Milestone.

Table 3.2: Project milestone

No.	Milestone	Date
1	Completion of Software Development	March 2014
2	Completion of Hardware Development	March 2014
3	Completion of Combination of Hardware and Software Development	April 2014
4	Completion of Field Testing	May 2014

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Simulation using MATLAB Simulink

The simulation is conducted to identify and analyze the behavior of fault pattern as well as identifying the parameters graph which are RMS current and average current. Figure 4.1 shows the design of three-phase induction motor using Simulink.

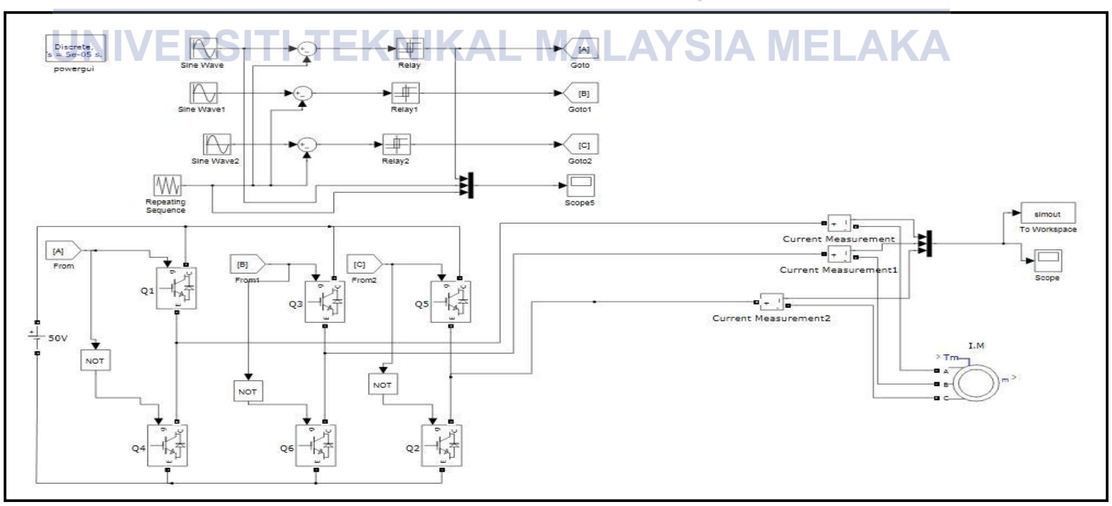


Figure 4.1: Designed circuit using Simulink

The DC voltage input for the designed circuit is 50V, the sampling time use is 50µs and fundamental frequency is 60 Hz. Figure 4.2 is the output waveform for normal three-phase VSI that had been created in the circuit. The output waveform is produced by the scope connected to the circuit when running or start debugging the simulation. The red signal represents Phase A, green signal represents Phase B and blue signal is Phase C.

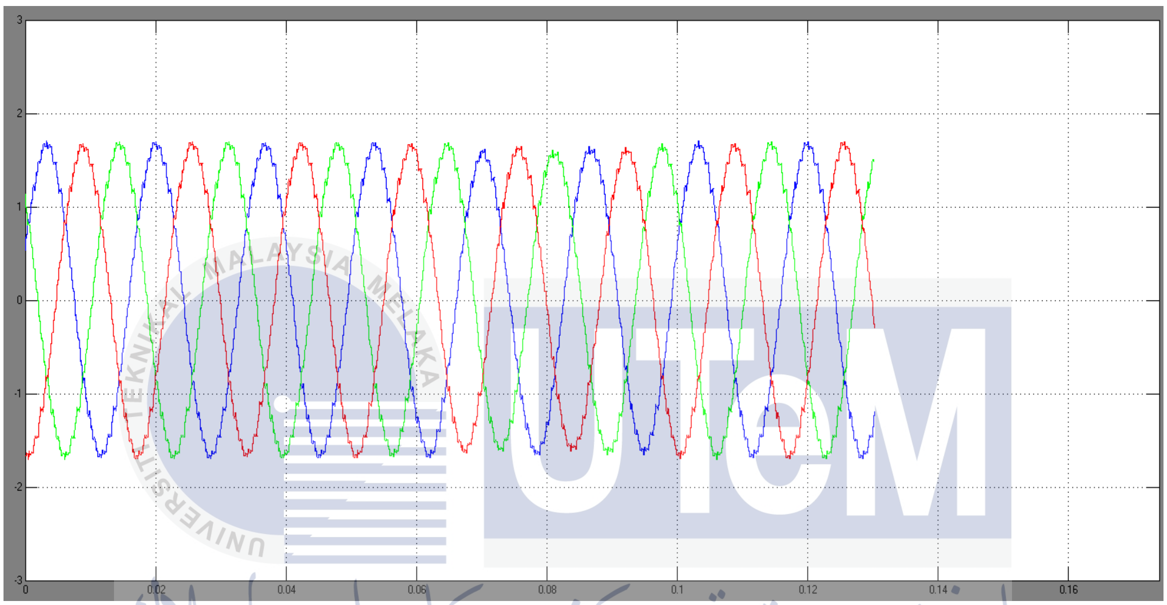


Figure 4.2: Three-phase VSI Waveform during Normal Condition

Fault generation is produced in the circuit by the aid of gating signal. The gating signal for open-circuit fault and short-circuit fault is shown in Figure 2.7 and Figure 2.8 in the second chapter. The output current of three-phase VSI for short-circuit fault is presented in Figure 4.3, Figure 4.4 and Figure 4.5. These figures show the fault signal for each phase for both upper and lower switch case. The magnitude of the fault signal increases or decreases from 0.2s to 0.3s for all phases.

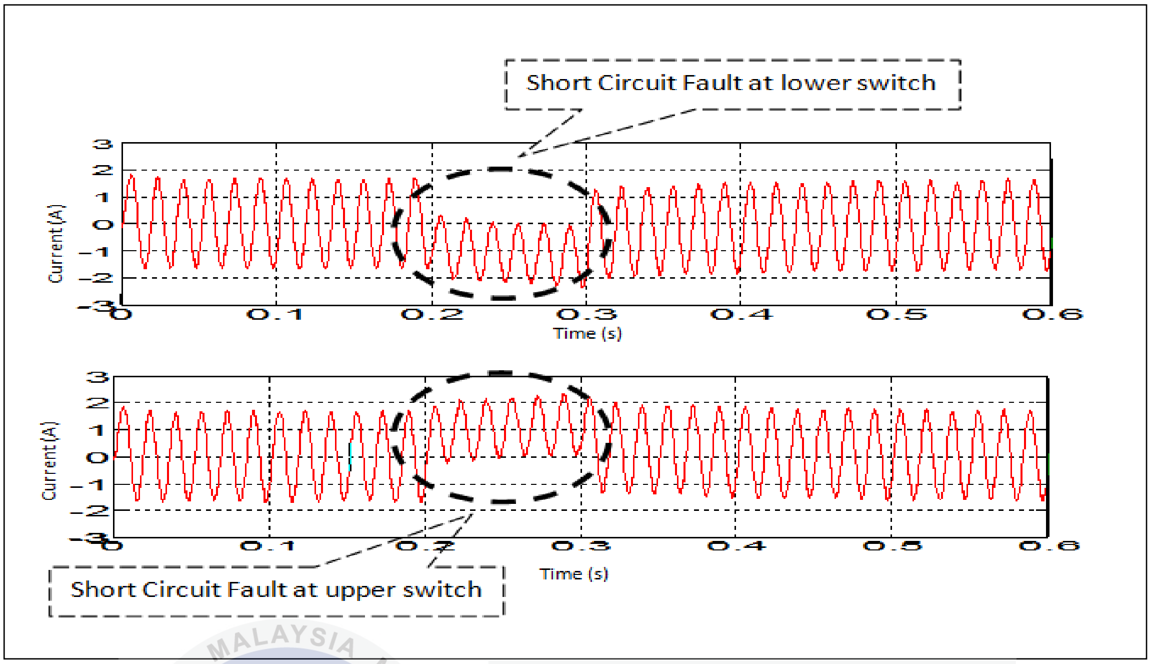


Figure 4.3: Upper and Lower Switch Short Circuit Fault Signal Phase A

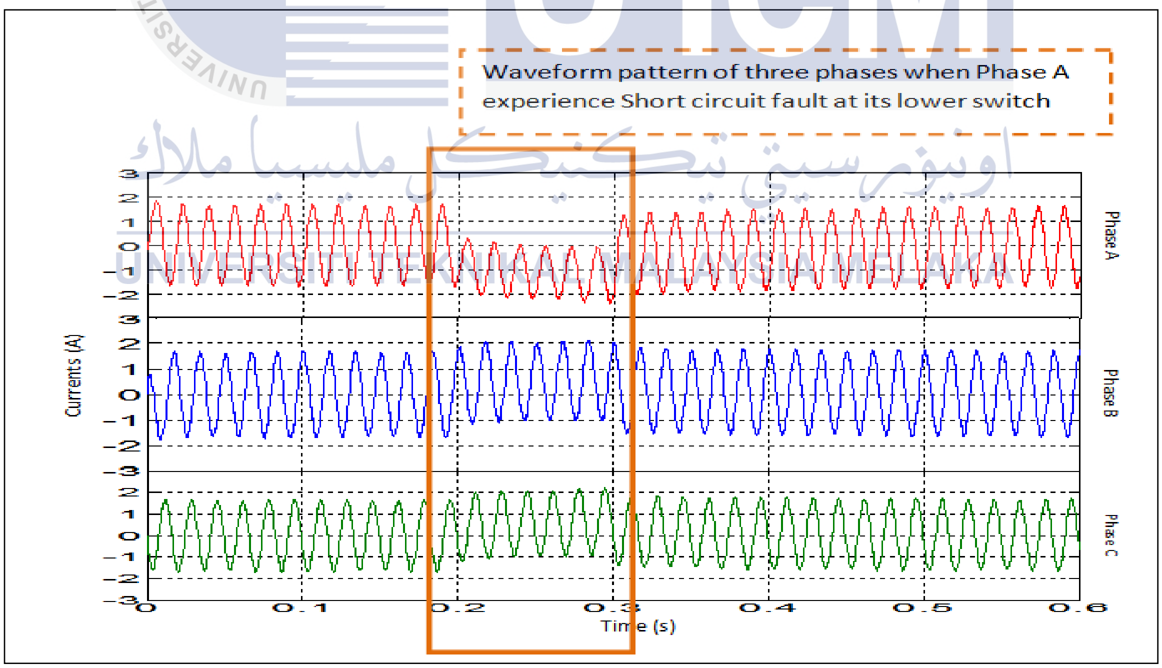


Figure 4.4: Waveform Pattern when short circuits at lower switch Phase A.

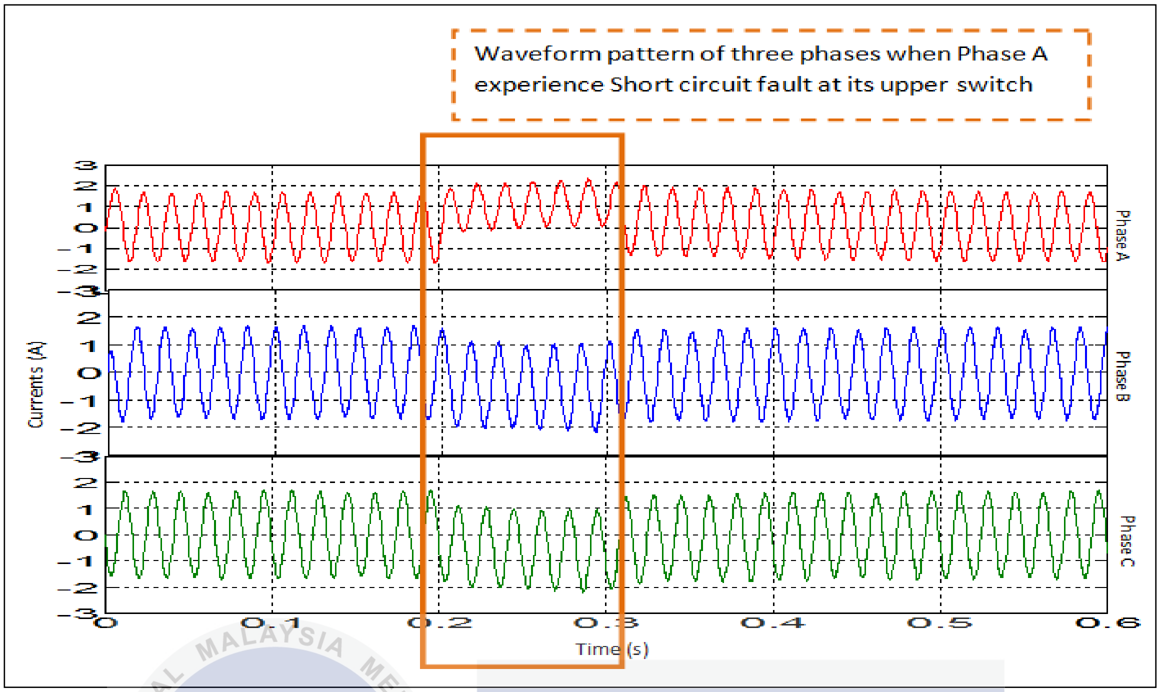


Figure 4.5: Waveform Pattern when short circuits at upper switch Phase A

The same technique is being approached to analyze the open-circuit fault for both upper and lower switch. This fault is simulated only for Phase A in order to identify its behavior. As being conducted in short-circuit fault, the occurrence of fault is at 0.2s to 0.3s. Figure 4.6 shows the upper and lower switch open circuit fault signal for Phase A while Figure 4.7 and Figure 4.8 presents the waveform pattern for every phase.

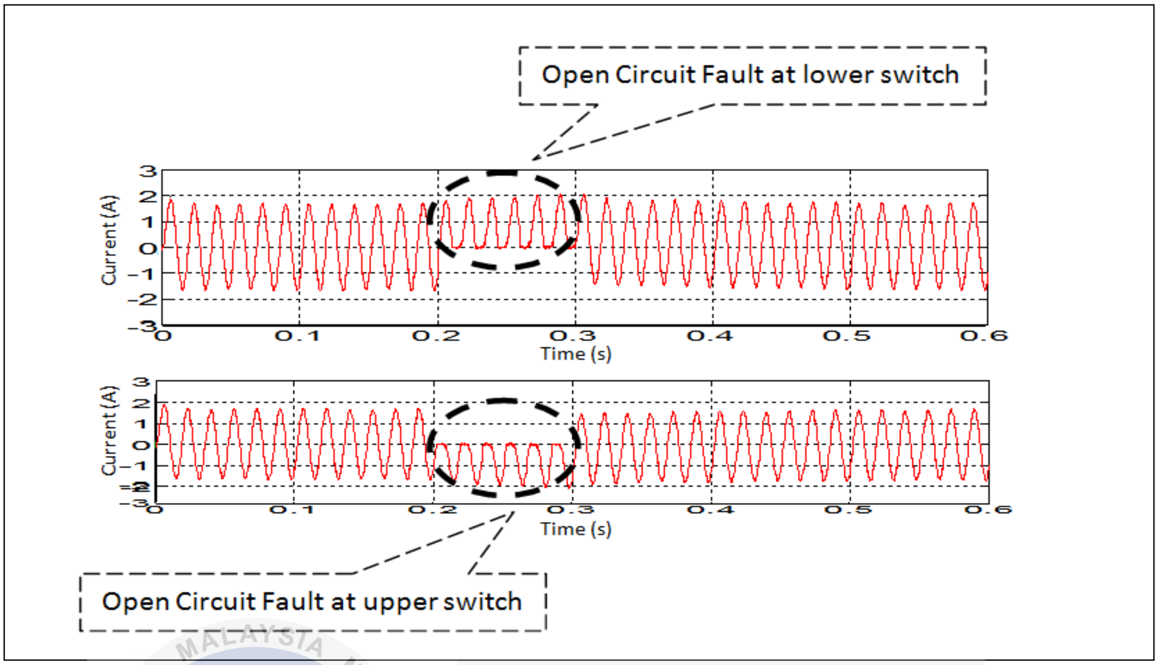


Figure 4.6: Upper and Lower Switch Open Circuit Fault Signal Phase A

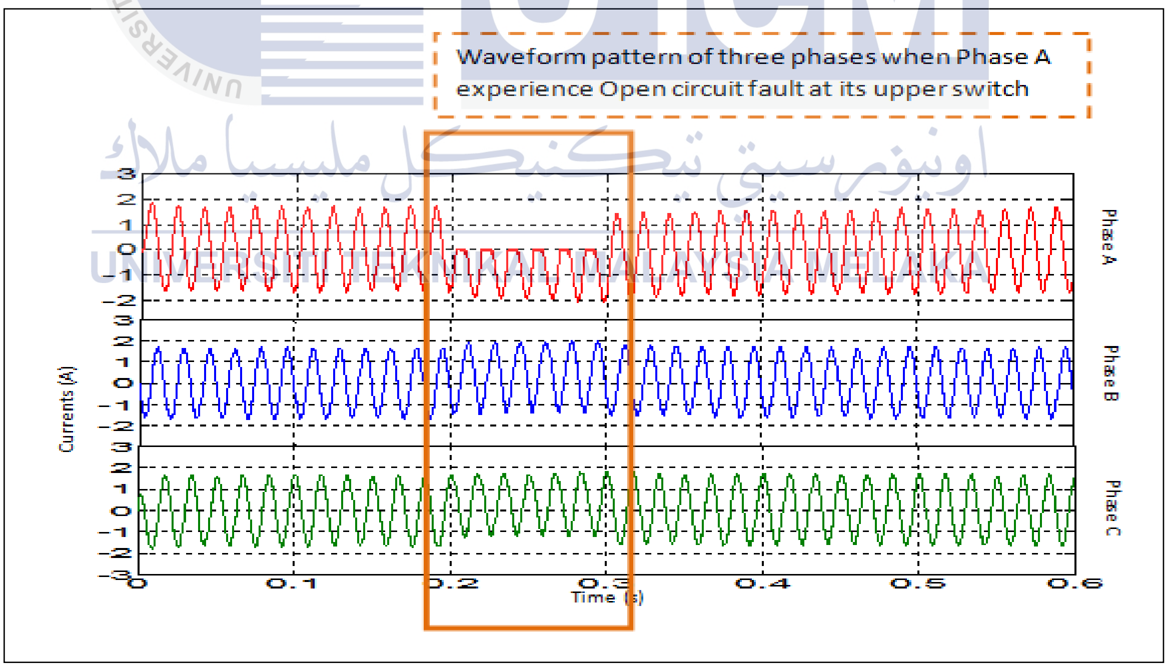


Figure 4.7: Waveform Pattern when open circuits at upper switch Phase A

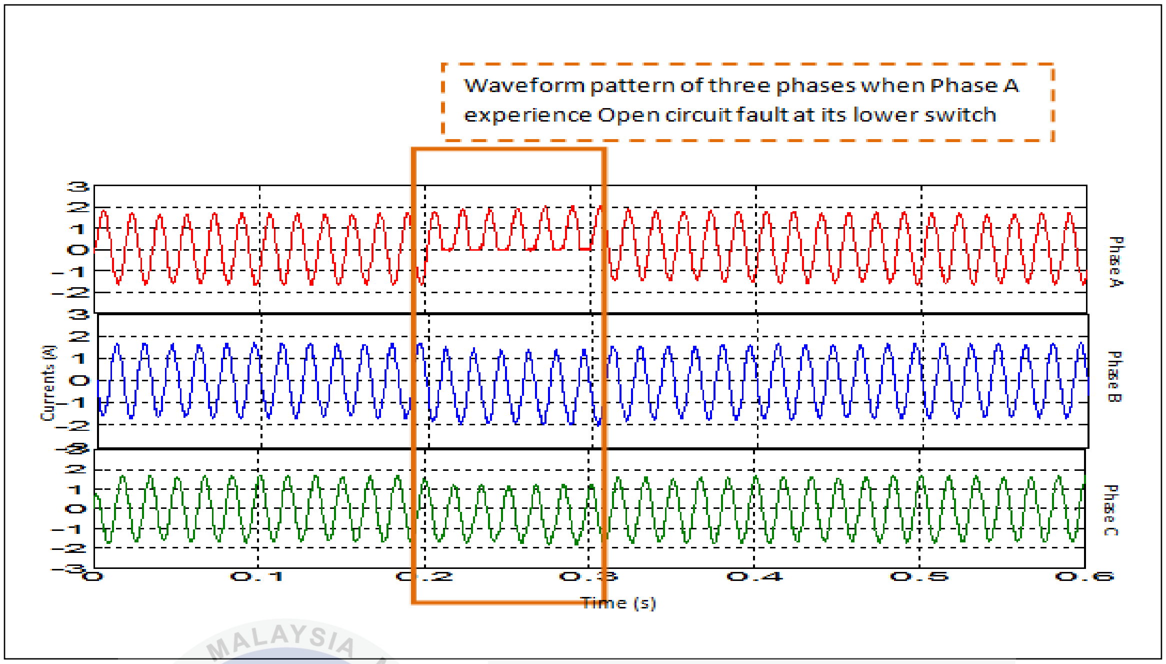


Figure 4.8: Waveform Pattern when open circuits at lower switch Phase A

4.1.2 Fault Detection using Analysis.

The parameters signal, which are RMS current and average current is estimated from the time-frequency representation (TFR). This technique refers to equation 2.1, squared magnitude of STFT in per unit (PU). The average and RMS current waveform patterns for short circuit faults at upper switch of Phase A are shown in Figure 4.9 and Figure 4.10. The peak average value for Phase A shows a positive higher value compared to Phase B and Phase C which are below zero whereas, the RMS value for three phases are positive and Phase A recorded high value than the other phases. The average value for Phase B and Phase C is nearly the same.

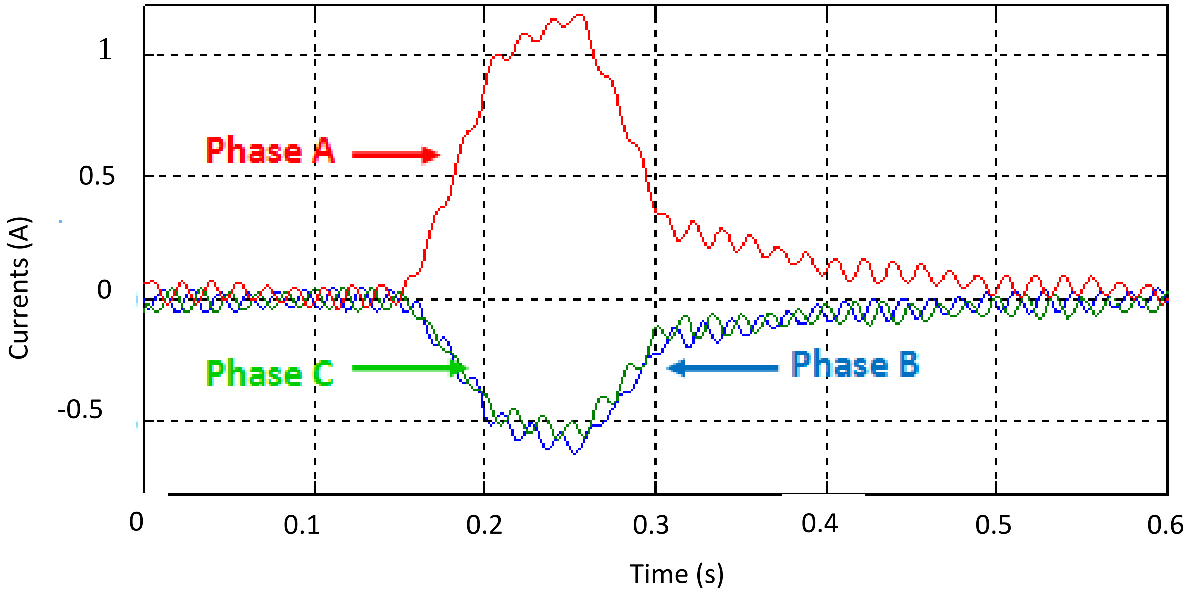


Figure 4.9: Average Current when short circuit occurred at upper switch of Phase A

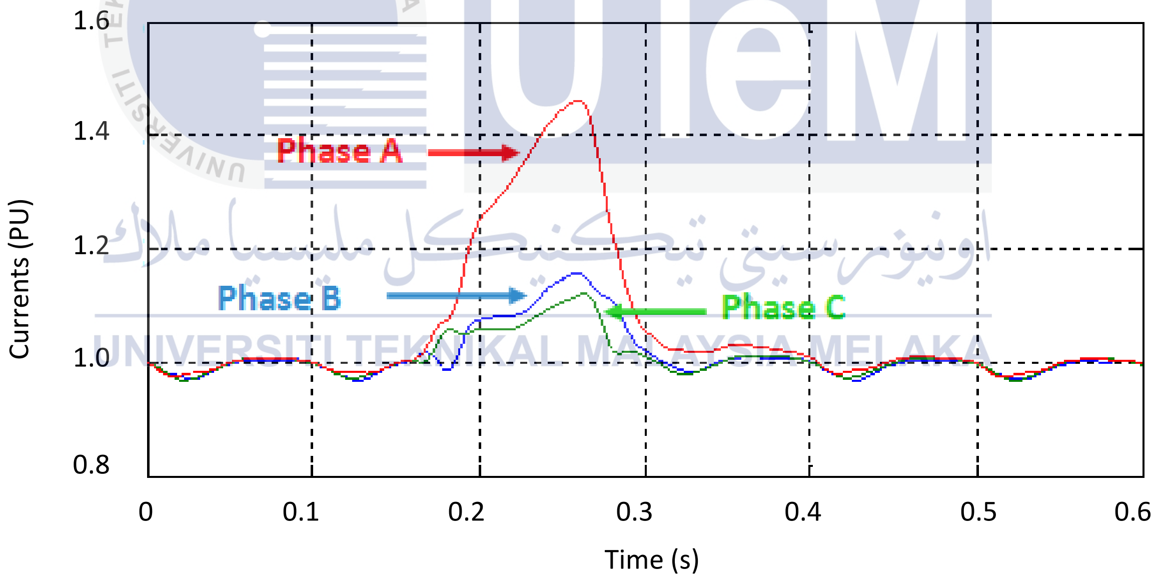


Figure 4.10: RMS Current when short circuit occurred at upper switch of Phase A

The average current when short circuit occurs at lower switch of Phase A is shown in Figure 4.11. The figure shows that the average current peak value of Phase A is lower than zero, while Phase B and Phase C value show positive value. The RMS waveform shown in

Figure 4.12 presents the pattern in which every phase shows positive value with Phase A as the highest value and Phase B is the lowest.

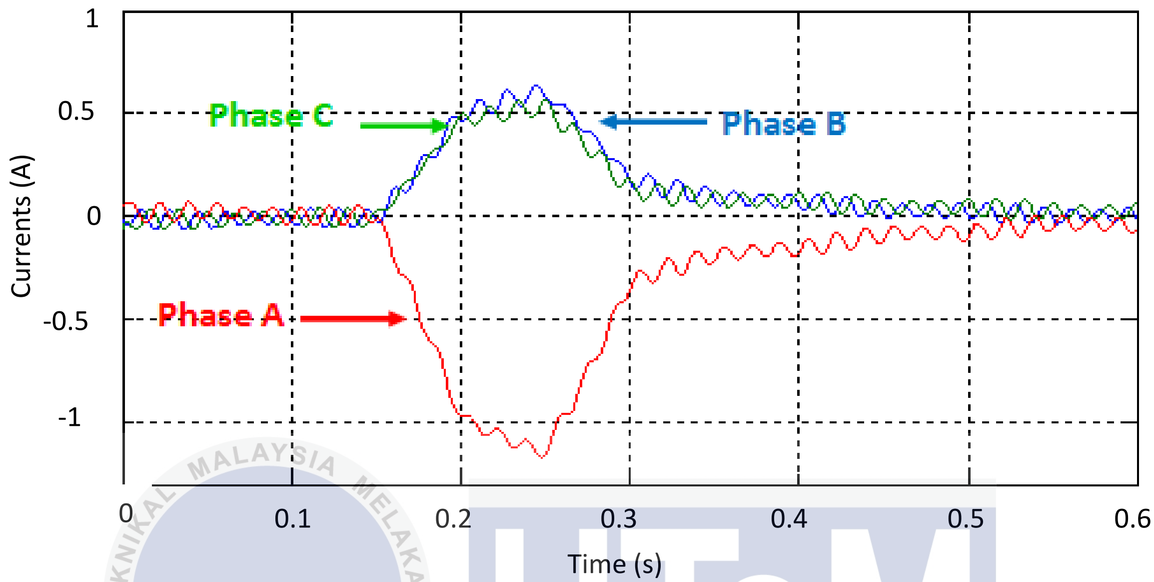


Figure 4.11: Average Current when short circuit occurred at lower switch of Phase A

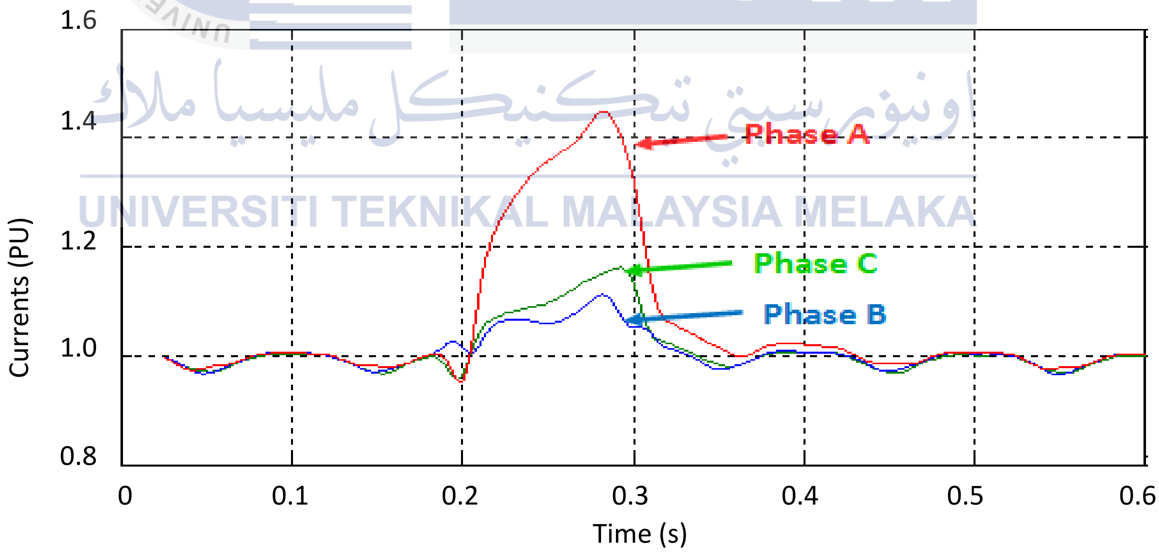


Figure 4.12: RMS Current when short circuit occurred at lower switch of Phase A

Figure 4.13 to Figure 4.16 shows the average and RMS current for both upper and lower switch of Phase A. In open circuit fault occur at upper switch, it shows that the peak value for Phase B and Phase C are nearly the same while Phase A shows negative value.

Figure 4.14 shows the RMS current and the peak value of Phase A and Phase B recorded negative value while Phase C shows positive value. In case of lower switch, Phase A gives a positive peak value while both Phase B and Phase C are negative as shown in Figure 4.15. The RMS pattern for upper and lower is the same but difference in magnitude. For lower switch case, Phase A and Phase C give a positive peak value while Phase B give value below zero.

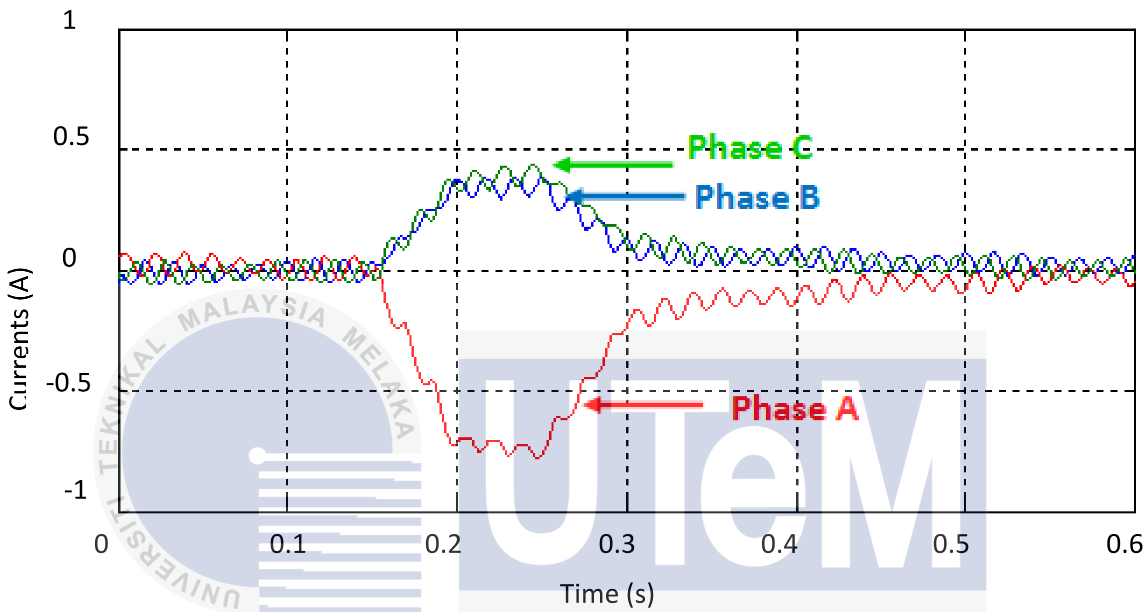


Figure 4.13: Average Current when open circuit occurred at upper switch of Phase A

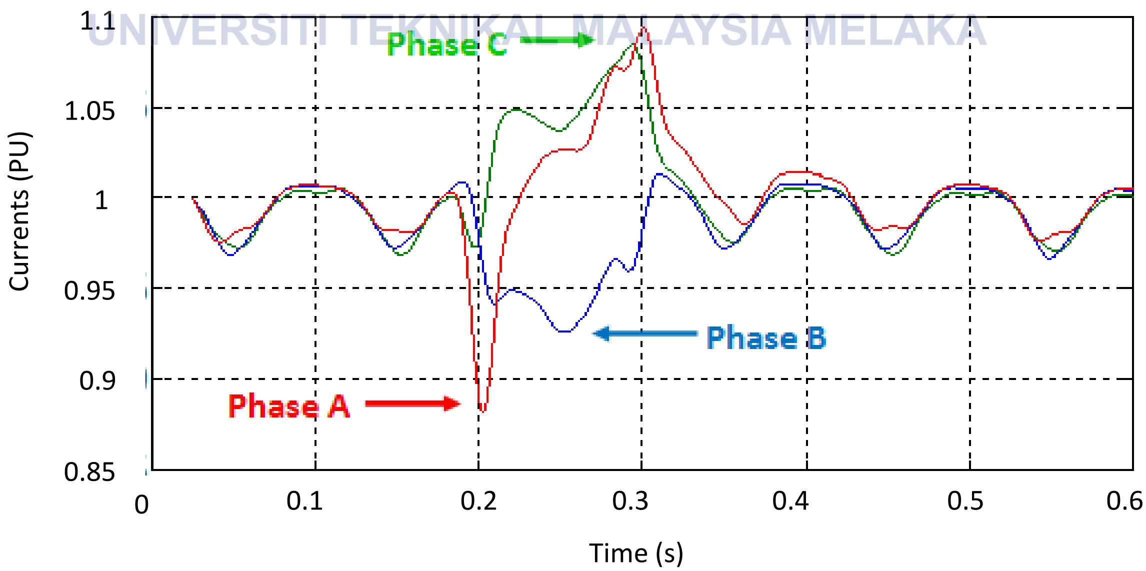


Figure 4.14: RMS Current when open circuit occurred at upper switch of Phase A

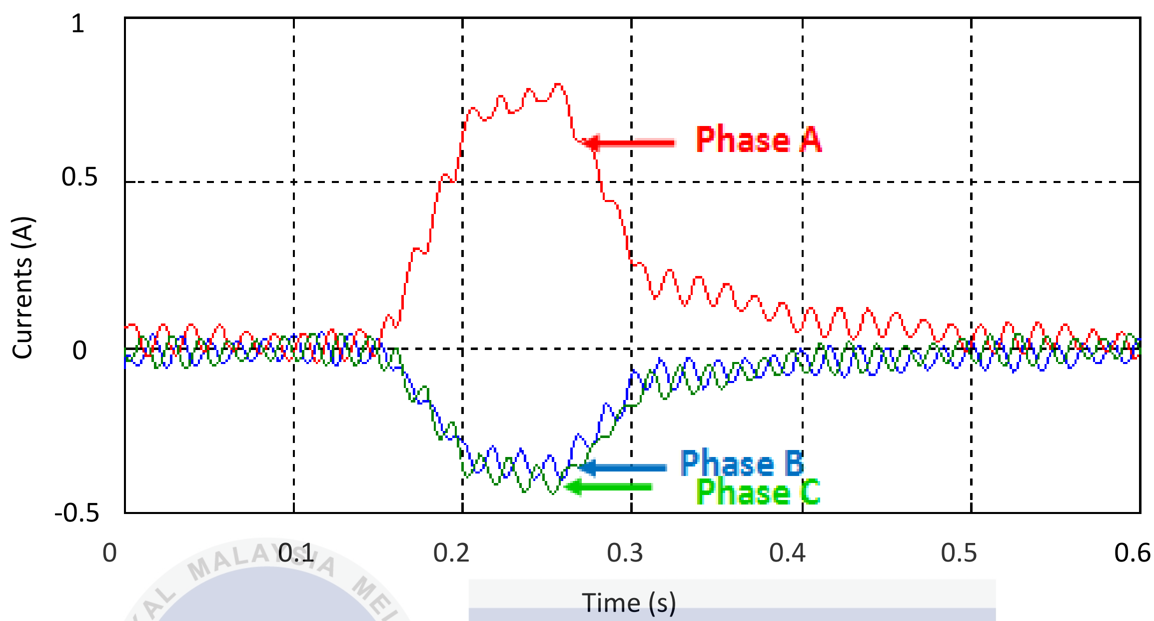


Figure 4.15: Average Current when open circuit occurred at lower switch of Phase A

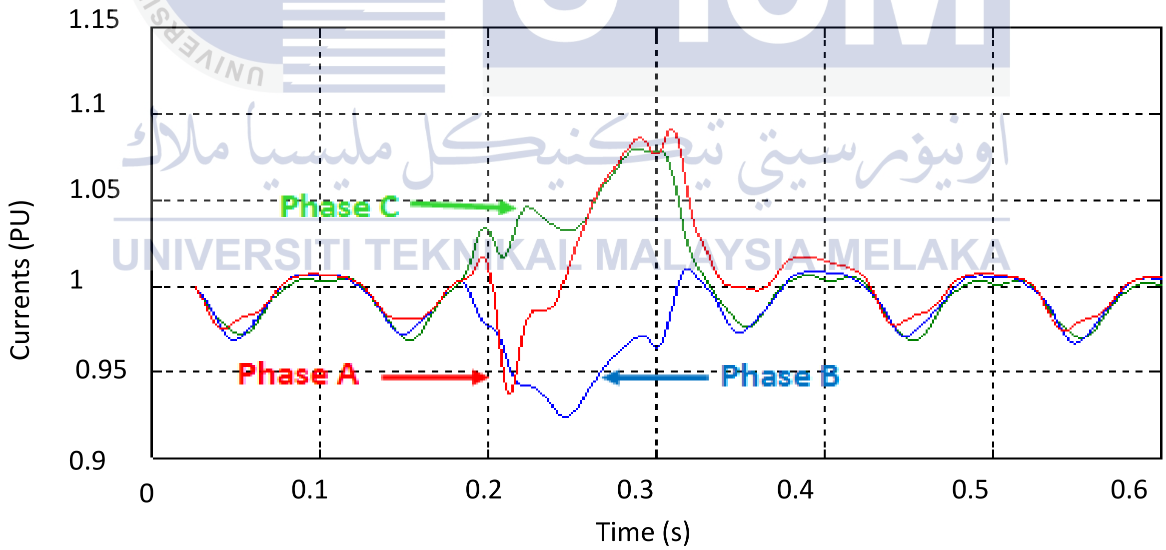


Figure 4.16: RMS Current when open circuit occurred at lower switch of Phase A

Further analysis is summarized and tabulated in Table 4.1. All waveforms pattern for open-circuit and short-circuit at upper and lower switch are analyzed and compared to get the suitable equations that will aid system in detecting the fault and the position of the fault occur.

Table 4.1: Analysis of Fault Occurs at Phase A

Fault	Switch Position	Average Current	RMS Current
Open Circuit	Upper	IAavg < 0 (IBavg = ICavg) > 0	IArms < 0 , IArms < IBrms ICrms > 0
	Lower	IAavg > 0 (IBavg = ICavg) < 0	IArms > 0 , ICrms< IArms IBrms < 0
Short Circuit	Upper	IAavg > 0 (IBavg = ICavg) < 0	IArms > IBrms > ICrms > 0
	Lower	IAavg < 0 (IBavg = ICavg) >0	IArms > ICrms > IBrms > 0
IAavg= Average current Phase A IBavg = Average current Phase B ICavg = Average current Phase C			IArms = RMS current Phase A IBrms = RMS current Phase B ICrms = RMS current Phase C

4.1.3 Graphical User Interface (GUI) Design in Visual Basic 2010.

The GUI of the system is designed as shown in Figure 4.17. This system is known as VSI Fault Detection System. It will display the output waveforms for both RMS and average current. So, the pattern or behavior of the signal or data captured can be identify and monitor. The VSI Fault Detection System will always continue to display the waveform of the parameters during normal and fault condition for the user to supervise and for the early detection of fault. This system can record parameters value and the status for further analysis in order for the user to trace or identified the solution to avoid more fault from happen. The use of LED in the system is to attract user attention on the condition of the inverter.

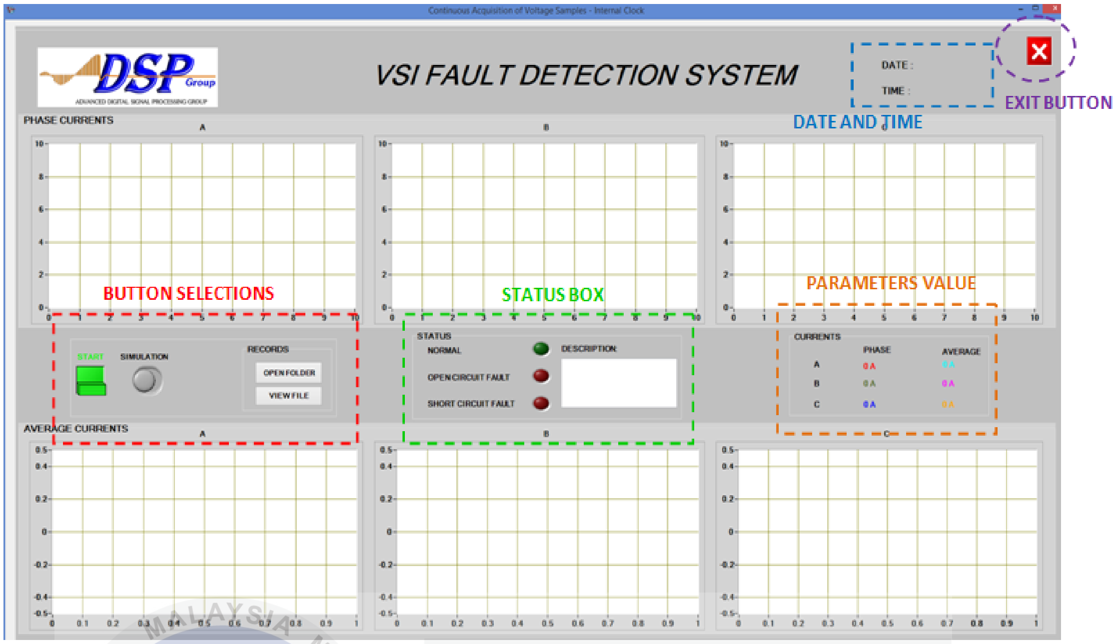


Figure 4.17: System designed using Visual Basic 2010

This system consists of four buttons or switches with different functions as shown in Figure 4.18. The start button will run and operate the system or stop the system when it is operating. The simulation switch as shown in Figure 4.19 gives example of how the system operates that will give the user a better understanding on the operation. The recorded data can be viewed when clicking the” VIEW FILE” button. The data will be saved in .txt format. User also can locate the file recorded by clicking the “OPEN FOLDER” button as shown in Figure 4.20.

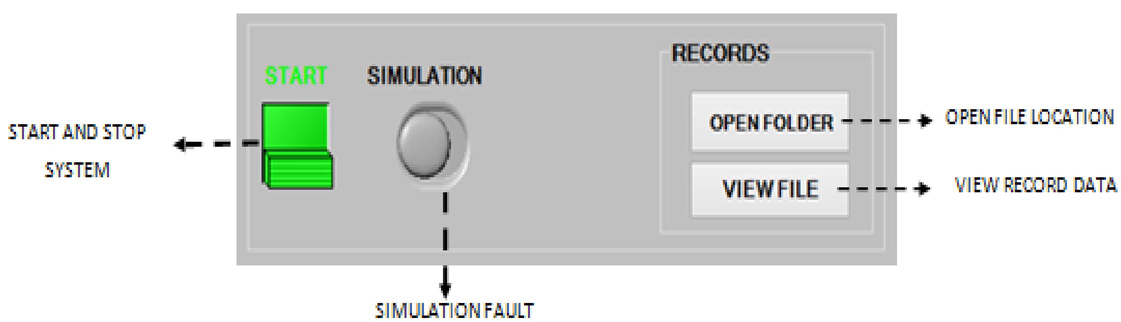


Figure 4.18: Button selection

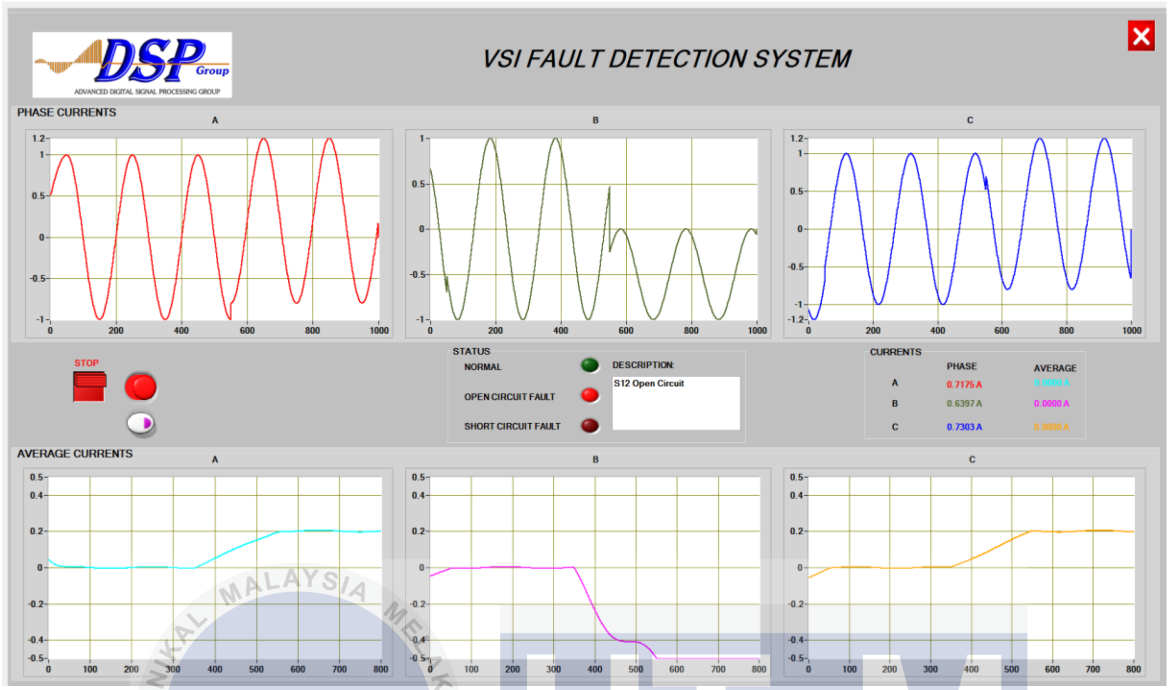


Figure 4.19: The system when simulation runs

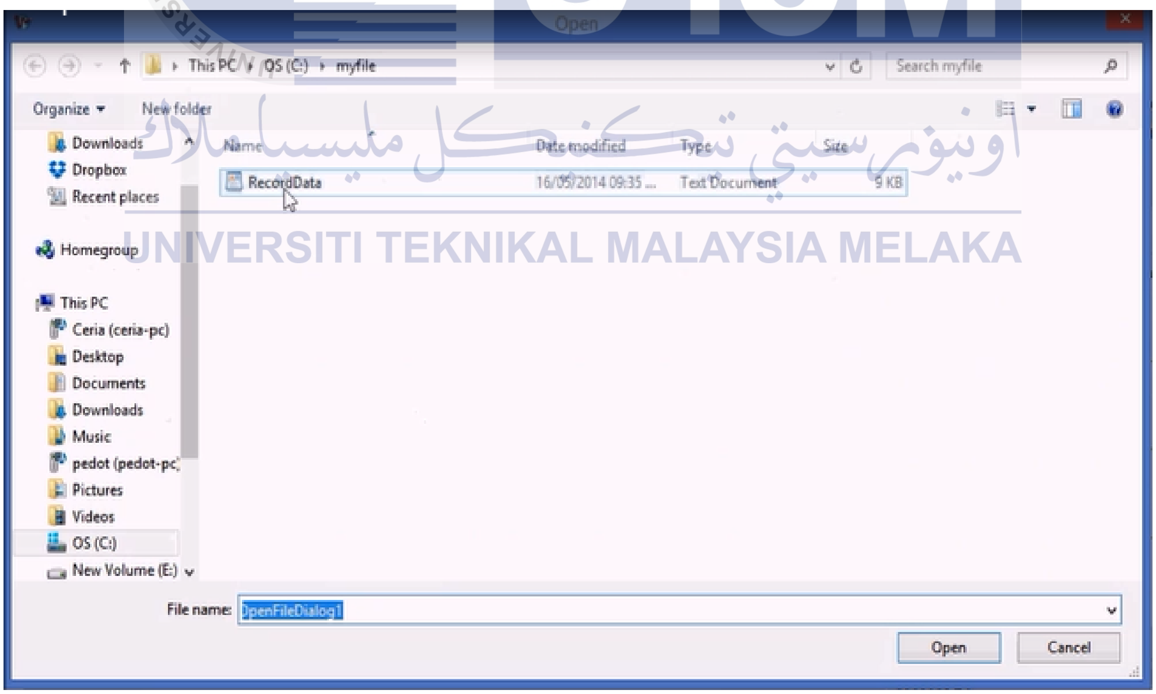
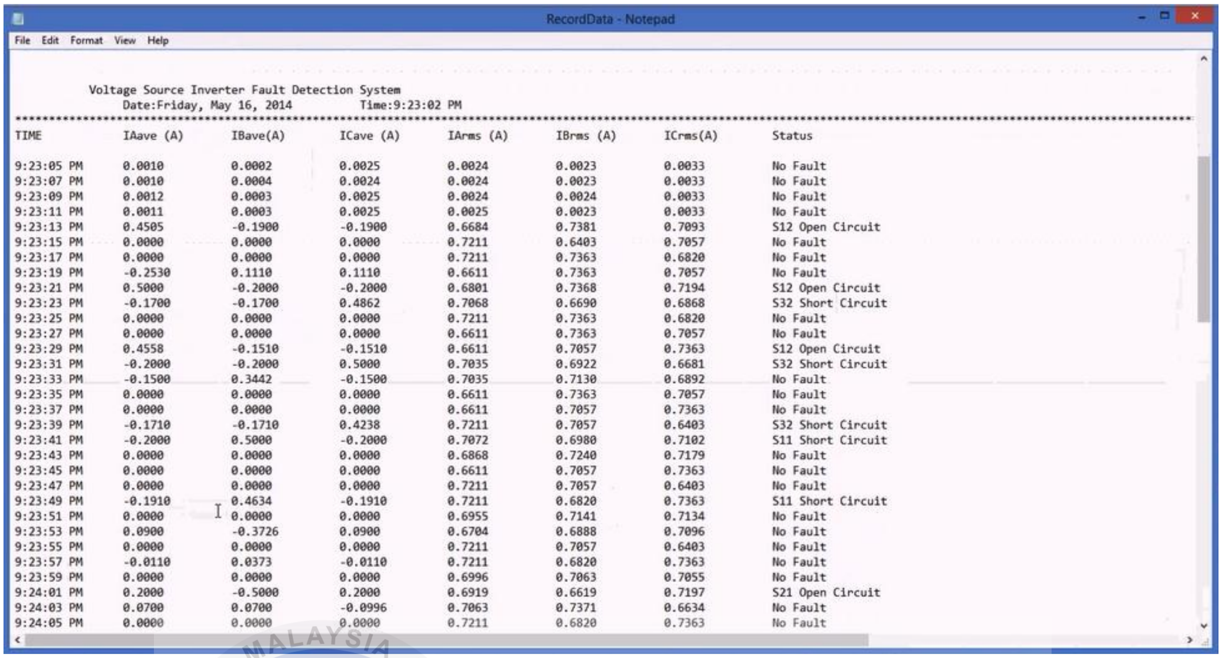


Figure 4.20: The file locations of data recorded.



RecordData - Notepad

File Edit Format View Help

Voltage Source Inverter Fault Detection System
Date:Friday, May 16, 2014 Time:9:23:02 PM

TIME	IAave (A)	IBave(A)	ICave (A)	IArms (A)	IBrms (A)	ICrms(A)	Status
9:23:05 PM	0.0010	0.0002	0.0025	0.0024	0.0023	0.0033	No Fault
9:23:07 PM	0.0010	0.0004	0.0024	0.0024	0.0023	0.0033	No Fault
9:23:09 PM	0.0012	0.0003	0.0025	0.0024	0.0024	0.0033	No Fault
9:23:11 PM	0.0011	0.0003	0.0025	0.0025	0.0023	0.0033	No Fault
9:23:13 PM	0.4505	-0.1900	-0.1900	0.6684	0.7381	0.7093	S12 Open Circuit
9:23:15 PM	0.0000	0.0000	0.0000	0.7211	0.6403	0.7057	No Fault
9:23:17 PM	0.0000	0.0000	0.0000	0.7211	0.7363	0.6820	No Fault
9:23:19 PM	-0.2530	0.1110	0.1110	0.6611	0.7363	0.7057	No Fault
9:23:21 PM	0.5000	-0.2000	-0.2000	0.6801	0.7368	0.7194	S12 Open Circuit
9:23:23 PM	-0.1700	-0.1700	0.4862	0.7068	0.6690	0.6868	S32 Short Circuit
9:23:25 PM	0.0000	0.0000	0.0000	0.7211	0.7363	0.6820	No Fault
9:23:27 PM	0.0000	0.0000	0.0000	0.6611	0.7363	0.7057	No Fault
9:23:29 PM	0.4558	-0.1510	-0.1510	0.6611	0.7057	0.7363	S12 Open Circuit
9:23:31 PM	-0.2000	-0.2000	0.5000	0.7035	0.6922	0.6681	S32 Short Circuit
9:23:33 PM	-0.1500	0.3442	-0.1500	0.7035	0.7130	0.6892	No Fault
9:23:35 PM	0.0000	0.0000	0.0000	0.6611	0.7363	0.7057	No Fault
9:23:37 PM	0.0000	0.0000	0.0000	0.6611	0.7057	0.7363	No Fault
9:23:39 PM	-0.1710	-0.1710	0.4238	0.7211	0.7057	0.6403	S32 Short Circuit
9:23:41 PM	-0.2000	0.5000	-0.2000	0.7072	0.6980	0.7102	S11 Short Circuit
9:23:43 PM	0.0000	0.0000	0.0000	0.6868	0.7240	0.7179	No Fault
9:23:45 PM	0.0000	0.0000	0.0000	0.6611	0.7057	0.7363	No Fault
9:23:47 PM	0.0000	0.0000	0.0000	0.7211	0.7057	0.6403	No Fault
9:23:49 PM	-0.1910	0.4634	-0.1910	0.7211	0.6820	0.7363	S11 Short Circuit
9:23:51 PM	0.0000	0.0000	0.0000	0.6955	0.7141	0.7134	No Fault
9:23:53 PM	0.0900	-0.3726	0.0900	0.6704	0.6888	0.7096	No Fault
9:23:55 PM	0.0000	0.0000	0.0000	0.7211	0.7057	0.6403	No Fault
9:23:57 PM	-0.0110	0.0373	-0.0110	0.7211	0.6820	0.7363	No Fault
9:23:59 PM	0.0000	0.0000	0.0000	0.6996	0.7063	0.7055	No Fault
9:24:01 PM	0.2000	-0.5000	0.2000	0.6919	0.6619	0.7197	S21 Open Circuit
9:24:03 PM	0.0700	0.0700	-0.0996	0.7063	0.7371	0.6634	No Fault
9:24:05 PM	0.0000	0.0000	0.0000	0.7211	0.6820	0.7363	No Fault

Figure 4.21: Data recorded in .txt format.

Figure 4.22: Status Box

The “STATUS BOX” as being shown in Figure 4.22 describes the status of the inverter when operating in a system. During normal condition, the normal green LED will light up and the description box will show “No Fault”. When fault detected, the red LED for open-circuit fault and short-circuit fault will light up according to the type of fault detected and the description box will show the fault types as well as the location of affected switch. The value of parameters needed for the detection is as shown in Figure 4.23. The parameters needed for the system is the RMS current and also the average current. The system is aid with colorful waveform for user to easily differentiate the waveform and the value readings.

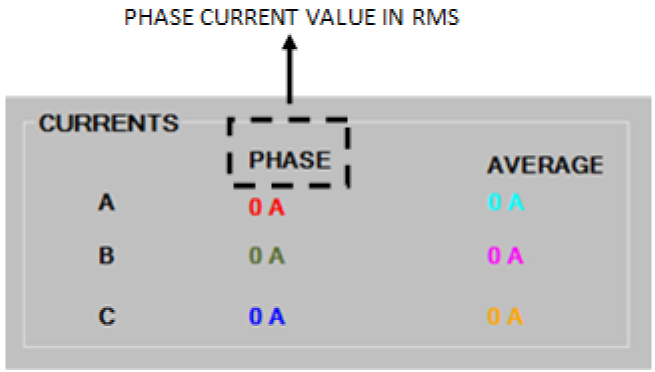


Figure 4.23: Parameters Value

4.1.4 Hardware Design

The system's hardware is design using three current transducers and NI USB-6009 DAQ Card. The three current transducers are isolate connected for differential measurement. They are connected to pin AI 0+ and AI 0-, AI 1+ and AI 1- and AI 2+ and AI 2- in DAQ Card. The connection diagram is shown in Figure 4.24. All current transducers and DAQ card use +5V at the input. The end product of the hardware is shown in Figure 4.25.

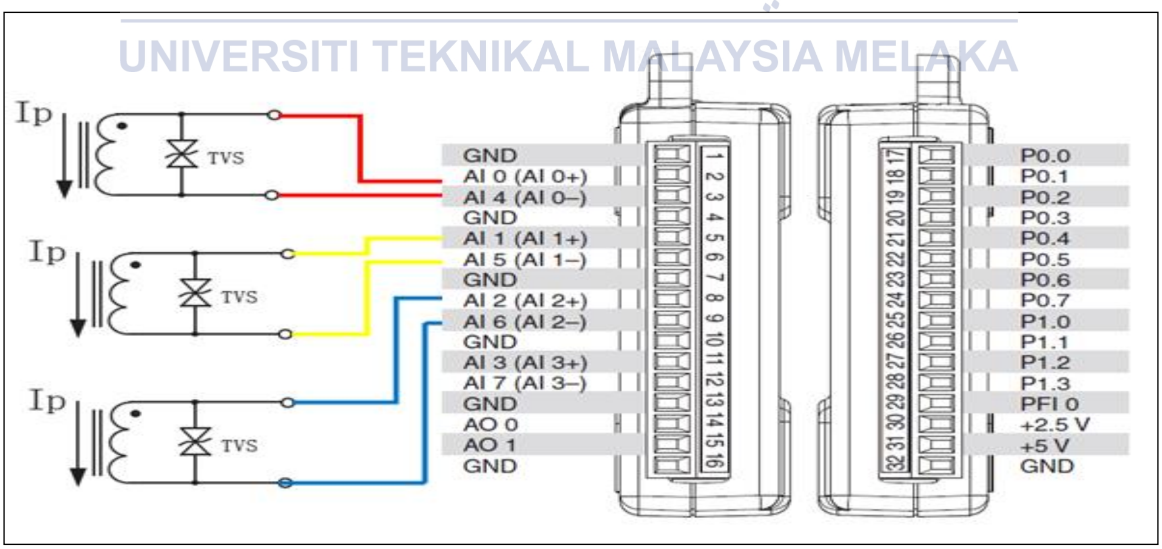


Figure 4.24: Hardware Connection Diagram

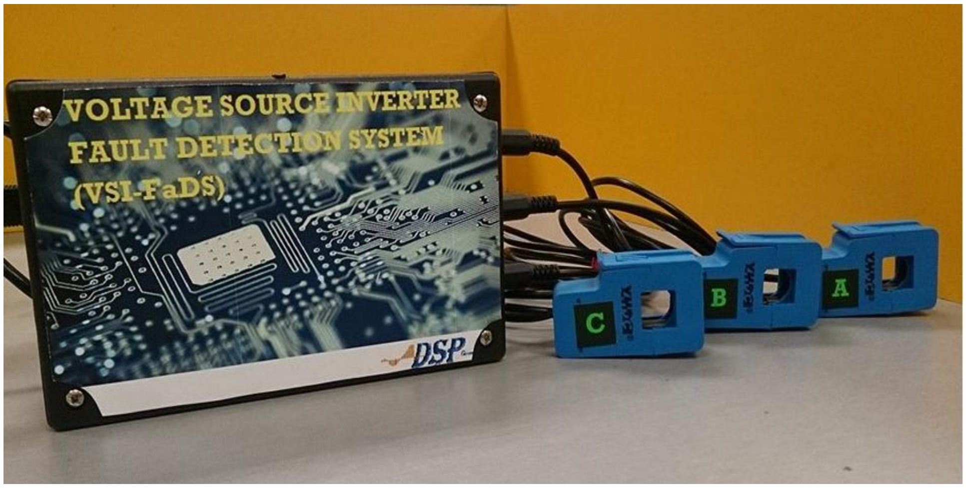


Figure 4.25: System Hardware

4.1.5 Performance Testing

Referring to connection diagram in Figure 3.11 in chapter three, the inverter was connected and analyzed as shown in Figure 4.26. The MOSFET three-phase inverter was supplied by 240V of Direct Current (DC) voltage. Figure 4.27 shows the current waveform during no fault condition with the magnitude of 2.02A.

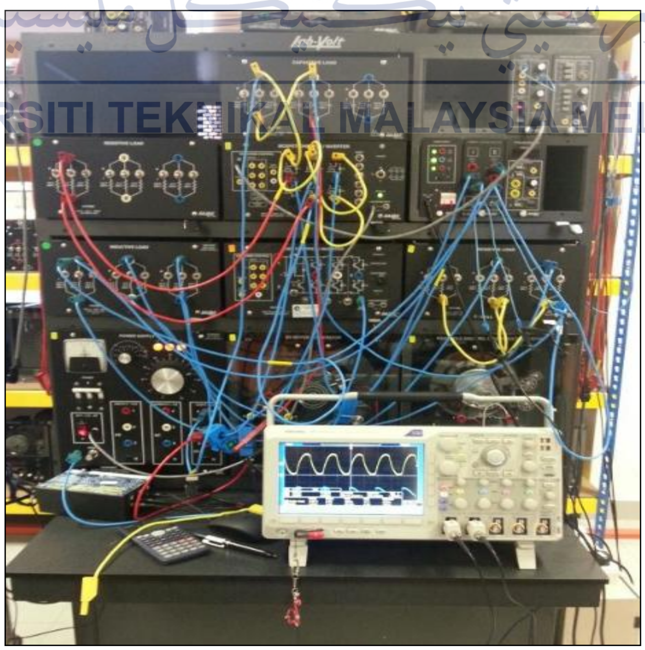


Figure 4.26: Connections for performance testing.

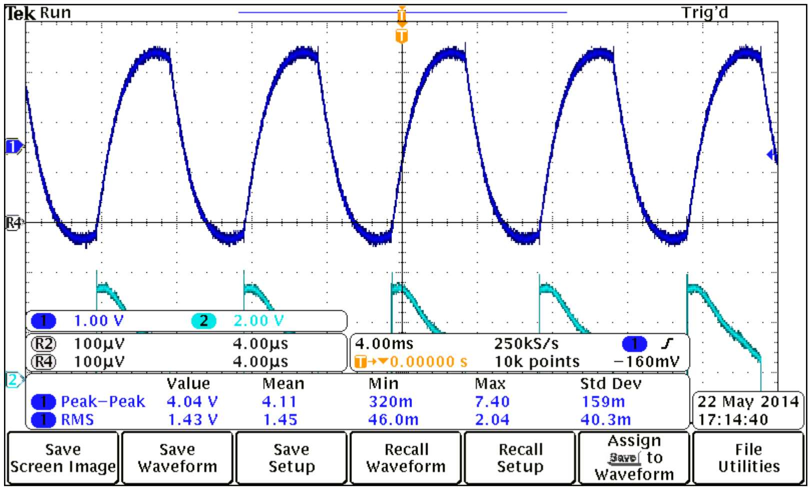


Figure 4.27: Current waveform during no fault conditions.

The upper switch of Phase A of the inverter was open circuited for fault generation purpose and then it was being short by using a resistor connected in parallel. The resulted waveforms are shown in Figure 4.28 and 4.29. From the results, there were some differences in the magnitude of the waveform. The faulted waveform were analyzed to be about half of the normal waveform. This shows the presents of DC source when fault was present as shown in Figure 4.3 and Figure 4.6 in simulation section.

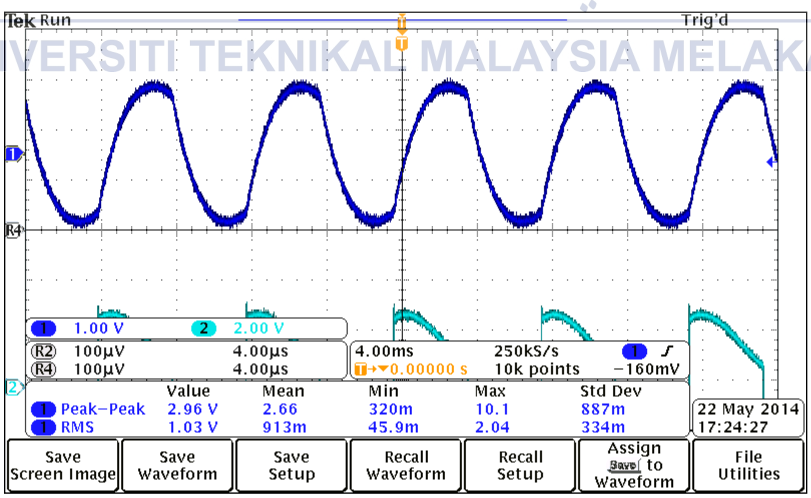


Figure 4.28: Open circuit fault waveform.

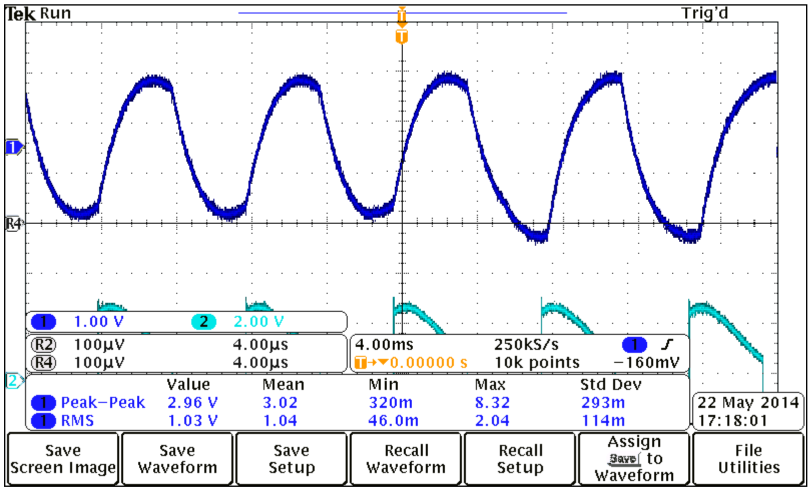


Figure 4.29: Short circuit fault waveform.

The performance of the system was analyzed by clamping three current transducers at each phase as illustrated in Figure 4.30. The system was tested with and without faults. The data recorded by the system was tabulated in Table 4.2.

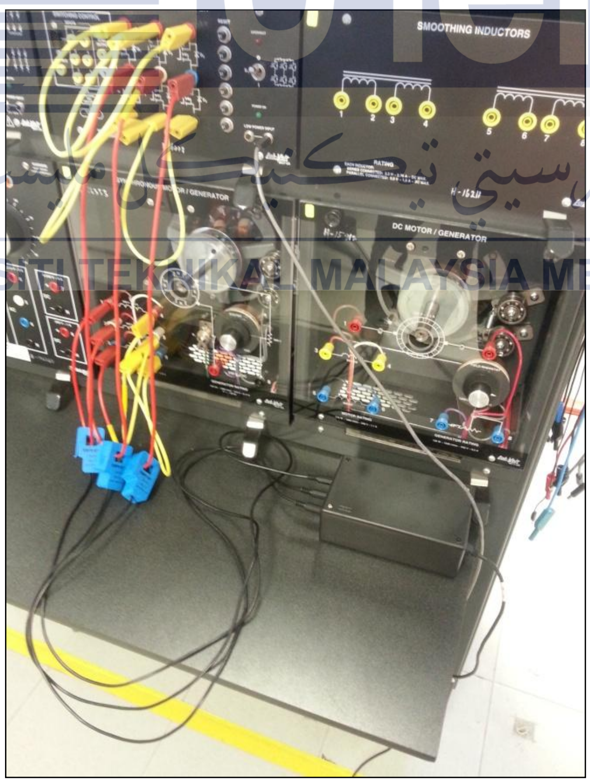


Figure 4.30: Current transducers clamped at each phase.

Table 4.2: Data classifications of faults

FAULT CREATED DURING PERFORMANCE TESTING	SYSTEM ANALYSIS FAULT	
	CLASSIFICATIONS	SWITCH POSITIONS
No fault created	No fault (Normal)	-
Open circuit connection at upper switch Phase A	Open circuit fault	S11
Open circuit connection at upper switch Phase B	Open circuit fault	S21
Open circuit connection at upper switch Phase C	Open circuit fault	S31
Open circuit connection at lower switch Phase A	Open circuit fault	S12
Open circuit connection at lower switch Phase B	Open circuit fault	S22
Open circuit connection at lower switch Phase C	Open circuit fault	S32
Short circuit connection at upper switch Phase A	Short circuit fault	S11
Short circuit connection at upper switch Phase B	Short circuit fault	S21
Short circuit connection at upper switch Phase C	Short circuit fault	S31
Short circuit connection at lower switch Phase A	Short circuit fault	S12
Short circuit connection at lower switch Phase B	Short circuit fault	S22
Short circuit connection at lower switch Phase C	Short circuit fault	S32

4.2 Project achievements

This project had being awarded with a silver award medal during the participations in International Engineering Invention & Innovation Exhibitions (i-ENVEX) on 11th of April 2014 to 13th of April 2014 which are held at Universiti Malaysia Perlis, UNIMAP. Figure 4.31 and Figure 4.32 shows the award certifications and the silver medal received. On May 18th, 2014 this project received a special award known as "Outstanding Achievement Award" during International Innovation Festival (INNOFEST) at Universiti Teknikal Malaysia Melaka (UTeM). Figure 4.33 shows the special award while Figure 4.34 shows the certification of participation.

Figure 4.31: The certificate of Silver Prize.

Figure 4.32: The Siver Medal received during i-ENVEX 2014

Figure 4.33: The Outstanding Achievement Award during INNOFEST 2014.

KEMENTERIAN PENDIDIKAN MALAYSIA

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MOSTI

INNOFEST 2014

CERTIFICATE OF PARTICIPATION

is here by granted to:

Sa'adah Daud

as a presenter of

VOLTAGE SOURCE INVERTER FAULT DETECTION SYSTEM (VSI.FADS)

INTERNATIONAL INNOVATION AND DESIGN EXPO

in conjunction with

INTERNATIONAL INNOVATION FESTIVAL 2014

[18TH MAY 2014]

at

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

organized by :

ASSOCIATION OF INVENTIVE, INNOVATIVE AND CREATIVE THINKER UTeM (ASIIC)

in collaboration with :

MINISTRY OF EDUCATION MALAYSIA (KPM)
MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION MALAYSIA (MOSTI)
STATE GOVERNMENT OF MALACCA
BOARD OF ENGINEERS MALAYSIA (BEM)
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Y.BHG. PROF MADYA DR. IZAIDIN BIN ABDUL MAJID
DEPUTY VICE CHANCELLOR (STUDENT AFFAIRS AND ALUMNI)
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.34: The certificate of participations INNOFEST 2014.

CHAPTER 5

CONCLUSIONS

Inverters are important devices used in everyday life. Power inverters are widely applied in many areas. It may used as portable consumer devices allowing the connection to a set of batteries to device that are producing AC power to run in various electrical such as kitchen appliances, power tools, televisions and lights. The main arrising issue in inverter is the switching device which are very sensitive to a small disturbance that can lead to whole system to malfunction. The development of inverter's fault detection system is necessary in order to ensure the continuity of devices and appliances without distinguishing in which area they are applied. Thus, this provide solutions in managing time and maintenance cost. The system is developed to be reliable by researching and selecting the accurate and most applicable technique which is analysis of fault using spectrogram technique. This technique is reliable and more accurate in presenting the signal as it can shows three parameters within a graph. The parameters are magnitude, frequency and time. A simulation is done to analyze the behavior of fault presents using MATLAB Simulink. Parameters such as average and RMS current aids in detecting fault which are short-circuit fault and open-circuit fault. The implementation of a new version software such as Microsoft Visual Basic 2010 is necessary to ensure the development of systematic system in line with increasingly sophisticated development.The use of three current transducers clamped at every phase of the inverter enables the measurement of parameters. NI USB 6009 DAQ Card interprate the analog signals from the transducers and convert it to digital signals that can be read by the system. For future development, a system that can detect other faults such as DC link capacitor short-circuit fault and ground fault with more parameters such as RMS voltage, average voltage and harmonic distortions are suggested in order to maintain the efficiency of the device.

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APPENDICES

Appendix A: Table A1 - Gantt chart

	FYP 1													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
TITLE SELECTION	■													
FYP BRIEFING		■												
LITERATURE REVIEW			■	■	■	■	■	■	■	■	■	■	■	■
SIMULATION			■	■	■	■	■	■	■	■				
SOFTWARE DEVELOPMENT (DESIGNING GUI)				■	■	■	■	■	■	■	■	■	■	■
HARDWARE DEVELOPMENT (DESIGNING)						■	■	■	■	■	■	■	■	■
REPORT PROGRESS (SUBMIT)									■					
SEMINAR 1 (PRESENTATION)										■				
	FYP 2													
LITERATURE REVIEW	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SOFTWARE DEVELOPMENT (TESTING, TROUBLESHOOTING)	■	■	■	■	■	■								
HARDWARE DEVELOPMENT (TESTING, TROUBLESHOOTING)	■	■	■	■	■	■								
INTERFACING HARDWARE AND SOFTWARE			■	■	■	■	■							
FIELD TESTING									■	■	■	■	■	■
FULL REPORT				■	■	■	■	■	■	■	■	■	■	■

Appendix B: NI USB 6009 DAQ Card Datasheet

USER GUIDE AND SPECIFICATIONS

NI USB-6008/6009

Bus-Powered Multifunction DAQ USB Device

Français Deutsch 日本語 한국어 简体中文

ni.com/manuals

This user guide describes how to use the National Instruments USB-6008 and National Instruments USB-6009 data acquisition (DAQ) devices and lists specifications.

The NI USB-6008/6009 provides connection to eight single-ended analog input (AI) channels, two analog output (AO) channels, 12 digital input/output (DIO) channels, and a 32-bit counter with a full-speed USB interface. Table 1 compares the devices.

Table 1. NI USB-6008 and NI USB-6009 Comparison

Feature	NI USB-6008	NI USB-6009
AI resolution	12 bits differential, 11 bits single-ended	14 bits differential, 13 bits single-ended
Maximum AI sample rate, single channel*	10 kS/s	48 kS/s
Maximum AI sample rate, multiple channels (aggregate)*	10 kS/s	48 kS/s
DIO configuration	Open collector†	Each channel individually programmable as open collector or active drive†

* System-dependent.
† This document uses NI-DAQmx naming conventions. Open-drain is called open collector and push-pull is called active drive.

Figure 1 shows key functional components of the NI USB-6008/6009.

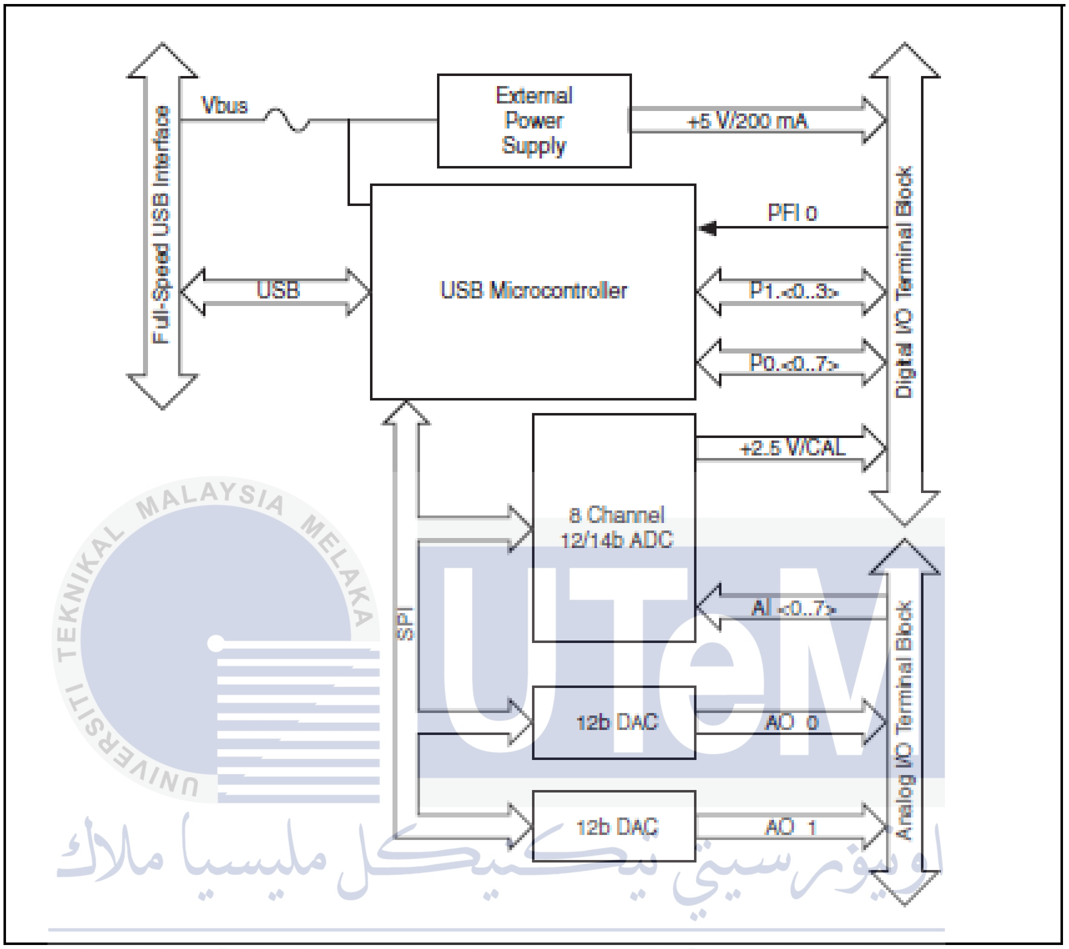


Figure 1. NI USB-6008/6009 Block Diagram

Contents

Safety Guidelines

Operate the NI USB-6008/6009 device only as described in this user guide.

Caution Do *not* operate the NI USB-6008/6009 in a manner not specified in this document. Misuse of the device can result in a hazard. You can compromise the safety protection built into the device if the device is damaged in any way. If the device is damaged, contact National Instruments for repair.

Caution Do *not* substitute parts or modify the device except as described in this document. Use the device only with the chassis, modules, accessories, and cables specified in the installation instructions. You must have all covers and filler panels installed during operation of the device.

Caution Do *not* operate the device in an explosive atmosphere or where there may be flammable gases or fumes. If you must operate the device in such an environment, it must be in a suitably rated enclosure.

Electromagnetic Compatibility Guidelines

This product was tested and complies with the regulatory requirements and limits for electromagnetic compatibility (EMC) as stated in the product specifications. These requirements and limits are designed to provide reasonable protection against harmful interference when the product is operated in its intended operational electromagnetic environment.

This product is intended for use in industrial locations. There is no guarantee that harmful interference will not occur in a particular installation, when the product is connected to a test object, or if the product is used in residential areas. To minimize the potential for the product to cause interference to radio and television reception or to experience unacceptable performance degradation, install and use this product in strict accordance with the instructions in the product documentation.

Furthermore, any changes or modifications to the product not expressly approved by National Instruments could void your authority to operate it under your local regulatory rules.

Caution To ensure the specified EMC performance, operate this product only with shielded cables and accessories.

Caution This product may become more sensitive to electromagnetic disturbances in the operational environment when test leads are attached or when connected to a test object.

Caution Emissions that exceed the regulatory requirements may occur when this product is connected to a test object.

Caution Changes or modifications not expressly approved by National Instruments could void the user's authority to operate the hardware under the local regulatory rules.

Unpacking

The NI USB-6008/6009 device ships in an antistatic package to prevent electrostatic discharge (ESD). ESD can damage several components on the device.

Caution *Never* touch the exposed pins of connectors.

To avoid ESD damage in handling the device, take the following precautions:

- Ground yourself with a grounding strap or by touching a grounded object.
- Touch the antistatic package to a metal part of your computer chassis before removing the device from the package.

Remove the device from the package and inspect it for loose components or any other signs of damage. Notify NI if the device appears damaged in any way. Do not install a damaged device in your computer or chassis.

Store the device in the antistatic package when the device is not in use.

Setting Up the NI USB-6008/6009

Complete the following steps to get started with the NI USB-6008/6009.

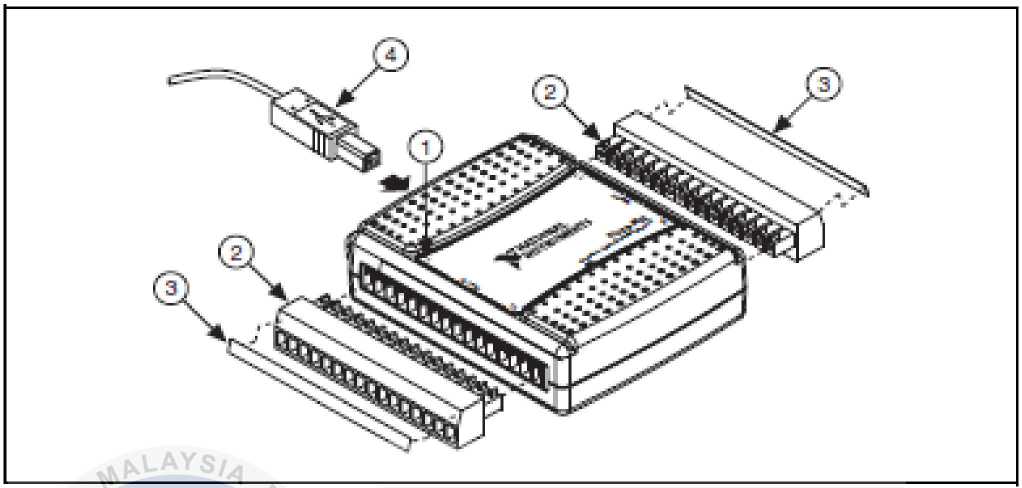
Note For information about non-Windows operating system support, refer to the *Getting Started with NI-DAQmx Base for Linux and Mac OS X Users* document available from `ni.com/manuals`.

1. Install the application software (if applicable), as described in the installation instructions that accompany your software.
2. Install NI-DAQmx[1].

Note The NI-DAQmx software is included on the disk shipped with your kit and is available for download at `ni.com/support`. The documentation for NI-DAQmx is available after installation from **Start»All Programs»National Instruments»NI-DAQ**. Other NI documentation is available from `ni.com/manuals`.

[1] NI USB-6008/6009 devices are supported by NI-DAQmx 7.5 and later.

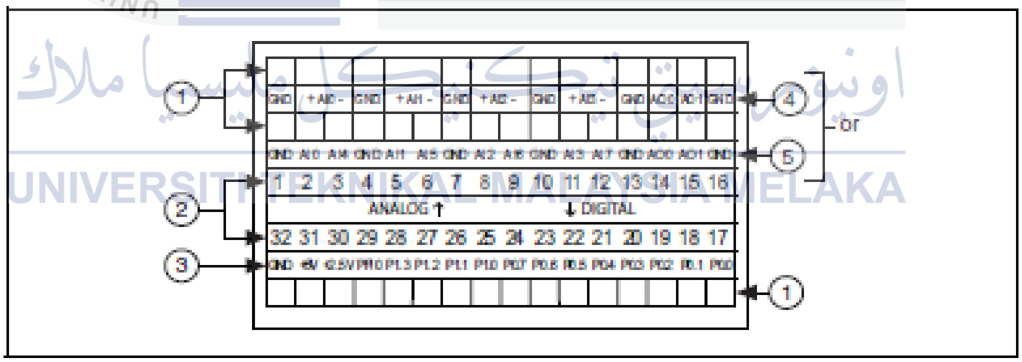
3. Install the 16-position screw terminal connector plugs by inserting them into the connector jacks as shown in Figure 2.



1	Overlay Label with Pin Orientation Guides	3	Signal Label
2	Screw Terminal Connector Plug	4	USB Cable

Figure 2. Signal Label Application Diagram

4. Affix the provided signal labels to the screw terminal connector plugs. You can choose labels with pin numbers, signal names, or blank labels, as shown in Figure 3. Choose one of the labels, align the correct label with the terminals printed on the top panel of your device and apply the label, as shown in Figure 2.



1	User-Defined Custom Label	4	Analog Input Differential Signal Name Label
2	Terminal Number Label	5	Analog Input Single-Ended Signal Name Label
3	Digital I/O Label		

Figure 3. NI USB-6008/6009 Signal Labels

Note After you label the screw terminal connector plugs, you must only insert them into the matching connector jack, as indicated by the overlay label on the device.

5. Plug one end of the USB cable into the NI USB-6008/6009 and the other end into an available USB port on the computer.

6. Double-click the **Measurement & Automation** icon, shown at left, on the desktop to open Measurement & Automation Explorer (MAX).
7. Expand **My System»Devices and Interfaces** and verify that the NI USB-6008/6009 is listed. If your device does not appear, press <F5> to refresh the view in MAX. If your device is still not recognized, refer to `ni.com/support/daqmx` for troubleshooting information.
8. Self-test your device in MAX by right-clicking **NI USB-600x** and selecting **Self-Test**. Self-test performs a brief test to determine successful device installation. When the self-test finishes, a message indicates successful verification or if an error occurred. If an error occurs, refer to `ni.com/support/daqmx`.

Caution To ensure the specified EMC performance, operate this product only with shielded cables and accessories.

9. Connect the wires (16 to 28 AWG) of a shielded, multiconductor cable to the screw terminals by stripping 6.35 mm (0.25 in.) of insulation, inserting the wires into the screw terminals, and securely tightening the screws with the flathead screwdriver to a torque of 0.22–0.25 N · m (2.0–2.2 lb · in.). Refer to Figure 6 for the NI USB-6008/6009 pinout.

   If using a shielded cable, connect the cable shield to a nearby GND terminal.

Note For information about sensors, go to `ni.com/sensors`. For information about IEEE 1451.4 TEDS smart sensors, go to `ni.com/teds`.

10. Run a Test Panel in MAX by right-clicking **NI USB-600x** and selecting **Test Panels**.

    Click **Start** to test the device functions, or **Help** for operating instructions. Click **Close** to exit the test panel.

Using the NI USB-6008/6009 in an Application

You can use the DAQ Assistant through many NI application software programs to configure virtual and measurement channels. Table 2 lists DAQ Assistant tutorial locations for NI applications.

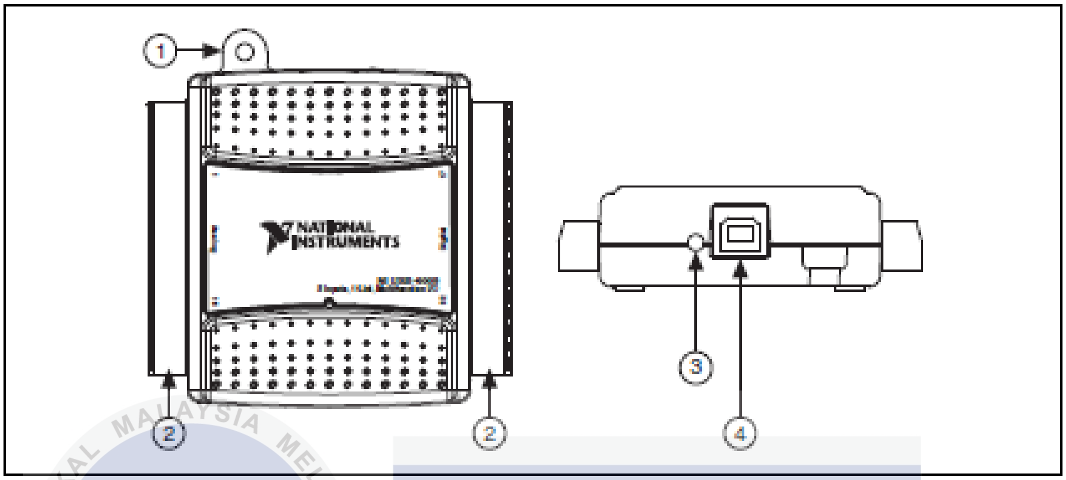
Table 2. DAQ Assistant Tutorial Locations

NI Application	Tutorial Location
LabVIEW	Go to **Help»LabVIEW Help**. Next, go to **Getting Started with LabVIEW»Getting Started with DAQ»Taking an NI-DAQmx Measurement in LabVIEW**.
LabWindows™/CVI™	Go to **Help»Contents**. Next, go to **Using LabWindows/CVI»Data Acquisition»Taking an NI-DAQmx Measurement in LabWindows/CVI**.
Measurement Studio	Go to **NI Measurement Studio Help»Getting Started with the Measurement Studio Class Libraries»Measurement Studio Walkthroughs»Walkthrough: Creating a Measurement Studio NI-DAQmx Application**.
LabVIEW SignalExpress	Go to **Help»Taking an NI-DAQmx Measurement in SignalExpress**.

Refer to the *Where to Go from Here* section for information about programming examples for NI-DAQmx and NI-DAQmx Base.

Features

The NI USB-6008/6009 features a USB connector, USB cable strain relief, two screw terminal connector plugs for I/O, and an LED indicator, as shown in Figure 4.



1	USB Cable Strain Relief	3	LED Indicator
2	Screw Terminal Connector Plug	4	USB Connector

Figure 4. NI USB-6008/6009 Top and Back Views

USB Connector and USB Cable Strain Relief

The NI USB-6008/6009 features a USB connector for full-speed USB interface. You can provide strain relief for the USB cable by threading a zip tie through the USB cable strain relief ring and tightening around a looped USB cable, as shown in Figure 5.

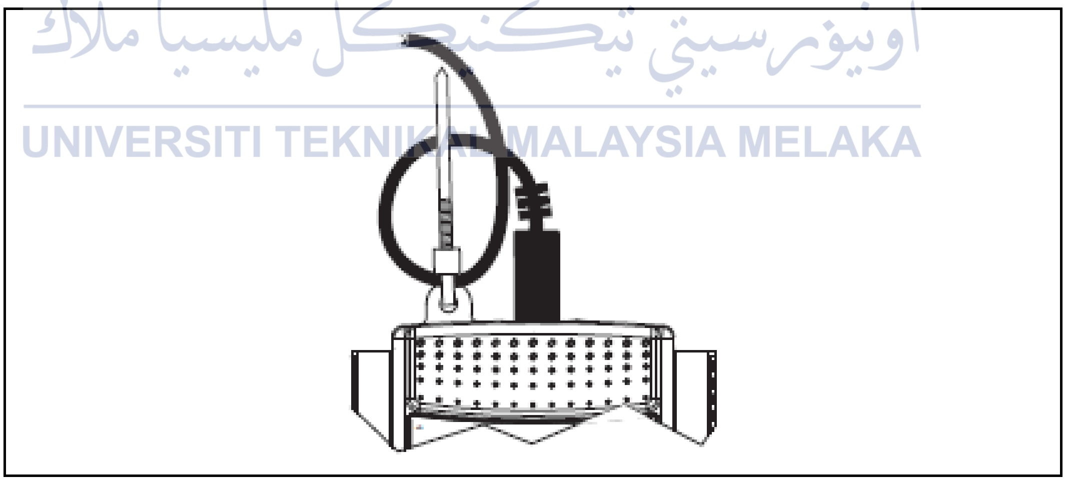


Figure 5. NI USB-6008/6009 Strain Relief

LED Indicator

The NI USB-6008/6009 device has a green LED indicator that indicates device status, as listed in Table 3. When the device is connected to a USB port, the LED blinks steadily to indicate that the device is initialized and is receiving power from the connection.

Table 3. LED State/Device Status

LED State	Device Status
Not lit	Device not connected or in suspend
On, not blinking	Device connected but not initialized, or the computer is in standby mode. In order for the device to be recognized, the device must be connected to a computer that has NI-DAQmx installed on it.
Single-blink	Operating normally

Screw Terminal Connector Plugs

The NI USB-6008/6009 ships with one detachable screw terminal connector plug for analog signals and one detachable screw terminal connector plug for digital signals. These screw terminal connectors provide 16 connections that use 16–28 AWG wire. Refer to step 4 of the *Setting Up the NI USB-6008/6009* section for information about selecting labels for the screw terminal connector plugs. Refer to the *Pinout and Signal Descriptions* section for the device pinout and signal descriptions.

You can order additional connectors and labels for your device. Refer to the *Cables and Accessories* section for ordering information.

Firmware

The firmware on the NI USB-6008/6009 refreshes whenever the device is connected to a computer with NI-DAQmx. NI-DAQmx automatically uploads the compatible firmware version to the device. The firmware version may be upgraded when new versions of NI-DAQmx release.

Cables and Accessories

Table 4 contains information about cables and accessories available for the NI USB-6008/6009. For a complete list of accessories and ordering information, refer to the pricing section of the NI USB-6008 or NI USB-6009 product page at `ni.com`.

Table 4. NI USB-6008/6009 Cables and Accessories

Accessory	Part Number	Description
USB-6008/6009 Accessory Kit	779371-01	Four additional screw-terminal connectors, connector labels, and a screwdriver
USB-6000 Series Prototyping Accessory	779511-01	Unshielded breadboarding accessory for custom-defined signal conditioning and prototyping. You can use up to two accessories per device.
Hi-Speed USB Cable	184125-01 184125-02	1 m and 2 m lengths

Caution: For compliance with Electromagnetic Compatibility (EMC) requirements, this product must be operated with shielded cables and accessories. If unshielded cables or accessories are used, the EMC specifications are no longer guaranteed unless all unshielded cables and/or accessories are installed in a shielded enclosure with properly designed and shielded input/output ports.

Pinout and Signal Descriptions

Figure 6 shows the pinout of the NI USB-6008/6009. Analog input signal names are listed as single-ended analog input name, AI *x*, and then differential analog input name, (AI *x*+/–). Refer to Table 5 for a detailed description of each signal.

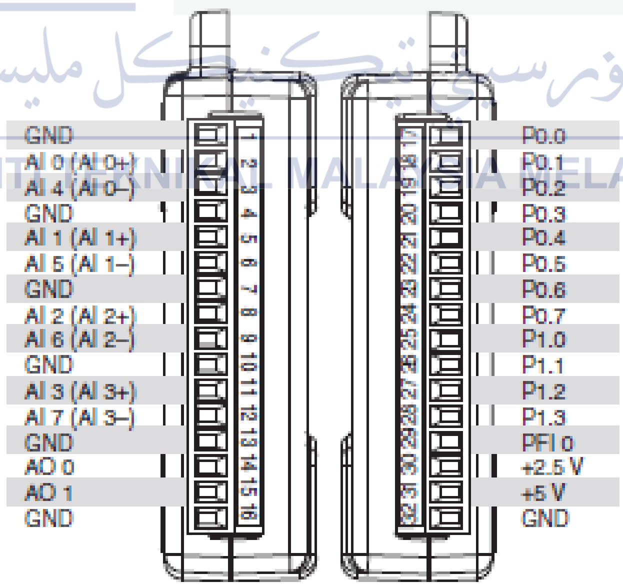


Figure 6. NI USB-6008/6009 Pinout

Table 5. Signal Descriptions

Signal Name	Reference	Direction	Description
GND	—	—	**Ground**—The reference point for the single-ended analog input measurements, analog output voltages, digital signals, +5 VDC supply, and +2.5 VDC at the I/O connector, and the bias current return point for differential mode measurements.
AI <0..7>	Varies	Input	**Analog Input Channels 0 to 7**—For single-ended measurements, each signal is an analog input voltage channel. For differential measurements, AI 0 and AI 4 are the positive and negative inputs of differential analog input channel 0. The following signal pairs also form differential input channels: AI<1, 5>, AI<2, 6>, and AI<3, 7>. Refer to the *Analog Input* section for more information.
AO <0, 1>	GND	Output	**Analog Output Channels 0 and 1**—Supplies the voltage output of AO channel 0 or AO channel 1. Refer to the *Analog Output* section for more information.
P0.<0..7>	GND	Input or Output	**Port 0 Digital I/O Channels 0 to 7**—You can individually configure each signal as an input or output. Refer to the *Digital I/O* section for more information.
P1.<0..3>	GND	Input or Output	**Port 1 Digital I/O Channels 0 to 3**—You can individually configure each signal as an input or output. Refer to the *Digital I/O* section for more information.
PFI 0	GND	Input	**PFI 0**—This pin is configurable as either a digital trigger or an event counter input. Refer to the *PFI 0* section for more information.
+2.5 V	GND	Output	**+2.5 V External Reference**—Provides a reference for wrap-back testing. Refer to the *+2.5 V External Reference* section for more information.
+5 V	GND	Output	**+5 V Power Source**—Provides +5 V power up to 200 mA. Refer to the *+5 V Power Source* section for more information.

Analog Input

The NI USB-6008/6009 has eight analog input channels that you can use for four differential analog input measurements or eight single-ended analog input measurements.

Figure 7 shows the analog input circuitry of the NI USB-6008/6009.

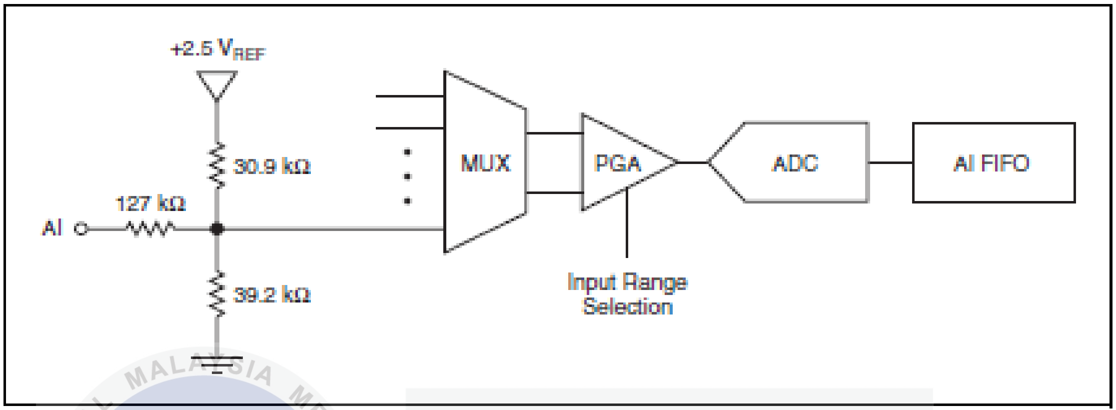


Figure 7. NI USB-6008/6009 Analog Input Circuitry

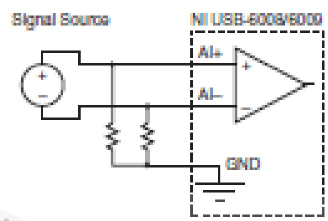
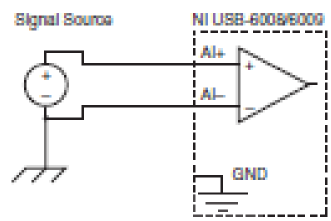
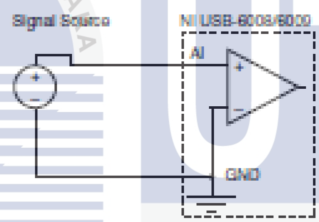
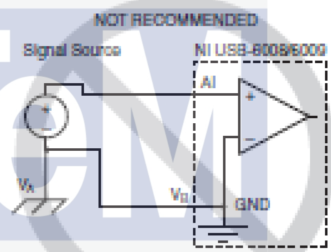
The main blocks featured in the NI USB-6008/6009 analog input circuitry are as follows:

- **MUX**—The NI USB-6008/6009 has one analog-to-digital converter (ADC). The multiplexer (MUX) routes one AI channel at a time to the PGA.
- **PGA**—The progammable-gain amplifier provides input gains of 1, 2, 4, 5, 8, 10, 16, or 20 when configured for differential measurements and gain of 1 when configured for single-ended measurements. The PGA gain is automatically calculated based on the voltage range selected in the measurement application.
- **ADC**—The analog-to-digital converter (ADC) digitizes the AI signal by converting the analog voltage into digital code.
- **AI FIFO**—The NI USB-6008/6009 can perform both single and multiple analog-to-digital conversions of a fixed or infinite number of samples. A first-in-first-out (FIFO) buffer holds data during AI acquisitions to ensure that no data is lost.

Analog Input Modes and Signal Sources

You can configure the AI channels on the NI USB-6008/6009 to take differential or referenced single-ended (RSE) measurements. Table 6 summarizes the recommended analog input mode(s) for floating signal sources and ground-referenced signal sources. Refer to Table 5 for more information about I/O connections for single-ended or differential measurements.

Table 6. Analog Input Configurations

Analog Input Mode	**Floating Signal Sources (Not Connected to Building Ground)** Examples: • Ungrounded thermocouples • Signal conditioning with isolated outputs • Battery devices	**Ground-Referenced Signal Sources** Example: • Plug-in instruments with non-isolated outputs
Differential (DIFF)		
Referenced Single-Ended (RSE)		 Ground-loop potential ($V_A - V_B$) are added to measured signal.

Floating Signal Sources

A floating signal source is not connected to the building ground system, but has an isolated ground-reference point. Some examples of floating signal sources are outputs of transformers, thermocouples, battery-powered devices, optical isolators, and isolation amplifiers. An instrument or device that has an isolated output is a floating signal source.

Refer to the NI Developer Zone document, *Field Wiring and Noise Considerations for Analog Signals*, for more information. To access this document, go to `ni.com/info` and enter the Info Code `rdfwn3`.

When to Use Differential Connections with Floating Signal Sources

Use DIFF input connections for any channel that meets any of the following conditions:

- Your application requires input ranges other than ±10 V.
- The input signal is low level and requires greater accuracy.
- The leads connecting the signal to the device are greater than 3 m (10 ft).
- The input signal requires a separate ground-reference point or return signal.

- The signal leads travel through noisy environments.
- Two analog input channels, AI+ and AI–, are available for the signal.

DIFF signal connections reduce noise pickup and increase common-mode noise rejection. DIFF signal connections also allow input signals to float within the working voltage of the device.

Refer to the *Taking Differential Measurements* section for more information about differential connections.

When to Use Referenced Single-Ended (RSE) Connections with Floating Signal Sources

Only use RSE input connections if the input signal meets all of the following conditions:

- The input signal can share a common reference point, GND, with other signals that use RSE.
- Your application permits the use of the ±10 V input range.
- The leads connecting the signal to the device are less than 3 m (10 ft).

DIFF input connections are recommended for greater signal integrity for any input signal that does not meet the preceding conditions.

In the single-ended modes, more electrostatic and magnetic noise couples into the signal connections than in DIFF configurations. The coupling is the result of differences in the signal path. Magnetic coupling is proportional to the area between the two signal conductors. Electrical coupling is a function of how much the electric field differs between the two conductors.

With this type of connection, the PGA rejects both the common-mode noise in the signal and the ground potential difference between the signal source and the device ground.

Refer to the *Taking Referenced Single-Ended Measurements* section for more information about RSE connections.

Ground-Referenced Signal Sources

A ground-referenced signal source is a signal source connected to the building system ground. It is already connected to a common ground point with respect to the device, assuming that the computer is plugged into the same power system as the source. Non-isolated outputs of instruments and devices that plug into the building power system fall into this category.

The difference in ground potential between two instruments connected to the same building power system is typically between 1 and 100 mV, but the difference can be much higher if power distribution circuits are improperly connected. If a grounded signal source is incorrectly measured, this difference can appear as measurement error. Follow the connection instructions for grounded signal sources to eliminate this ground potential difference from the measured signal.

Refer to the NI Developer Zone document, *Field Wiring and Noise Considerations for Analog Signals*, for more information. To access this document, go to `ni.com/info` and enter the Info Code `rdfwn3`.

When to Use Differential Connections with Ground-Referenced Signal Sources

Use DIFF input connections for any channel that meets any of the following conditions:

- Your application requires input ranges other than ±10 V.
- The input signal is low level and requires greater accuracy.
- The leads connecting the signal to the device are greater than 3 m (10 ft).
- The input signal requires a separate ground-reference point or return signal.
- The signal leads travel through noisy environments.
- Two analog input channels, AI+ and AI–, are available for the signal.

DIFF signal connections reduce noise pickup and increase common-mode noise rejection. DIFF signal connections also allow input signals to float within the working voltage of the device.

Refer to the *Taking Differential Measurements* section for more information about differential connections.

When to Use Referenced Single-Ended (RSE) Connections with Ground-Referenced Signal Sources

Do *not* use RSE connections with ground-referenced signal sources. Use differential connections instead.

As shown in the bottom-rightmost cell of Table 6, there can be a potential difference between GND and the ground of the sensor. In RSE mode, this ground loop causes measurement errors.

Taking Differential Measurements

For differential signals, connect the positive lead of the signal to the AI+ terminal, and the negative lead to the AI– terminal.

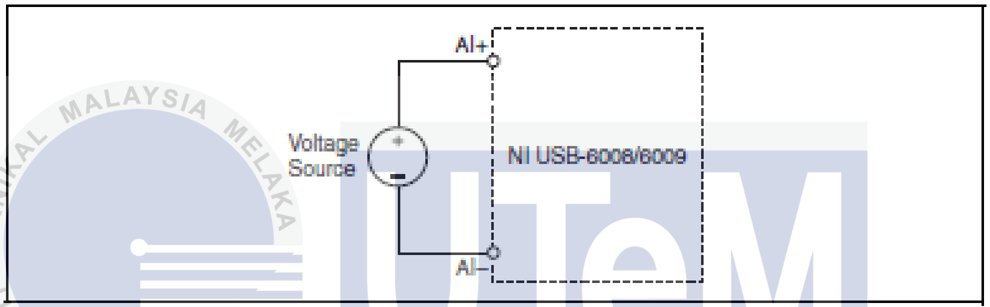


Figure 8. Connecting a Differential Voltage Signal

The differential input mode can measure ±20 V signals in the ±20 V range. However, the maximum voltage on any one pin is ±10 V with respect to GND. For example, if AI 1 is +10 V and AI 5 is –10 V, then the measurement returned from the device is +20 V.

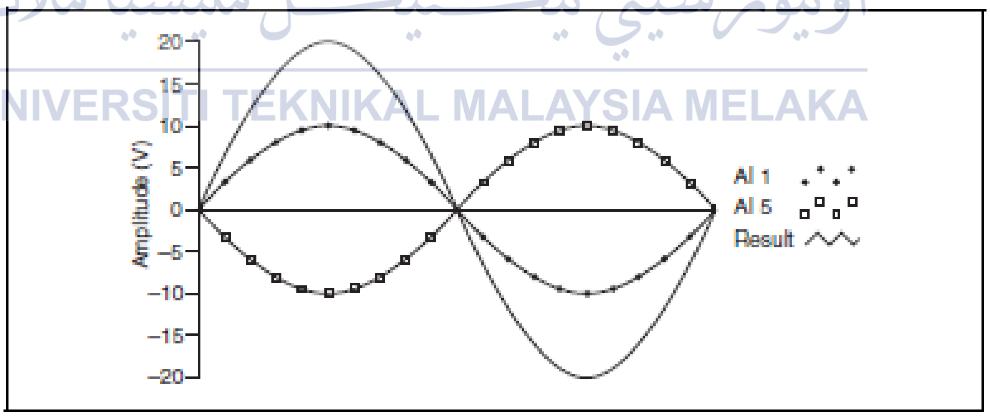


Figure 9. Example of a Differential 20 V Measurement

Connecting a signal greater than ±10 V on either pin results in a clipped output.

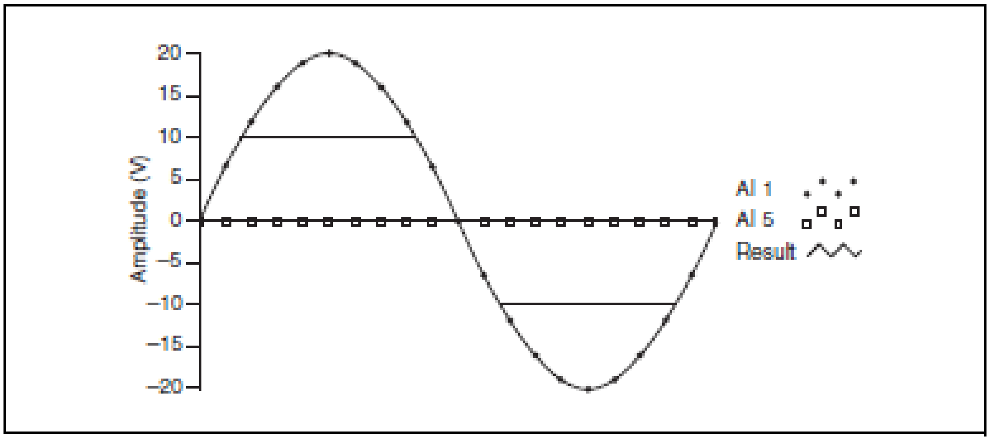


Figure 10. Exceeding ±10 V on AI Returns Clipped Output

Taking Referenced Single-Ended Measurements

To connect referenced single-ended (RSE) voltage signals to the NI USB-6008/6009, connect the positive voltage signal to an AI terminal, and the ground signal to a GND terminal, as shown in Figure 11.

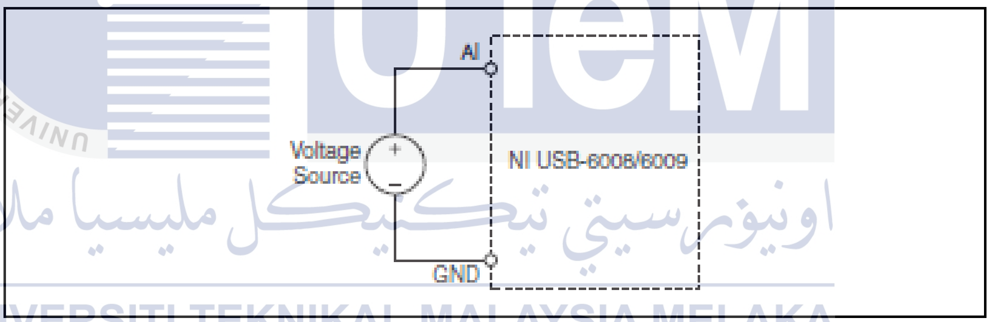


Figure 11. Connecting a Referenced Single-Ended Voltage Signal

When no signals are connected to the analog input terminal, the internal resistor divider may cause the terminal to float to approximately 1.4 V when the analog input terminal is configured as RSE. This behavior is normal and does not affect the measurement when a signal is connected.

Digital Trigger

You can configure PFI 0 as a digital trigger input for analog input tasks. Refer to the *Using PFI 0 as a Digital Trigger* section for more information.

Analog Output

The NI USB-6008/6009 has two independent analog output channels that can generate outputs from 0 to 5 V. All updates of analog output channels are software-timed. GND is the ground-reference signal for the analog output channels.

Figure 12 shows the circuitry of one analog output channel on the NI USB-6008/6009.

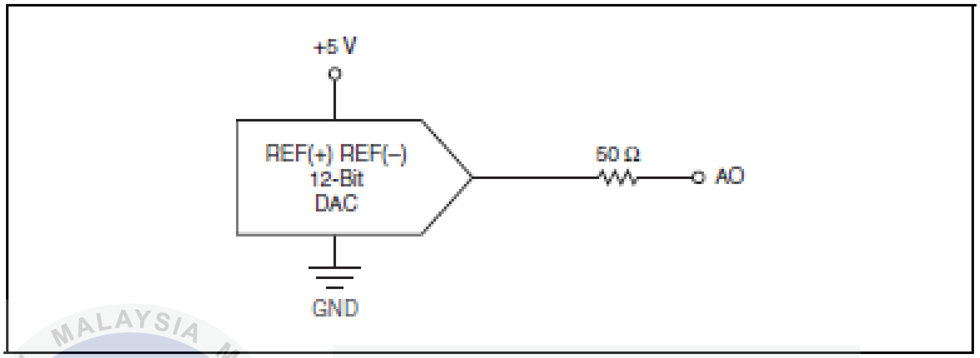


Figure 12. Circuitry of One Analog Output Channel

The main block featured in the NI USB-6008/6009 analog output circuitry is the digital-to-analog converter (DAC), which converts digital codes to analog voltages. There is one DAC for each analog output line.

Connecting Analog Output Loads

To connect loads to the NI USB-6008/6009, connect the positive lead of the load to the AO terminal, and connect the ground of the load to a GND terminal, as shown in Figure 13.

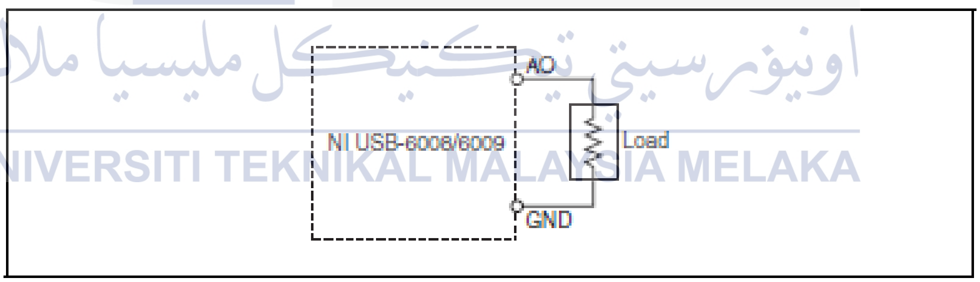


Figure 13. Connecting a Load

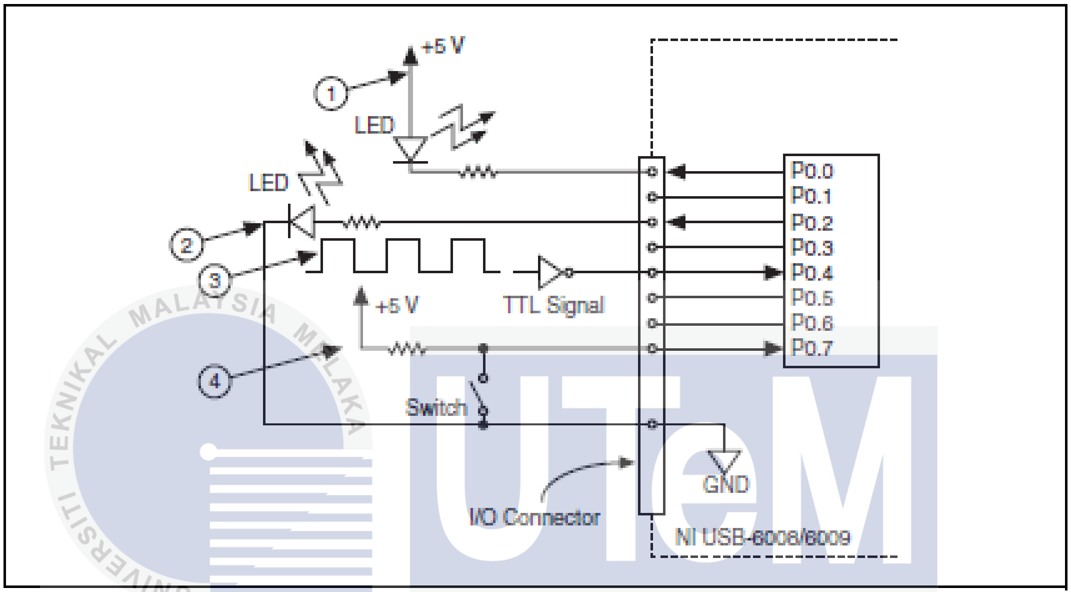
Minimizing Glitches on the Output Signal

When you use a DAC to generate a waveform, you may observe glitches in the output signal. These glitches are normal; when a DAC switches from one voltage to another, it produces glitches due to released charges. The largest glitches occur when the most significant bit of the DAC code changes. You can build a lowpass deglitching filter to remove some of these glitches, depending on the frequency and nature of the output signal. For more information about minimizing glitches. refer to the KnowledgeBase document, *Reducing Glitches on the Analog Output of MIO DAQ Devices*. To access this document, go to `ni.com/info` and enter the Info Code `exszek`.

Digital I/O

The NI USB-6008/6009 has 12 digital lines on two ports, Port 0 has eight lines, P0.<0..7>, and Port 1 has four lines, P1.<0..3>. GND is the ground-reference signal for the digital I/O ports. You can individually program all lines as inputs or outputs.

Figure 14 shows P0.<0..7> connected to example signals configured as digital inputs and digital outputs. You can configure P1.<0..3> similarly.



1	P0.0 configured as an open collector digital output driving an LED
2	P0.2 configured as an active drive digital output driving an LED
3	P0.4 configured as a digital input receiving a TTL signal from a gated invertor
4	P0.7 configured as a digital input receiving a 0 V or 5 V signal from a switch

Figure 14. Example of Connecting a Load

⚠ **Caution** Exceeding the maximum input voltage ratings or maximum output ratings, which are listed in the *Specifications* section, can damage the device and the computer. National Instruments is *not* liable for any damage resulting from such signal connections.

Source/Sink Information

The default configuration of the NI USB-6008/6009 digital I/O ports is open collector, allowing 5 V operation, with an onboard 4.7 kΩ pull-up resistor. An external user-provided pull-up resistor can be added to increase the source current drive up to a 8.5 mA limit per line as shown in Figure 15.[1]

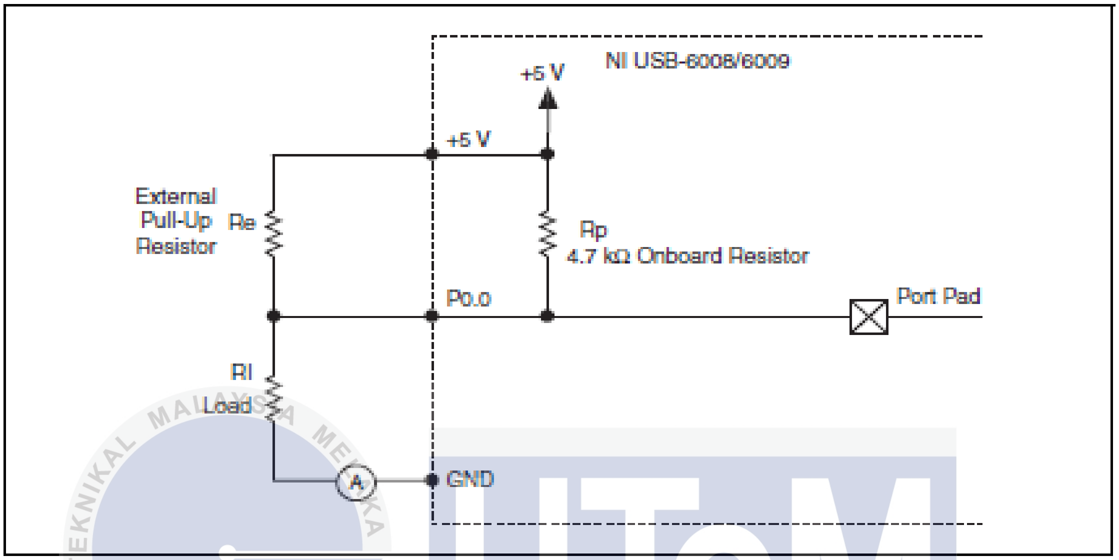


Figure 15. Example of Connecting an External User-Provided Resistor

The NI USB-6009 ports can also be configured as active drive using the NI-DAQmx API, allowing 3.3 V operation with a source/sink current limit of ±8.5 mA. For more information about how to set the DIO configuration, refer to the KnowledgeBase document, *Configuring NI Devices to be Open-Drain (Open Collector) or Push-Pull (Active Drive)*. To access this document, go to `ni.com/info` and enter the Info Code `ex52sp`.

Complete the following steps to determine the value of the user-provided pull-up resistor:

1. Place an ammeter in series with the load.
2. Place a variable resistor between the digital output line and the +5 V supply.
3. Set P0.0 to high.
4. Adjust the variable resistor until the ammeter current reads as the intended current. The intended current must be less than 8.5 mA.
5. Remove the ammeter and variable resistor from your circuit.
6. Measure the resistance of the variable resistor. The measured resistance is the ideal value of the pull-up resistor.
7. Select a static resistor value for your pull-up resistor that is greater than or equal to the ideal resistance.
8. Reconnect the load circuit and the pull-up resistor.

[1] This document uses NI-DAQmx naming conventions. Open-drain is called open collector and push-pull is called active drive.

I/O Protection

To protect the NI USB-6008/6009 against overvoltage, undervoltage, and overcurrent conditions, as well as ESD events, you should avoid these fault conditions by using the following guidelines:

- If you configure a DIO line as an output, do *not* connect it to any external signal source, ground signal, or power supply.
- If you configure a DIO line as an output, understand the current requirements of the load connected to these signals. Do *not* exceed the specified current output limits of the DAQ device.

  National Instruments has several signal conditioning solutions for digital applications requiring high current drive.
- If you configure a DIO line as an input, do *not* drive the line with voltages outside of its normal operating range. The DIO lines have a smaller operating range than the AI signals.
- Treat the DAQ device as you would treat any static-sensitive device. Always properly ground yourself and the equipment when handling the DAQ device or connecting to it.

Power-On States

At system startup and reset, the hardware sets all DIO lines to high-impedance inputs. The DAQ device does not drive the signal high or low. Each line has a weak pull-up resistor connected to it.

Static DIO

Each of the NI USB-6008/6009 DIO lines can be used as a static DI or DO line. You can use static DIO lines to monitor or control digital signals. All samples of static DI lines and updates of DO lines are software-timed.

PFI 0

PFI 0 is configurable as either a digital trigger input or an event counter input.

Using PFI 0 as a Digital Trigger

When an analog input task is defined, you can configure PFI 0 as a digital trigger input. When the digital trigger is enabled, the AI task waits for a rising or falling edge on PFI 0 before starting the acquisition. To use AI Start Trigger (ai/StartTrigger) with a digital source, specify PFI 0 as the source and select a rising or falling edge.

Using PFI 0 as an Event Counter

You can configure PFI 0 as a source for counting digital edges. In this mode, falling-edge events are counted using a 32-bit counter. For more information about event timing requirements, refer to the *Specifications* section.

External Reference and Power Source

The NI USB-6008/6009 creates an external reference and supplies a power source. All voltages are relative to ground (GND).

+2.5 V External Reference

The NI USB-6008/6009 creates a high-purity reference voltage supply for the ADC using a multi-state regulator, amplifier, and filter circuit. You can use the resulting +2.5 V reference voltage as a signal for self-test.

+5 V Power Source

The NI USB-6008/6009 supplies a 5 V, 200 mA output. You can use this source to power external components.

Note When the device is in USB suspend, the output is disabled.

Specifications

The following specifications are typical at 25 °C, unless otherwise noted.

Analog Input

Analog inputs	
Differential	4
Single-ended	8, software-selectable
Input resolution	
NI USB-6008	
Differential	12 bits
Single-ended	11 bits
NI USB-6009	
Differential	14 bits
Single-ended	13 bits
Max sample rate (aggregate)[1]	
NI USB-6008	10 kS/s
NI USB-6009	48 kS/s
Converter type	Successive approximation
AI FIFO	512 bytes
Timing resolution	41.67 ns (24 MHz timebase)
Timing accuracy	100 ppm of actual sample rate
Input range	
Differential	±20 V[2], ±10 V, ±5 V, ±4 V, ±2.5 V, ±2 V, ±1.25 V, ±1 V
Single-ended	±10 V

[1] System-dependent.

[2] ±20 V means that $|AI+ - (AI-)| \le 20$ V. However, AI+ and AI– must both be within ±10 V of GND. Refer to the *Taking Differential Measurements* section for more information.

Working voltage ....±10 V

Input impedance ....144 kΩ

Overvoltage protection..±35 V

Trigger source ....Software or external digital trigger

System noise[1]

Differential

±20 V range ....5 mVrms

±1 V range ....0.5 mVrms

Single-ended

±10 V range ....5 mVrms

Absolute accuracy at full scale, differential[2]

Range (V)	Typical at 25 °C (mV)	Maximum over Temperature (mV)
±20	14.7	138
±10	7.73	84.8
±5	4.28	58.4
±4	3.59	53.1
±2.5	2.56	45.1
±2	2.21	42.5
±1.25	1.70	38.9
±1	1.53	37.5

Absolute accuracy at full scale, single-ended

Range (V)	Typical at 25 °C (mV)	Maximum over Temperature (mV)
±10	14.7	138

Analog Output

Analog outputs 2

Output resolution ....12 bits

Maximum update rate ....150 Hz, software-timed

Output range ....0 to +5 V

Output impedance...50 Ω

Output current drive ....5 mA

Power-on state ....0 V

[1] System noise measured at maximum sample rate.

[2] Input voltages may not exceed the working voltage range.

Slew rate..1 V/µs

Short circuit current ....50 mA

Absolute accuracy (no load)

Typical...7 mV

Maximum at full scale ....36.4 mV

Digital I/O

Digital I/O lines

P0.<0..7>..8 lines

P1.<0..3>..4 lines

Direction control ....Each channel individually programmable as input or output

Output driver type[1]

NI USB-6008 ....Open collector

NI USB-6009 ....Each channel individually programmable as open collector or active drive

Compatibility ....TTL, LVTTL, CMOS

Absolute maximum voltage range ....–0.5 to 5.8 V with respect to GND

Pull-up resistor...4.7 kΩ to 5 V

Power-on state..Input

Digital logic levels

Level	Min	Max
Input low voltage	–0.3 V	0.8 V
Input high voltage	2.0 V	5.8 V
Input leakage current	—	50 µA
Output low voltage (I = 8.5 mA)	—	0.8 V
Output high voltage		
Active drive, I = –8.5 mA	2.0 V	3.5 V
Open collector, I = –0.6 mA, nominal	2.0 V	5.0 V
Open collector, I = –8.5 mA, with external pull-up resistor	2.0 V	—

External Voltage

+5 V output (200 mA maximum)

Minimum ....+4.85 V

Typical...+5 V

+2.5 V output (1 mA maximum) ....+2.5 V

+2.5 V accuracy ....0.25% maximum

Reference temperature drift ....50 ppm/°C maximum

[1] This document uses NI-DAQmx naming conventions. Open-drain is called open collector and push-pull is called active drive.

Event Counter

Number of counters 1

Resolution ....32 bits

Counter measurements..Edge counting (falling-edge)

Counter direction ....Count up

Pull-up resistor..4.7 kΩ to 5 V

Maximum input frequency..5 MHz

Minimum high pulse width..100 ns

Minimum low pulse width..100 ns

Input high voltage ....2.0 V

Input low voltage ....0.8 V

Bus Interface

USB specification ....USB 2.0 full-speed

USB bus speed ....12 Mb/s

Power Requirements

USB

4.10 to 5.25 VDC

Typical..80 mA

Maximum..500 mA

USB suspend

Typical..300 µA

Maximum..500 µA

Physical Characteristics

Dimensions ....Refer to Figure 16.

Without connectors..63.5 mm × 85.1 mm × 23.2 mm (2.50 in. × 3.35 in. × 0.91 in.)

With connectors ....81.8 mm × 85.1 mm × 23.2 mm (3.22 in. × 3.35 in. × 0.91 in.)

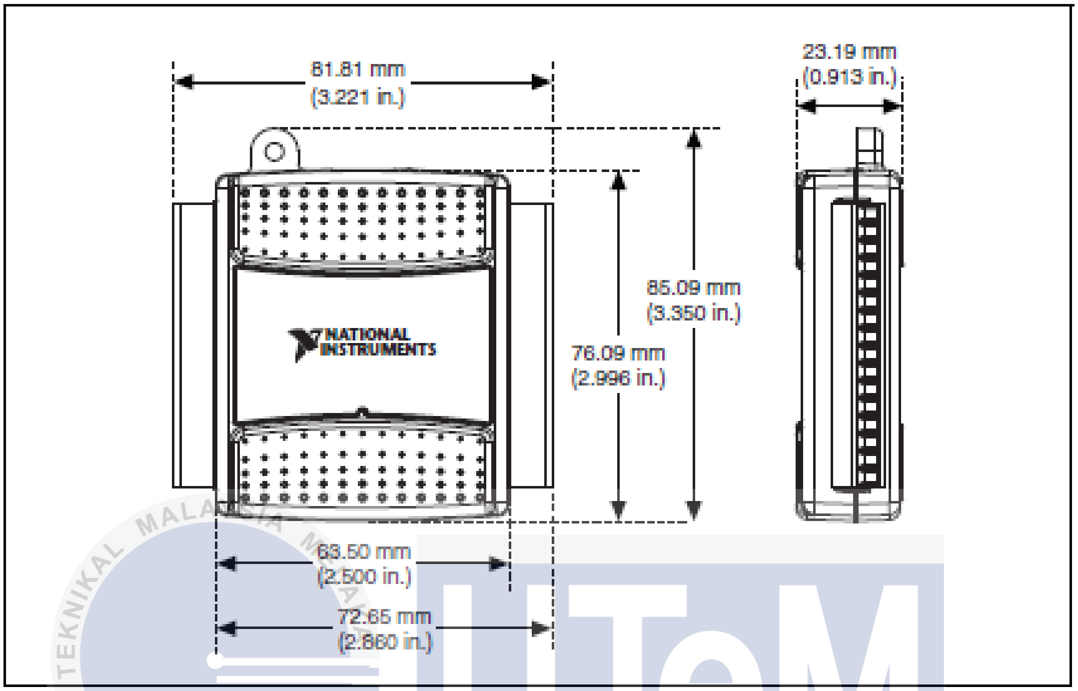


Figure 16. NI USB-6008/6009 Dimensions

Weight

Without connectors ....54 g (1.9 oz)

With connectors ....84 g (3 oz)

I/O connectors...USB series B receptacle, (2) 16 position screw terminal plugs

Screw-terminal wiring ....16 to 28 AWG

Torque for screw terminals ....0.22–0.25 N · m (2.0–2.2 lb · in.)

If you need to clean the module, wipe it with a dry towel.

Safety Voltages

Connect only voltages that are within these limits.

Channel-to-GND...±30 V max, Measurement Category I

Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as *MAINS* voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.

Caution Do *not* use this module for connection to signals or for measurements within Measurement Categories II, III, or IV.

Environmental

Temperature (IEC 60068-2-1 and IEC 60068-2-2)

- Operating ....0 to 55 °C
- Storage ....–40 to 85 °C

Humidity (IEC 60068-2-56)

- Operating ....5 to 95% RH, noncondensing
- Storage ....5 to 90% RH, noncondensing

Pollution Degree (IEC 60664) 2

Maximum altitude ....2,000 m

Indoor use only.

Safety

This product meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Basic immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

Note In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

Note Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generates radio frequency energy for the treatment of material or inspection/analysis purposes.

Note For EMC declarations and certifications, and additional information, refer to the *Environmental Management* section.

CE Compliance CE

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

Online Product Certification

To obtain product certifications and the Declaration of Conformity (DoC) for this product, visit `ni.com/certification`, search by model number or product line, and click the appropriate link in the Certification column.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *NI and the Environment* Web page at `ni.com/environment`. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers The symbol indicates that the waste products should be disposed of separately from municipal household waste according to Directive 2002/96/EC of the European Parliament and the Council on waste electrical and electronic equipment (WEEE). At the end of the product life cycle, all products must be sent to a WEEE collection and recycling center. Proper disposal of WEEE reduces the environmental impact and risk to human health due to potentially hazardous substances that are generally used in such equipment. Your cooperation in the correct disposal of the products will contribute to the effective usage of natural resources. For information about the available collection and recycling scheme in a particular country, refer to `ni.com/citizenship/weee`.

电子信息产品污染控制管理办法（中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。(For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.)

Where to Go from Here

This section lists where you can find example programs for the NI USB-6008/6009 and relevant documentation.

Example Programs

NI-DAQmx and NI-DAQmx software include example programs to help you get started programming with the NI USB-6008/6009. Modify example code and save it in an application, or use examples to develop a new application, or add example code to an existing application.

NI-DAQmx

To locate NI software examples, go to `ni.com/info` and enter the Info Code `daqmxexp`. For additional examples, refer to `zone.ni.com`.

To run examples without the device installed, use an NI-DAQmx simulated device. For more information, in Measurement & Automation Explorer (MAX), select **Help»Help Topics»NI-DAQmx»MAX Help for NI-DAQmx** and search for simulated devices.

NI-DAQmx Base

NI-DAQmx Base examples are accessible from **Start»All Programs»National Instruments»NI-DAQmx Base»Examples**.

Related Documentation

Each application software package and driver includes information about writing applications for taking measurements and controlling measurement devices. The following references to documents assume you have NI-DAQmx 9.3 or later, and where applicable, version 8.5 or later of the NI application software.

NI-DAQmx

The *NI USB-6008/6009 Quick Start* packaged with the NI USB-6008/6009 describes how to install NI-DAQmx software, install the device, and confirm that your device is operating properly.

The *NI-DAQ Readme* lists which devices, ADEs, and NI application software are supported by this version of NI-DAQ. Select **Start»All Programs»National Instruments»NI-DAQ»NI-DAQ Readme**.

The *NI-DAQmx Help* contains API overviews, general information about measurement concepts, key NI-DAQmx concepts, and common applications that are applicable to all programming environments. Select **Start»All Programs»National Instruments»NI-DAQ»NI-DAQmx Help**.

NI-DAQmx Base (Linux/Mac OS X/LabVIEW PDA 8.*x*)

The *NI-DAQmx Base Getting Started Guide* describes how to install your NI-DAQmx Base software, your NI-DAQmx Base-supported DAQ device, and how to confirm that your device is operating properly. In Windows, select **Start»All Programs»National Instruments»NI-DAQmx Base»Documentation»NI-DAQmx Base Getting Started Guide**.

The *Getting Started with NI-DAQmx Base for Linux and Mac OS X Users* document describes how to install your NI-DAQmx Base software, your NI-DAQmx Base-supported DAQ device, and how to confirm that your device is operating properly on your Linux or Mac machine.

The *NI-DAQmx Base Readme* lists which devices are supported by a version of NI-DAQmx Base. In Windows, select **Start»All Programs»National Instruments»NI-DAQmx Base»DAQmx Base Readme**.

The *NI-DAQmx Base VI Reference Help* contains VI reference and general information about measurement concepts. In LabVIEW, select **Help»NI-DAQmx Base VI Reference Help**.

The *NI-DAQmx Base C Function Reference Help* contains C reference and general information about measurement concepts. In Windows, select **Start»All Programs»National Instruments»NI-DAQmx Base»Documentation»C Function Reference Help**.

Note All NI-DAQmx Base documentation for Linux is installed at `/usr/local/natinst/nidaqmxbase/documentation`.

Note All NI-DAQmx Base documentation for Mac OS X is installed at `/Applications/National Instruments/NI-DAQmx Base/documentation`.

LabVIEW

If you are a new user, use the *Getting Started with LabVIEW* manual to familiarize yourself with the LabVIEW graphical programming environment and the basic LabVIEW features you use to build data acquisition and instrument control applications. Open the *Getting Started with LabVIEW* manual by selecting **Start»All Programs»National Instruments»LabVIEW»LabVIEW Manuals** or by navigating to the `labview\manuals` directory and opening `LV_Getting_Started.pdf`.

Use the *LabVIEW Help*, available by selecting **Help»LabVIEW Help** in LabVIEW, to access information about LabVIEW programming concepts, step-by-step instructions for using LabVIEW, and reference information about LabVIEW VIs, functions, palettes, menus, and tools. Refer to the following locations on the **Contents** tab of the *LabVIEW Help* for information about NI-DAQmx:

- **Getting Started with LabVIEW»Getting Started with DAQ**—Includes overview information and a tutorial to learn how to take an NI-DAQmx measurement in LabVIEW using the DAQ Assistant.
- **VI and Function Reference»Measurement I/O VIs and Functions» DAQmx - Data Acquisition VIs and Functions**—Describes the LabVIEW NI-DAQmx VIs and functions.
- **Property and Method Reference»NI-DAQmx Properties** contains the property reference.
- **Taking Measurements**—Contains the conceptual and how-to information you need to acquire and analyze measurement data in LabVIEW, including common measurements, measurement fundamentals, NI-DAQmx key concepts, and device considerations.

LabWindows/CVI

The **Data Acquisition** book of the *LabWindows/CVI Help* contains *Taking an NI-DAQmx Measurement in LabWindows/CVI*, which includes step-by-step instructions about creating a measurement task using the DAQ Assistant. In LabWindows™/CVI™, select **Help»Contents**, then select **Using LabWindows/CVI»Data Acquisition**. This book also contains information about accessing detailed information through the *NI-DAQmx Help*.

The **NI-DAQmx Library** book of the *LabWindows/CVI Help* contains API overviews and function reference for NI-DAQmx. Select **Library Reference»NI-DAQmx Library** in the *LabWindows/CVI Help*.

Measurement Studio

If you program your NI-DAQmx-supported device in Measurement Studio using Visual C# or Visual Basic .NET, you can interactively create channels and tasks by launching the DAQ Assistant from MAX or from within Visual Studio. You can use Measurement Studio to generate the configuration code based on your task or channel. Refer to the *DAQ Assistant Help* for additional information about generating code.

The *NI Measurement Studio Help* is fully integrated with the Microsoft Visual Studio help. To view this help file in Visual Studio, select **Measurement Studio»NI Measurement Studio Help**. For information related to developing with NI-DAQmx, refer to the following topics within the *NI Measurement Studio Help*:

- For step-by-step instructions on how to create an NI-DAQmx application using the Measurement Studio Application Wizard and the DAQ Assistant, refer to *Walkthrough: Creating a Measurement Studio NI-DAQmx Application*.
- For help with NI-DAQmx methods and properties, refer to *NationalInstruments.DAQmx Namespace* and *NationalInstruments.DAQmx.ComponentModel Namespace*.
- For conceptual help with NI-DAQmx, refer to *Using the Measurement Studio NI-DAQmx .NET Library* and *Developing with Measurement Studio NI-DAQmx*.
- For general help with programming in Measurement Studio, refer to *Getting Started with the Measurement Studio Class Libraries*.

To create an application in Visual Basic .NET or Visual C#, follow these general steps:

1. In Visual Studio, select **File»New»Project** to launch the New Project dialog box.
2. In the Project types pane, expand the **Visual Basic** or **Visual C#** node, depending on which language you want to create the project in, and select **Measurement Studio**.
3. Choose a project type. You add DAQ tasks as a part of this step.

ANSI C without NI Application Software

The *NI-DAQmx Help* contains API overviews and general information about measurement concepts. Select **Start»All Programs»National Instruments»NI-DAQ»NI-DAQmx Help**.

The *NI-DAQmx C Reference Help* describes the NI-DAQmx Library functions, which you can use with National Instruments data acquisition devices to develop instrumentation, acquisition, and control applications. Select **Start»All Programs»National Instruments»NI-DAQ» Text-Based Code Support»NI-DAQmx C Reference Help**.

.NET Languages without NI Application Software

With the Microsoft .NET Framework version 2.0 or later, you can use NI-DAQmx to create applications using Visual C# and Visual Basic .NET without Measurement Studio. You need Microsoft Visual Studio .NET 2005 or later for the API documentation to be installed.

The installed documentation contains the NI-DAQmx API overview, measurement tasks and concepts, and function reference. This help is fully integrated into the Visual Studio documentation. To view the NI-DAQmx .NET documentation, go to **Start»All Programs»National Instruments»NI-DAQ» Text-Based Code Support**. For function reference, refer to the *NationalInstruments.DAQmx Namespace* and *NationalInstruments.DAQmx.ComponentModel Namespace* topics. For conceptual help, refer to the *Using the Measurement Studio NI-DAQmx .NET Library* and *Developing with Measurement Studio NI-DAQmx* sections.

To get to the same help topics from within Visual Studio 2005 or 2008, go to **Help»Contents** and select **Measurement Studio** from the **Filtered By** drop-down list. To get to the same help topics from within

Visual Studio 2010, go to **Help»View Help** and select **NI Measurement Studio Help** from the **Related Links** section.

Training Courses

If you need more help getting started developing an application with NI products, NI offers training courses. To enroll in a course or obtain a detailed course outline, refer to `ni.com/training`.

Technical Support on the Web

For additional support, refer to `ni.com/support` or `zone.ni.com`.

Note You can download these documents at `ni.com/manuals`.

DAQ specifications and some DAQ manuals are available as PDFs. You must have Adobe Acrobat Reader with Search and Accessibility 5.0.5 or later installed to view the PDFs. Refer to the Adobe Systems Incorporated Web site at `www.adobe.com` to download Acrobat Reader. Refer to the National Instruments Product Manuals Library at `ni.com/manuals` for updated documentation resources.

Where to Go for Support

The National Instruments Web site is your complete resource for technical support. At `ni.com/support` you have access to everything from troubleshooting and application development self-help resources to email and phone assistance from NI Application Engineers.

A Declaration of Conformity (DoC) is our claim of compliance with the Council of the European Communities using the manufacturer's declaration of conformity. This system affords the user protection for electromagnetic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting `ni.com/certification`. If your product supports calibration, you can obtain the calibration certificate for your product at `ni.com/calibration`.

National Instruments corporate headquarters is located at 11500 North Mopac Expressway, Austin, Texas, 78759-3504. National Instruments also has offices located around the world to help address your support needs. For telephone support in the United States, create your service request at `ni.com/support` and follow the calling instructions or dial 512 795 8248. For telephone support outside the United States, visit the Worldwide Offices section of `ni.com/niglobal` to access the branch office Web sites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

 371303M-01 Feb12

Appendix C: SCT-013-000A , 100A:50mA Split Core current sensor Datasheet

SPECIFICATION

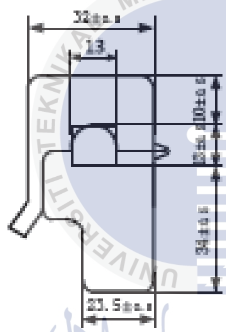
Customer Title : XiDi Technology

Product Name:

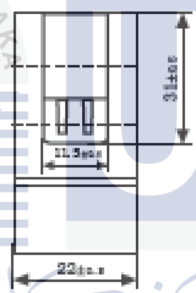
Manufacture Model : SCT-013-000

Charateristics: open size:13mm×13mm
1m leading wire
Core material:Ferrite
Fire resistance property:in accordance with
UL 94-V0
Dielectric strength: 1000V AC/1min 5mA
(between shell and output)

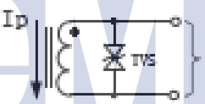
Outline size diagram:(in mm)



Front View



Side View



Schematic Diagram

Typical table of technical parameters:

input current	output voltage	non-linearity	build-in sampling resistance (RL)
0-100A	0-50mV	±3%	Ω
turn ratio	resistance grade	work temperature	dielectric strength(between shell and output)
100A:0.05A	Grade B	-25℃~+70℃	1000V AC/1min 5mA

Customer Sign:

Phone: 0555-7929499-805
Cell: 13695554514
Contact Name: Engineer Chen

2011-7-26