DEVELOPMENT OF THREE PHASE BACK TO BACK CONVERTER WITH CURRENT FLOW CONTROL USING RASPBERRY PI MICROCONTROLLER

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ABSTRACT

A High-Voltage Direct Current (HVDC) electric power transmission system uses direct current form the bulk transmission of electrical power, in contrast with the common Alternating Current (AC) systems. For a long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. The overall HVDC system is call back-to-back converter. Therefore, this project is to design and to develop a back-to-back converter with Proportional-Integrative-derivative (PID) control current that could be applied for the resistive load. The basic structure of the PID controller makes it easy to regulate the process output. The control technique is called a current control technique by comparing the output current with the reference current. Thus, the PID controller will force the output current to follow the reference current by creating and changing the pulse width modulation (PWM) signals. The PID controller is developed and simulated by using MATLAB/Simulink software and then implemented to the hardware by using Raspberry Pi Microcontroller. The result from the simulation shows that, the load current follows the reference current from 0 amperes until 1 amperes and the results from the experiment shows that the output current at the load follows the reference current from 0 amperes until 0.4 amperes. The high sensitivity of current sensor and also due to very low resolution of analogue to digital converter effect the result in this project. The results explanation of the project can be divided into three categories; simulation, open loop control and closed loop control.

ABSTRAK

Sistem arus terus voltan tinggi (HVDC) bagi penghantaran bekalan elektrik menggunakan arus terus secara pukal digunakan berbeza dengan sistem arus ulang alik yang sediaada. Ini kerana bagi penghantaran bekalan elektrik yang mempunyai jarak jauh, sistem HVDC lebih murah dan dapat mengurangkan kehilangan kuasa disebabkan oleh talian penghantaran. Keseluruhan sistem ini dinamakan sebagai pengubah arus ulangalik kepada arus terus dan arus terus kepada arus ulangalik. Oleh itu projek ini adalah untuk merekabentuk dan membangunkan pengubah arus ulangalik kepada arus terus dan arus terus kepada arus ulangalik menggunakan teknik pengawal arus PID yang boleh diaplikasi terhadap beban rintangan. Kaedah kawalan ini dinamakan sebagai kawalan arus yang mana arus keluaran akan dibandingkan dengan arus yang telah ditetapkan atau disetkan. Pengawal PID akan memaksa arus keluaran supaya mengikut arus yang telah ditetapkan dengan menghasilkan dan mengubah isyarat PWM. Pengawal PID dibangunkan dengan menggunakan perisian MATLAB/Simulink dan diimplimentasi menggunakan pengawal mikro Raspberry Pi. Keputusan yang diperolehi daripada simulasi menunjukkan arus pada beban mengikut arus yang telah ditetapkan daripada 0 ampere sehingga 1 ampere dan keputusan yang dipeolehi daripada eksperimen penuh menunjukkan arus pada beban mengikut arus ditetapkan dari 0 ampere hingga 0.4 ampere. Sensitiviti yang tinggi oleh pengesan arus dan juga resolusi rendah oleh penukar analog ke digital memberi kesan kepada keputusan eksperimen ini. Keputusan ini boleh dibahagikan kepada tiga kategori iaitu simulasi, kawalan gelung terbuka dan kawalan gelung tertutup.

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CHAPTER 1

RESEARCH BACKGROUND

1.1 Introduction

Electrical power is generated as an alternating current (AC). Electric power transmission is the bulk transfer of electrical energy, from generating power plants to electrical substations located near demand centers. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. Transmission lines, when interconnected with each other, become transmission networks. In many circumstances, however, it is economically and technically advantageous to introduce direct current (DC) links into the electrical supply system. The DC use two conductor for the power transmission compare to the AC.

The back-to-back converter has the capability to convert the AC to the DC and then converted back to AC. This converter used the semiconductor devices or named specifically MOSFET as main switching devices. The pulse width modulation (PWM) signal is using to control the MOSFET by connecting this signal into the gate pin on the MOSFET. The Raspberry Pi Microcontroller is used to produce the PWM while the MATLAB Simulink Toolbox software used to program the Raspberry Pi. The back-to-back converter connected to the current sensor before connected to the linear load or resistive as a load. This sensor measured the current flow to the linear load and sends the signal back to Raspberry Pi Microcontroller as a feedback signal.

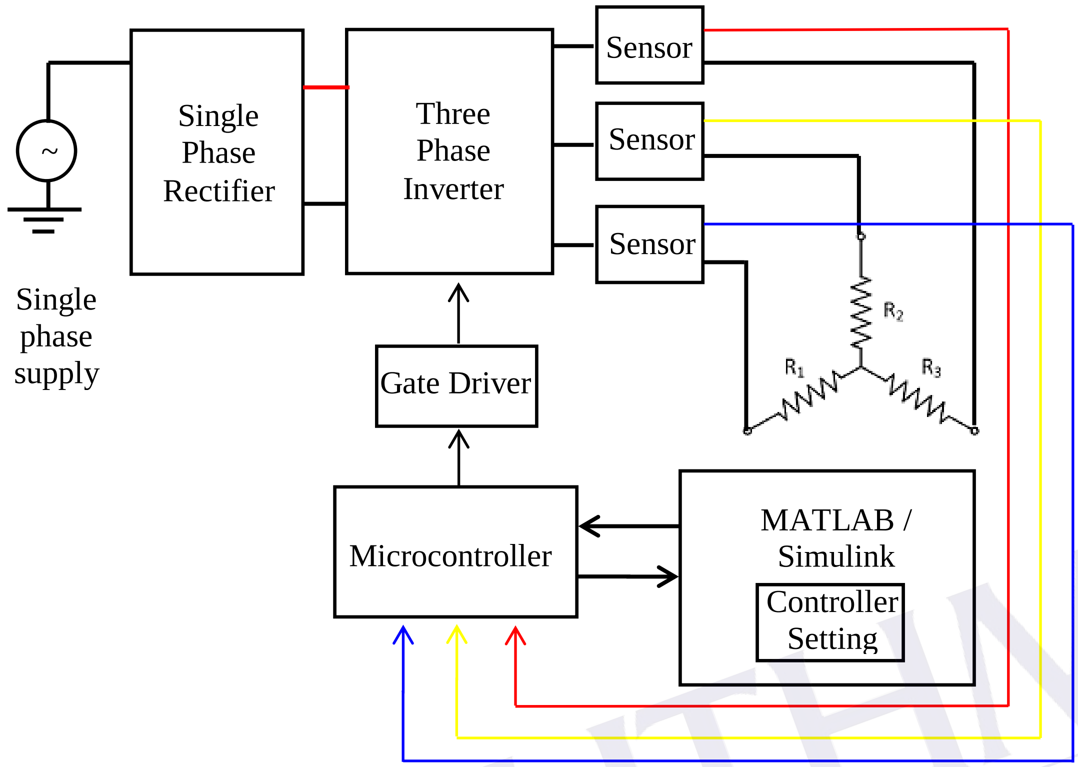

Figure 1:1: General block diagram of project

Figure 1.1 shows the general block diagram for this project. This project consists of single phase rectifier, three phase inverter, gate driver, current sensor, Raspberry Pi Microcontroller, MATLAB R2014a Simulink Toolbox software and resistive load.

1.2 Problem Statement

With the advancement in the field of power electronics it has been well established that multilevel inverter is the most widely used static power converters for alternating current applications which includes variable speed industrial electric drives, electric vehicles, reactive power compensation in large distribution and transmission systems, electric traction drives and interfacing of renewable energy sources (photovoltaic and fuel cell) with the utility. Many of these application required bidirectional operation of the multilevel converters [1]. Multilevel power converters are now finding increased attention in industry and academia as one of the preferred choices of electronic power conversion for medium/high power application

[2] like high power AC motor drives. The main objective of using multilevel converter in high power application is to eliminate heavy costly transformers from the motor drive. Another advantage of using multilevel converters are nearly sinusoidal current waveform, lower common-mode voltage & lower dv/dt that lead to reduce stress on motor bearings & windings [3,4]. The multilevel converters can be used to operate in either inverter or the rectifier. When the converters used in inverter mode, the DC input is converted to the AC supply while in rectifier mode, the AC are converted to the DC supply. The multilevel converters is used the same circuit and component to operate in inverter or rectifier mode. These concepts are used in HVDC system to convert the AC to DC and then back to AC supply. The multilevel converters in rectifier mode is used to converts the AC supply to DC supply and the multilevel converters in inverter mode to convert to AC supply before connected to the load. This sort of connection of multilevel converters for AC-DC-AC conversion is commonly known as Back-to-Back Configuration (BTB). There is another advantage of BTB configuration is that, it provide power controllability at both machine and grid side.

The control strategy of multilevel power converters is the heart of the whole system, it actually decide the performance of converter designed for particular application. The basic aim of the control is to produce multilevel voltages with good spectral quality in multilevel power converters (MPCs). As the control part plays an important role in the working of MPCs, it is worth to present some of the basics for the effective implementation of the control strategy. Normally control is implemented in following three steps [5].

i. Sensing of variable used in control like voltage, supply current, output dc voltage etc.
ii. Implementation of control algorithm responsible for the high level transient and steady state performance of MPCs.
iii. Deriving of the gate signals for the solid state devices.

The important modulation techniques to control BTB can be classified as shown in Figure 1.2.

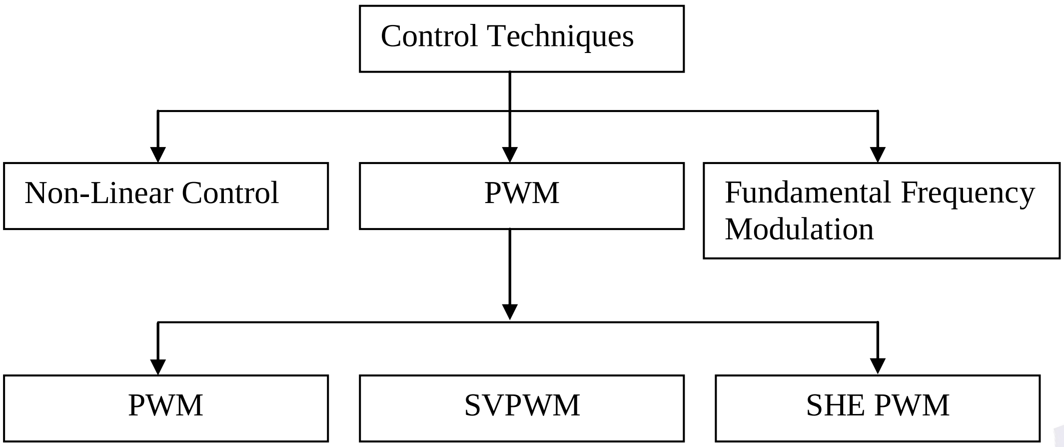

Figure 1:2:Classification of control techniques for MPCs connected Back to Back

In this review some specific and important applications on BTB connection are presented which clearly shows that this technology is now capable enough to handle the pressure of fast moving technology in this area and this is only possible due to major development in multilevel topologies, modulation technology and control methodology [6-7].

Nowadays, manual controller is also not practical in the technology era because it can waste time and cost. Operation cost regarding controller is got attention from industrial field. In order to reduce cost and time, making a controller based on computer because it is portable suggested. The user can monitor their system at certain place without need to going the plant (machine) especially in industrial implementation. From that, the man power can be reduced and reserve with computer which is more precise and reliable. The hardware of may be complicated and maintenance cost is higher. The simple electronic devices can be designed using power electronic control device to make a speed controller system [19].

The adaptive PID with MATLAB/Simulink controller is so designed that it can be used to overcome the problem in industry like to avoid machine damages and to avoid slow rise time and high overshoot. This is because when the starting voltage is high, it is not suitable for machine and can make machine damages. With the aid of feedback control, the controller monitors the current flow to the load.

1.3 Research Objectives

The objective of this research is:

i. To develop the single phase uncontrolled rectifier and three phase controlled inverter.
ii. To develop the three phase gate driver.
iii. To design an adaptive PID current controller using MATLAB/Simulink Toolbox function block.
iv. To investigate the communication between MATLAB Simulink software and Raspberry Pi Microcontroller.

1.4 Research Scopes

In this project the scope of work will be undertaken in the following four developmental stages:

i. The rating for the three phase inverter is the alternating current (AC) output between 0V to 40V. For this project, 100V input voltage; 30A maximum current power MOSFET (IRF540) is selected to be used as switching device due to the specification of resistive load is 4Ω, 10W produces 2.5A maximum current.
ii. The rating for the three phase gate driver is (10V-15V) output to drive the inverter. This circuit receive the signal from Raspberry Pi and MATLAB/Simulink. This gate driver consists of six inputs and three outputs to the load.
iii. Investigating the communication between MATLAB R2014a Simulink software and Raspberry Pi Microcontroller. The MATLAB R2014a Simulink software and Raspberry Pi Microcontroller should be able to communicate each other.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will focus on studies, facts and research on a particular topic on this project title. Although the literature have covers a wide variety of such theories, this review will focus on eight major themes which emerge repeatedly throughout the literature reviewed. These themes are: single-phase uncontrolled rectifier, gate driver, three phase inverter, controller method, software, Raspberry Pi and current sensor.

2.1 Single Phase Uncontrolled Rectifier

A single-phase full-wave rectifier consists of four diodes arranged as shown in Figure 2.1 in what is called a bridge. This rectifier circuit produces an output waveform that is the positive half of the incoming AC voltage waveform and the inverted negative half. The bias path for the positive output pulse is through diode D1, then the load, then D2, and back to the other side of the power supply. Diodes D3 and D4 are reverse-biased during this part [8].

The bias path for the negative cycle of the input waveform is through diode D4, then the load, then D3, and back to the opposite side of the power supply. The current flow through the load resistor is once again down. That is, it is flowing through the load in the same direction as during the positive cycle of the input waveform. Diodes D1 and D2 are reverse-biased during this part. The resulting output waveform is a series of positive pulses without the “gaps” of the half-wave rectifier output [8].

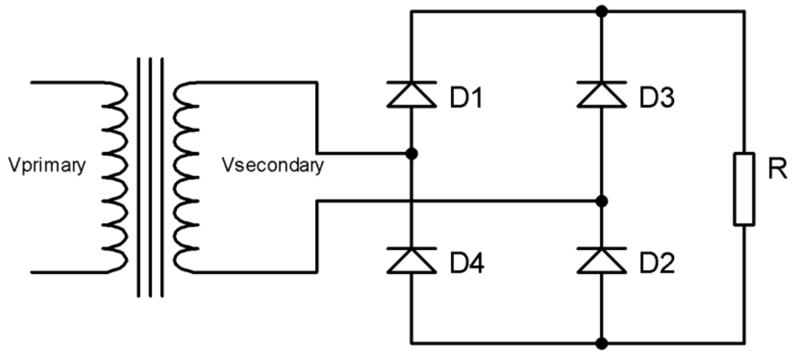

Figure 2.1: Single-phase full-wave bridge rectifier[8]

In many industrial applications, the full wave bridge rectifier is used along with a DC filter capacitor to smooth the ripples across the load. The load is simply a representative of a resistive or inductive load. It could be an inverter system or a high-frequency resonant link.

2.2 Gate Driver

Gate driver is a device that connects the control electronics up to the power stage. It is actually a powerful amplifier that can power Mosfet and IGBT. It accept a low power input from a controller IC and produce a high-current drive input for the gate of a high-power transistor which are power Mosfet and IGBT. Besides, these driver help to control electronics that need higher power than the PWM signals can generate. Gate driver also help to increase the input capacitance of power semiconductor associated with the circuit the driver is located on. This can be used in conjunction with several of other discrete transistors. There are two type of gate driver can be used for the electronics devices which are on-chip gate drivers and off-chip gate drivers. The on chip gate drivers can be used when application is for a low , voltage and low-current uses. For the off-chip gate driver, which are referred to as discrete gate drivers. These are ideal for high voltage and high current applications. Discrete gate drivers also increase the galvanic isolation to help protect the device from electrical faults and mechanical faults [9].

2.3 Pulse Width Modulation

Due to advances in solid state power devices, switching power converters are used in more and more modern motor drives to convert and deliver the required energy to the motor. The energy that a switching power converter delivers to a motor is controlled by Pulse Width Modulated (PWM) signals applied to the gates of the power transistors. PWM signals are pulse trains with fixed frequency and magnitude and variable pulse width. There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from pulse to pulse according to a modulating signal. When a PWIVI signal is applied to the gate of a power transistor, it causes the turn on and turns off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load depends mostly on the modulating signal [9].

Many PWM strategies, control schemes, and realization techniques have been developed nowadays. PWM strategy plays an important role in the minimization of harmonics and switching losses in converters, especially in three-phase applications. The first modulation techniques were developed in the mid-1960s by Kirnnich, Heinrick, and Bowes. The research in PWM schemes has intensified in the last few decades. The main aim of any modulation technique is to obtain a variable output with a maximum fundamental component and minimum harmonics [10].

2.4 Three Phase Inverter

A standard three-phase inverter is shown in Figure 2.2 consisting of six controlled switches such as IGBT. In this converter, the line currents can be shaped to be sinusoidal at a unity power factor, as well as the output ac voltage can be regulated at a desired value. The inverter is connected to the load through three LC filters. Third Harmonic Injection Pulse Width Modulation (THIPWM) employed to make full use of the DC bus voltage with minimum harmonic distortion in the output voltage and current [11].

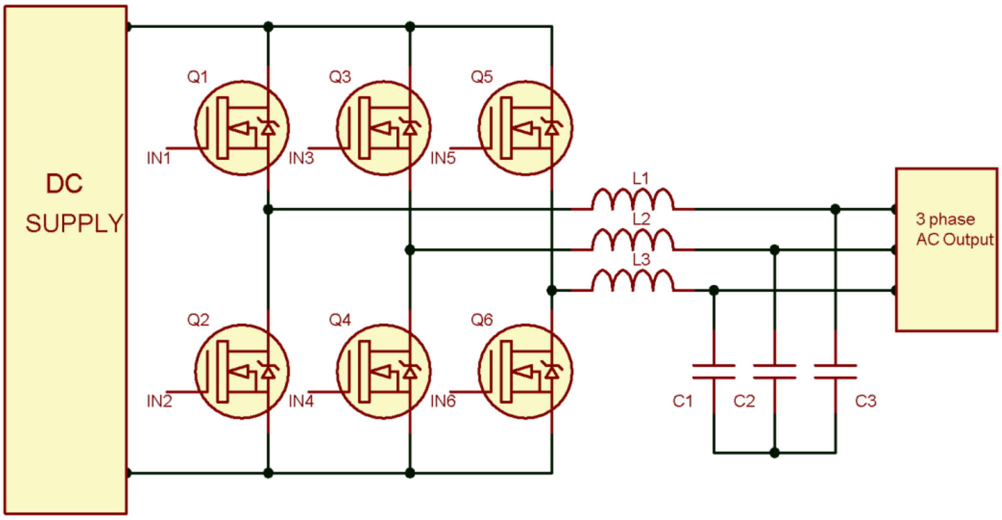

Figure 2.2: Three-Phase Inverter[11]

Figure 2.3 shows a typical configuration of a three-phase full-bridge UPS inverter. If switching frequency is high enough, the PWM inverter is considered as a voltage source inverter (VSI) and dynamic response of the UPS inverter is mainly determined by the elements of the filter. SPWM techniques are applied to inverters in order to obtain a sinusoidal output voltage with minimal undesired harmonics. Semiconductor switching devices (Q1–Q6) of the inverter are controlled by PWM signals to obtain three-phase near sinusoidal ac voltages of the desired magnitude and frequency at the inverter output [12].

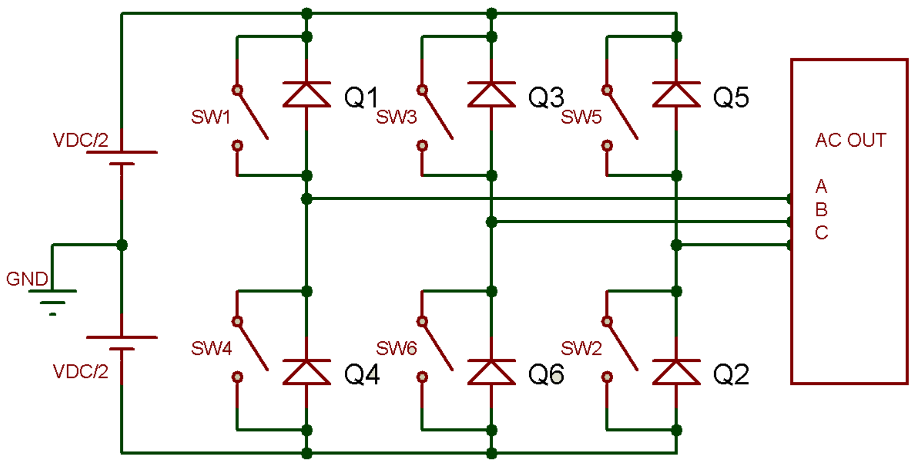

Figure 2.3: Basic three-phase voltage source inverter[12]

2.5 Overview of High-Voltage-Direct-Current (HVDC).

The power system begins from power plant. Inside the power plant, electrical power is producing by generator. From power plant, electrical power will transmit to transmission substation to step up by using transformer. From power plant to substation, the system operate in AC HVDC is used at transmission line only. To convert AC to DC, rectifier is used. In the end of transmission line, inverter is used to convert DC to AC again. The next station is power substation. The electrical power will step down here and transmit to the load or user. The Figure 2.4 shows the HVDC system in power transmission system [13].

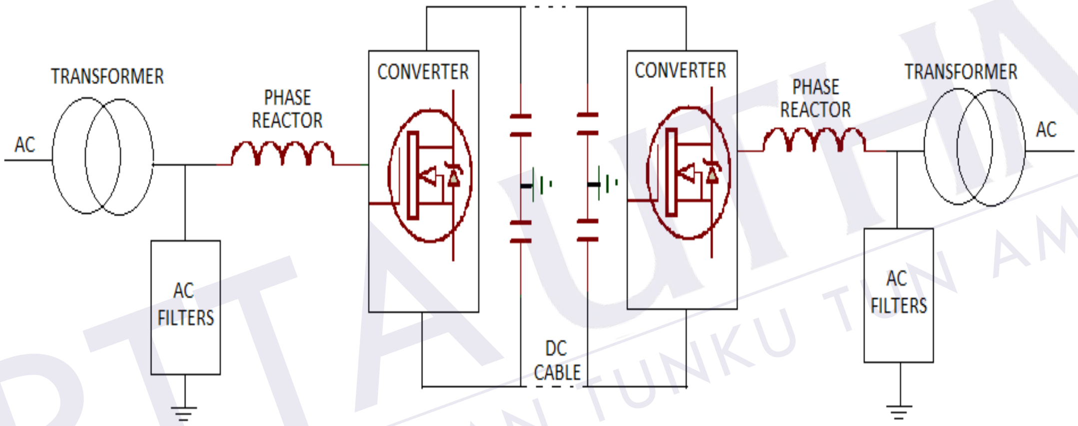

Figure 2.4: HVDC System[13]

Figure 2.4 show that how HVDC operate in two systems. As we know, the DC has only real power (P) not reactive power (Q) and apparent power(S). In DC, the value of frequency is equal to zero. So, the unsynchronized of AC can be combined together when the system convert to DC. To convert AC to DC, rectifier is used and to convert DC to AC, inverter is used. In DC, there are no reactive component like inductance and capacitance. Capacitance is leading (+ve) and inductance is lagging (-ve). After generation, transformer is used to step up the voltage. Transformer is used in AC only because transformer is component of inductance. After HVDC transmission, electrical power will convert to AC and step down by using transformer again [13].

2.6 Basic Controller Types

The PID controller (proportional integral derivative controller) is widely used in industrial control system. A PID controller calculates an “error” value as the difference between the measured process variable and the desired set point. The PID controller calculation involves three separate constants and is accordingly sometimes called three-term control which the proportional, the integral and derivative values are denoted by P, I and D. A proportional controller may not give steady state error performance which is needed in the system. An integral controller may give steady state error performance but it slows a system down. So the addition of a derivative term helps to cure both of these problems [14].

2.6.1 Proportional (P) Controller

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain constant.

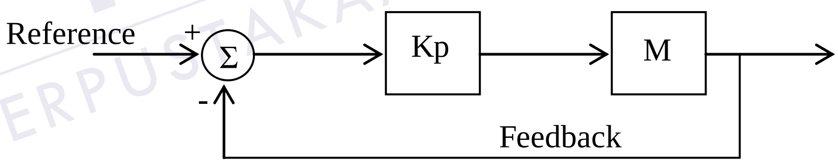

Figure 2.5: P control logic

In general it can be said that P controller cannot stabilize higher order processes. For the 1st order processes, meaning the processes with one energy storage, a large increase in gain can be tolerated. Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics. A large controller gain will result in control system with smaller steady state error, i.e. better reference following faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise and smaller amplitude and phase margin. When P controller is used, large gain is needed to improve steady state error. Stable systems do not have problems when large gain is used. Such systems are systems with one energy storage (1st order capacitive systems). If constant steady state error can be accepted with such processes, than P controller can be used. Small steady state errors can be accepted if sensor will give measured value with error or if importance of measured value is not too great anyway [15]. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain. The proportional term is given by equation 2.1 [16]:

$$u(t) = Kpe(t) \qquad (2.1)$$

2.6.2 Proportional-Integral (PI) Control

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used.

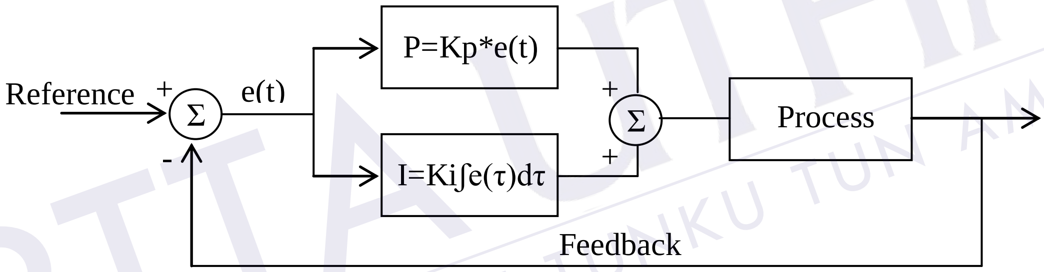

Figure 2.6: PI control logic

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when[17]:

a) fast response of the system is not required
b) large disturbances and noise are present during operation of the process
c) there is only one energy storage in process (capacitive or inductive)
d) there are large transport delays in the system

In order to calculate the output of the PI controller this can be expressed as equation 2.2:

$$u(t) = Kpe(t) + Ki\int_0^t e(\tau)d\tau \qquad (2.2)$$

2.6.3 Proportional-Integral-Derivative (PID) control

PID control logic is widely used in the process control industry. PID controllers have traditionally been chosen by control system engineers due to their flexibility and reliability [18]. A PID controller has proportional, integral and derivative terms that can be represented in transfer function form as $K(s) = K_p + K_i/s + K_d s$ where Kp represents the proportional gain, Ki represents the integral gain, and Kd represents the derivative gain, respectively. By tuning these PID controller gains, the controller can provide control action designed for specific process requirements [18]. The proportional term drives a change to the output that is proportional to the current error. This proportional term is concerned with the current state of the process variable.

The integral term (Ki) is proportional to both the magnitude of the error and the duration of the error. It (when added to the proportional term) accelerates the movement of the process 8 towards the set point and often eliminates the residual steady-state error that may occur with a proportional only controller. The rate of change of the process error is calculated by determining the differential slope of the error over time (i.e., its first derivative with respect to time). This rate of change in the error is multiplied by the derivative gain (Kd) [18].

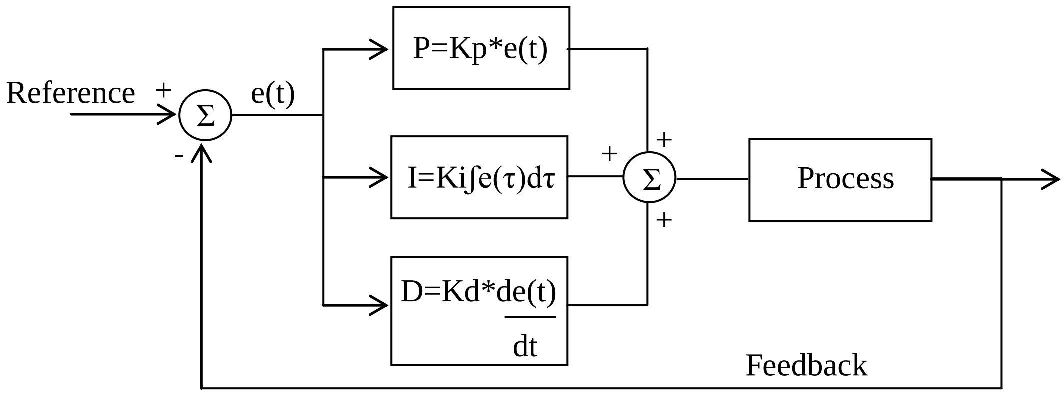

Figure 2.7: PID control logic

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. In order to calculate the output of the PID controller, the three terms are summed together, which can be expressed as equation 2.3:

:

$$u(t) = Kpe(t) + Ki\int_0^t e(\tau)d\tau + Kd\frac{de(t)}{dt} \quad (2.3)$$

Kp: Proportional gain, a tuning parameter

Ki: Integral gain, a tuning parameter

Kd: Derivative gain, a tuning parameter

ϵ: Error = Set Point – Process Variable

t: Time or instantaneous time (the present)

Γ: Variable of integration; takes on values from time 0 to the present time

Using above equation of the PID controller in time domain it is possible to develop an equation of a digital PID controller in order to use it on the Raspberry Pi Microcontroller. To approximate the formula, a T period sampling rate was used, thus the integral action is close to the sum of all values of the sampled error multiplied by the period, and the derivative action multiplied by the difference between the current and previous error divided by the period [19].

2.6.4 Tuning of PID Control parameters

For the control process, better performance can be achieved by tuning the control loop, which is adjusting the control parameters to satisfy the desired control response. For PID controller, each of the three parameters has different effect on system control which is summarized in Table 2.1 from [20] based on the situation of increasing the parameter individually.

Table 2.1:Effects caused by increasing the PID control parameter individually

Parameter	Rise Time	Overshoot	Settling Time	S-S Error	Stability
Kp	Decrease	Increase	Small Change	Decrease	Reduce
Ki	Decrease	Increase	Increase	Large Decrease	Reduce
Kd	Small Decrease	Decrease	Decrease	Small Change	Small Change

Therefore, tuning PID control parameters is a complicated process that we have to find an optimal way to arrange the values of the parameters for the control response.

2.6.5 Tuning PID Method

The meaning of tuning is adjustment of control parameters to the optimum values for the desired control response. The stability is a basic requirement. However, different systems have different behaviour, different applications have different requirements, and requirements may conflict with one another. PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, some of them [17]:

i- Manual tuning method,

ii- Ziegler–Nichols tuning method,

iii- PID tuning software methods.

2.6.5.1 Manual Tuning Method

Using manual tuning method, parameters are adjusted by watching system responses. Kp, Ki, Kd are changed until desired or required system response is obtained. Even though this method is simple, it should be used by experienced personal. For example, using One Manual Tuning Method, firstly, Ki and Kd are set to zero. Then, the Kp is increased until the output of the loop oscillates, after obtaining optimum Kp value, it should be set to approximately half of that value for a "quarter amplitude decay" type response. Then, Ki is increased until any offset is corrected in sufficient time for the process. However, too much Ki will cause instability. Finally, Kd is increased, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much Kd also will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a Kp setting significantly less than half that of the Kp setting causing oscillation [17]. Referring to Table 2.2, the effects of changing control parameters can be seen.

Table 2.2: Effect of changing control parameter

Parameter	Rise Time	Overshoot	Settling Time	S-S Error	Stability
Kp	Decrease	Increase	Small Change	Decrease	Worse
Ki	Decrease	Increase	Increase	Eliminate	Worse
Kd	Minor Dec.	Minor Decrease	Minor Decrease	No change	If Kd small, better

2.6.5.2 Ziegler–Nichols Tuning Method

Ziegler-Nichols oscillation method, which is introduced by john G Ziegler and Nathaniel B. Nichols in the 1940s. The strategy of the method is that first set Ki and Kd to zero while Kd as a small gain, and then gradually increase the value of Kp until the value Ko that caused the oscillation of the control output, record the oscillation period Po [21].

Table 2.3: Ziegler-Nichols method

Type/ Control Parameters	P Controller	PI Controller	PID Controller
Kp	$0.5K_o$	$0.45K_o$	$0.60K_o$
Ki		$1.2K_p/P_o$	$2K_p/P_o$
Kd			$K_pK_o/8$

2.6.5.3 PID Tuning Software Method

There is some prepared software that they can easily calculate the gain parameter. Any kind of theoretical methods can be selected in some these methods. Here the examples of software most used [17]:

i. MATLAB Simulink PID Controller Tuning,

ii. BESTune,

iii. Exper Tune etc.

2.6.6 Advantages and Disadvantages of Tuning Methods

There is some prepared software that they can easily calculate the gain parameter. Any kind of theoretical methods can be selected in some these methods, MATLAB Simulink PID Controller Tuning, BESTune or Exper Tune [17].

Table 2.4: Overview of tuning methods

Method	Advantages	Disadvantages
Manual Tuning	- No math required. - Online method	Requires experienced personnel.
Ziegler-Nichols	- Proven method. - Online method	- Process upset, some trial and error, very aggressive tuning.
Software Tools	- Consistent tuning. - Online or offline method. May include value and sensor analysis. - Allow simulation before downloading. - Can support non-steady state (NSS) tuning.	- Some cost and training involved.

2.7 SOFTWARE

The two software used in this project, it is MATLAB and MPLAB IDE from MicroChip. In this part consists of the software with details explanation.

2.7.1 MATLAB and SIMULINK

Simulink is a software package for modelling, simulating, and also for analysing dynamic systems. It supports linear and nonlinear systems, modelled in continuous time, sampled time, or a hybrid of the two. Systems can also be multi rate, i.e., have different parts that are sampled or updated at different rates. Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse. With this interface, drawing the models will be easier compared to previous simulation packages that require formulating differential equations in a language or program [22].

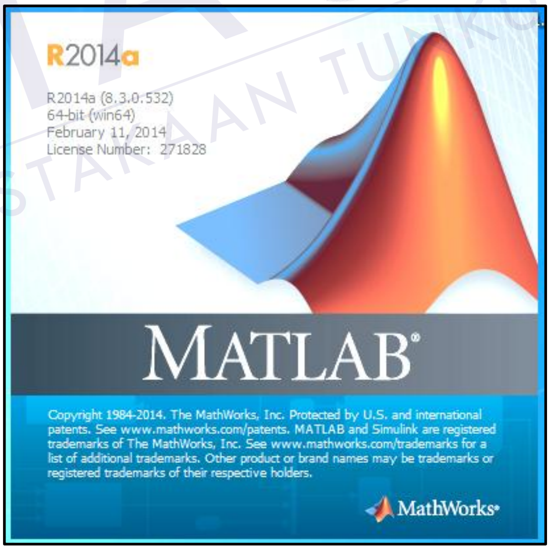

Figure 2.8: MATLAB Software

Simulink is software for modeling, simulating, and analyzing dynamic systems. With Simulink, it’s easily to build models from scratch, or modify existing models. Simulink supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate — having different parts that are sampled or updated at different rates. Thousands of scientists and engineers around the world use Simulink® to model and solve real problems in a variety of industries, including [23]:

i. Aerospace and Defense
ii. Automotive
iii. Communications
iv. Electronics and Signal Processing
v. Medical Instrumentation

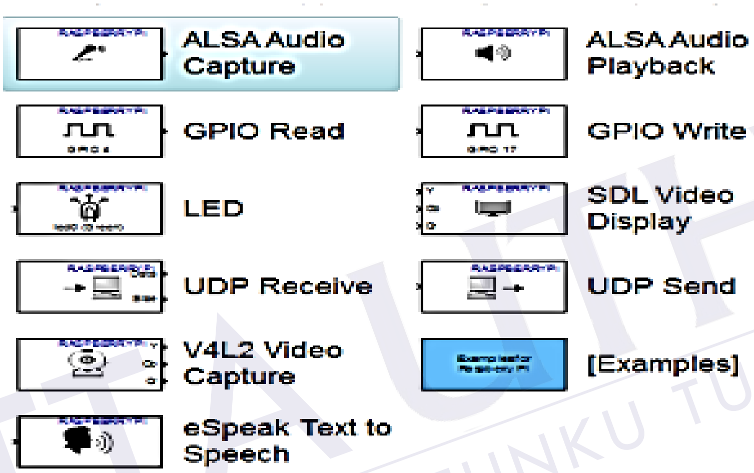

Figure 2.9: Simulink Support Package for Raspberry Pi

Figure 2.9 shows the Simulink Support Package for Raspberry Pi. The program can be created by using the library to control the hardware. Table 2.5 shows the Simulink Support Package for Raspberry Pi and the description of each package that have been used in this project.

Table 2.5: Description of Simulink Support Package for Raspberry Pi

Support Package	**Description**
GPIO Write	Sets the logical value of a GPIO pin configured as output
GPIO Read	Reads the logical value of a GPIO pin configured as input
LED	Turns an LED on or off

2.7.2 MPLAB INTEGRATED DEVELOPMENT ENVIRONMENT (IDE)

MPLAB Integrated Development Environment (IDE) is a free, integrated toolset for the development of embedded applications on Microchip's PIC and dsPIC microcontrollers.

Figure 2.10: MPLAB IDE Software

MPLAB IDE is a software program that runs on a PC (Windows, Mac OS, Linux) to develop applications for Microchip microcontrollers and digital signal controllers. It is called an Integrated Development Environment (IDE), because it provides a single integrated "environment" to develop code for embedded microcontrollers. In this project, this software are used to convert the analog signal from current sensor to the digital signal before send to the Raspberry Pi Microcontroller. The Raspberry Pi Microcontroller only received the digital signal to process the data.

2.8 Current Sensor

Figure 2.11 shows the diagram of ACS712 current sensor used in this project. The Allegro ACS712 family of current sensor ICs provides economical and precise solutions for AC or DC current sensing in industrial, automotive, commercial, and communications systems. Typical applications include motor control, load detection and management, power supplies, and overcurrent fault protection.

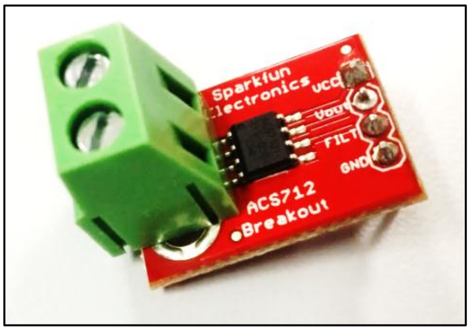

Figure 2.11: Diagram of ACS712 Current Sensor

The current sensor will connected in series with the resistive load. The changes of current will have a feedback current to the Raspberry Pi to take action. The current sensor should be able to measure the current flow to the load and the current should not exceed the maximum current sensor.

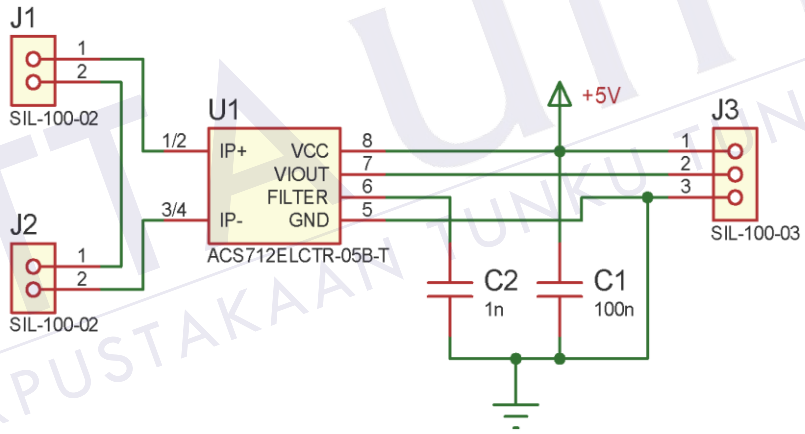

Figure 2.12: ACS712 Schematic Circuit

Figure 2.12 shows the ACS712 schematic circuit for the current sensor. The ACS712 outputs an analog signal, VIOUT that varies linearly with the uni- or bi-directional AC or DC primary sensed current, IP , within the range specified. CF is recommended for noise management, with values that depend on the application.

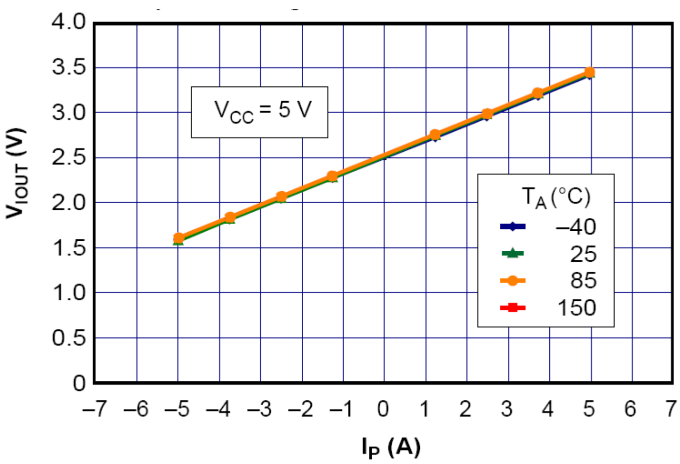

Figure 2.13: Output Voltage versus Sensed Current

Figure 2.13 shows the output voltage of the current sensor when the sensed current detected. The Ip(A) is primary current that flow to the current sensor. When no current is detected, Ip=0 ampere the the output voltage (VIOUT) at 2.5 Volt. The changes of current are depend on the sensitivity of the current sensor itself. Based on the datasheet of ACS756, the sensor has sensitivity of 185mV/A. The sensitivity versus sensed current is shown in Table 2.6.

Table 2.6: Sensitivity versus Sensed Current

Current	**Calculation** Formulae: V = 2.5V + (sensitivity x ΔI)	**Voltage**
0A	(2.5V + (0.185 x 0)	2.500
0.2A	(2.5V + (0.185 x 0.2)	2.537
0.4A	(2.5V + (0.185 x 0.4)	2.574
0.6A	(2.5V + (0.185x 0.6)	2.611
0.8A	(2.5V + (0.185 x 0.8)	2.648
1.0A	(2.5V + (0.185 x 1.0)	2.685

2.9 Raspberry Pi Microcontroller

This project use Raspberry Pi GPIO as the input and output for communication and SD Card with preloaded with the official Raspberry Pi NOOBS (New out Of the Box Software).

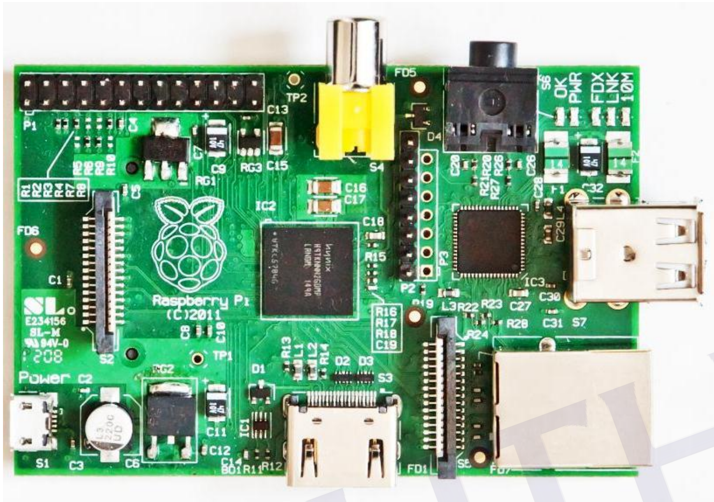

Figure 2.14: Raspberry Pi Hardware

The Raspberry Pi is a small, powerful and lightweight ARM based computer which can do many of the things a desktop PC can do. The powerful graphics capabilities and HDMI video output make it ideal for multimedia applications such as media centers and narrowcasting solutions. The Raspberry Pi is based on a Broadcom BCM2835 chip. It does not feature a built-in hard disk or solid-state drive, instead relying on an SD card for booting and long-term storage.

2.9.1 Raspberry Pi Specification

Table 2.7 shows the Raspberry Pi specification for the model B. The Model B is used in this project.

Table 2.7: Raspberry Pi Specification

Microcontroller	Model B
System On a Chip	Broadcom BCM2835
CPU	700 MHz ARM1176JZF-S core
Memory (SDRAM)	512 MB
Onboard Storage	SD / MMC / SDIO card slot
Low-level peripherals	17 x GPIO, plus the following, which can also be used as GPIO:UART, I^2C bus, SPI bus with two chip selects, I^2S audio +3.3 V, +5 V, ground
Power ratings	700 mA (3.5 W)
Power Source	5V via MicroUSB or GPIO header
Size	85.60 mm x 56.5 mm (3.370 in x 2.224 in) – not including protruding connectors
Weight	45g (1.6 oz)

2.9.2 GPIO Headers

One powerful feature of the Raspberry Pi is the row of GPIO (general purpose input/output pins along the edge of the board, next to the yellow video out socket. These pins are physical interface between the Pi and the outside world. The Raspberry Pi GPIO pin configuration is shown in Figure 2.15.

REFERENCES

1. J.R. Rodriguez, J.W. Dixon, J.R. Espinoza, J. Pontt, and P. Lezana, "PWM regenerative rectifiers: state of the art," Industrial Electronics, IEEE Transactions on , vol.52, no.1, pp. 5- 22, Feb. 2005.
2. M. Glantschnig, A. Porst, J. G. Bauer, D. Reznik, H. J. Schulze, J. Gottert, M. Hierholzer, T. Schutze, and R. Spanke F. Auerbach, "6.5kv IGBT modules," , pp. Conf. Rec. IEEE IAS Annu. Meeting, Phoenix, AZ, 1999, pp. 1770.
3. M. Sumner, and T. Alexander C. Newton, "Multi-level converters:A real solution to high voltage drives?," , 1997, pp. IEE Colloq. Dig., no. 1997/091,pp. 3/1-3/5.
4. F. Z. Peng, and T. G. Habetler L. M. Tolbert, "Multilevel converters for large electric drives," , Jan./Feb. 1999, pp. IEEE Trans. Ind. Appl., vol. 35, no. 1, pp. 36-44.
5. Pradyumn K. Chaturvedi, Arvind Mittal, Shailendra K. Jain Amit Ojha, "Back to Back Connected Multilevel Converters: A Review," , May. - Jun. 2013, pp. PP 57-67.
6. M. A. Parker, L. Ran, P. J. Tavner, J. R. Bumby, and E. Spooner C. H. Ng, "A multilevel modular converter for a large, light weight wind turbine generator," , May 2008, pp. vol. 23, no. 3, pp. 1062.
7. J. Dorn, D. Retzmann, and D. Soerangr B. Gemmell, "Prospects of multilevel VSC technologies for power transmission," , Apr. 21-24, 2008,pp. 1-16.
8. Mahesh M. Swamy, Ana Stankovic Sam Guccione, Rectifiers.: CRC Press LLC, 2002.
9. Chew Hong Ping, "Sinusoidal Pwm Controller Of Voltage Source Inverter For Better Efficiency Of Three Phase Induction Motor," University Malaysia Pahang, June 2013.

10. P.A. Michael, J.P. John And S.S. Kumar K.V. Kumar, "Simulation And Comparison Of SPWM And SVPWM Control For Three Phase Inverter," Asian Research Publishing Network, Vol. 5, No. 7, Pp. 61-74, July 2010.
11. N. A. Rahim, And S. Mekhilef M.A.A. Younis, "Harmonic Reduction In Three-Phase Parallel Connected Inverter," University Of Malaya, Kuala Lumpur, Malaysia., 2009.
12. Jawad Faiz And Ghazanfar Shahgholian, "Modeling And Simulation Of A Three-Phase Inverter With Rectifier-Type Nonlinear Loads," University Of Tehran, Iran, September, 2009.
13. Mohd Amri, Lai Din, "Back To Back Converter Control Technique Using Matlab," Faculty Of Electrical & Electronic Engineering University Malaysia Pahang, November, 2010.
14. Arbin Bin Ebrahim, "Adaptive Nonlinear Induction Motor Control," Department Of Electrical And Computer, University Of Alabama, 2007.
15. V. M. V. Rao, "Performance Analysis Of Speed Control Of Dc Motor Using P, PI, PD And PID Controllers," Vol. 2, No. 5, Pp. 60–66, 2013.
16. Suhairiyanti Binti Mohd Yusoff, "Pid Current Control Technique For Three Phase Induction Motor Using Matlab Simulink And Arduino," Universiti Tun Hussein Onn Malaysia, January 2014.
17. Faik Tekin Asal, Mert Coşgun Kemal Ari, "Pi, Pd, Pid Controllers," Middle East Technical University Electrical & Electronics Engineering,.
18. Richard C. And Robert H. Bishop Dorf, Modern Control Systems, 9th Ed. New Jersey-07458, USA: Prentice–Hall Inc, 2001.
19. Mohd Khairul Akli Bin Ab Ghani, "Development Of Pid Control Current For Dc Motor Using Arduino," University Tun Hussein Onn, Batu Pahat, Johor, July 2014.
20. "Control Tutorials For Matlab," Carnegie Mellon University,.
21. Ang Li, "Comparison Between Model Predictive Control And Pid Control For Water-Level Maintenance In A Two-Tank System," University Of Science And Technology, Beijing, 2008.
22. Hasmizar Binti Abd Halim, "Three Phase Inverter Development Using Common Mode Voltage Pulse Width Modulation (Pwm) Method," Faculty Of Electrical And Electronic Engineering Universiti Tun Hussein Onn Malaysia, July 2013.

23. Mohamed Farid Bin Mohamed Faruq, "Pid Controller Design For Controlling Dc Motor Speed Using Matlab Application," Faculty Of Electrical & Electronics Engineering Universiti Malaysia Pahang, November, 2008.