# DEVELOPMENT OF BACK-TO-BACK CONVERTER WITH POWER TRANSFER CONTROL USING RASPBERRY PI

## SHAHRIZAN BIN AHMAD SHAH

A project report submitted in partial

Fulfilment of the requirement for the award of the

Degree of Master Electrical Engineering

Faculty of Electrical and Electronic Engineering

Universiti Tun Hussein Onn Malaysia

**MARCH 2015**

**ABSTRACT**

It is undeniable that power electronic plays importance role in development of modern technologies. With the aid of power electronics converters its able to manipulate source of power depends on its application. Rapid developments of power electronic device with integration of wide range of controller with intelligence control system have been achieved. In this project, power electronic converters are applied to implement a back-to-back converter with resistive load using Raspberry Pi single board computer as the microcontroller and Hysteresis Band as the controller. MATLAB-Simulink is used to develop the control scheme of the back-to-back converter and incorporate it with Raspberry Pi. Simulation and hardware of back-to-back converter have been developed and the performance of this system is then tested in simulation and hardware for open-loop and closed condition. Interfacing between analog and digital device also has been developed in this project. The output can be controlled according to set point in open-loop and close-loop of simulation analysis.

# ABSTRAK

Adalah tidak dinafikan elektronik kuasa memainkan peranan penting dalam pembangunan teknologi moden. Elektronik kuasa membolehkan punca kuasa dimanupulasikan dan diubah untuk memenuhi kehendak pengguna. Pembangunan pesat elektronik kuasa telah dibuat dengan mengabungkan pengawal yang pintar seperti logic kabur dan kecerdasan buatan. Projek ini menggunakan aplikasi elektronik kuasa untuk membentuk penyonsang-berbalik mengabungkan Raspberry Pi sebagai mikro pengawal dan band hysteresis sebagai pengawal berserta perintang sebagai beban kepada litar. MATLAB-Simulink digunakan sebagai alat untuk membangunkan skim kawalan kepada penyongsang berbalik tersebut dan mengabungkan bersama Raspberry Pi. Simulasi dan perkakasan bagi penyongsang-berbalik turut dibangunkan di dalam projek ini dan prestasi sistem ini diuji dalam keadaan gelung terbuka dan gelung tertutup. Perantaramuka antara alat analog dan digital juga telah dibangunkan di dalam projek ini dan cadangan-cadangan pembangunan dinyatakan juga di dalam projek ini. Keluaran dari litar ini berjaya dikawal bergantung kepada penanda aras yang ditetapkan dalam keputusan simulasi.

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# LIST OF SYMBOLS AND ABBREVIATIONS

Ω        -        Ohm

mH        -        Mili Henry

μF        -        Micro Farad

BTB        -        Back-to-back

FPGA -        Field programmable logic array

VHDL -        VHSIC Hardware Description Language

AC        -        Alternating current

DC        -        Direct current

RPI        -        Raspberry pi

PWM -        Pulse width modulation

GPIO        -        General-purpose input/output

RMS        -        Root mean square

HB        -        Hysteresis band

PI        -        Proportional-integral

PID        -        Proportional-integral-derivative

SPI        -        Serial peripheral interface

SMC        -        Sliding mode control

MOSFET        -        Metal oxide field effect transistor

ADC        -        Analog to digital converter

DAC        -        Digital to analog converter

MISO -        Master in slave out

MOSI -        Master out slave in

LCD        -        Liquid crystal display

BJT        -        Bipolar junction transistor

VSI        -        Voltage source inverter

RCCB -        Residual current circuit breaker

MCB        -        Miniature circuit breaker

GUI    -         Graphical user interface

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1    Background

Back to back converter intensively uses in several applications such as High Voltage Direct Current (HVDC) transmission system, wind turbine power generation and electronic control of alternating current motors. The basic principles of back to back converter are rectifying the incoming ac voltage to dc, and the dc is reconverted to ac by an inverter.

There are several advantages compared to conventional method. For example DC power can be controlled much more quickly in HVDC transmission system. When change happen to the output of inverter (variation of load), the rectifier can be controlled to counteract and dampen the output oscillation [1]. The BTB will regulate the output towards its state its reference and this regulation will be made by rectifier and inverter.   In applications which integrate sinusoidal pulse-width modulated (PWM) voltages, it can prevent undesirable harmonics [1]. In wind turbine application, the speed of generator will varies according to speed of wind, hence effect the output. The back to back converter can quickly react to make sure the outputs are stable and usable.
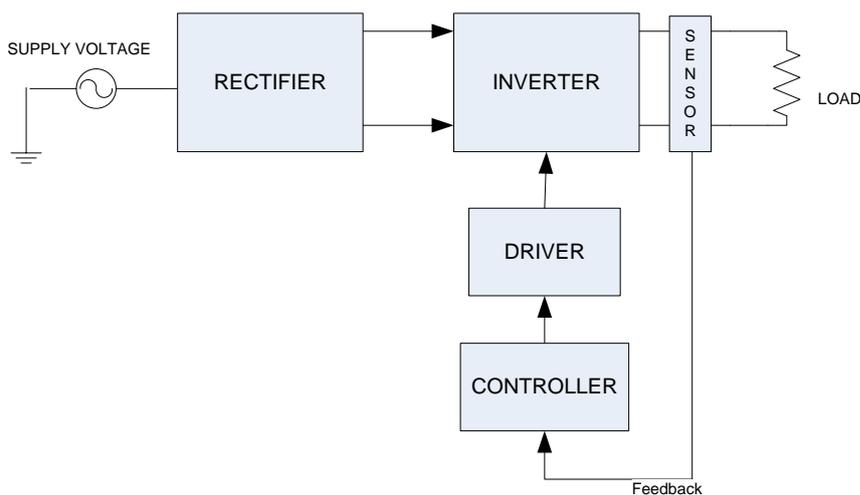
Figure1.1: General Block Diagram of Project

This project consists several elements as shown in Figure 1.1. A rectifier will convert single phase alternating current (AC) supply to a direct current (DC). On the other side, an inverter will reconvert direct current to alternating current and end with load of resistor. Several sensor will attached to the line of the inverter output to measure current and voltages to control system consist of MATLAB-Simulink, Raspberry Pi, and a gate driver. Comparison and calculation of error will be done by Hysteresis Band controller embeds in MATLAB-Simulink.

Raspberry Pi has been selected as microcontroller for this system. This microcontroller can act like master-slave controller or standalone. It will receive the input from sensors, process the data through control algorithm downloaded from MATLAB-Simulink and send appropriate data to trigger the inverter. A set point determines how the controller reacts.

Compared to others microcontroller, Raspberry Pi have completed package in term of operating system, speed, ethernet connectivity, universal serial bus (USB) and etc. that others computers have. The most important is this single-board computer in credit-card-size. RPI using open source Linux and can be utilized with width use of application but this system is new and hence takes time to be uncovered [2]. With usage of RPI to a BTB converter, IT will enable researcher in power electronic to choose wider variety of microcontrollers and make comparison of performance between them.

## 1.2    Problem Statement

Systems that have no control system will end up with unsatisfied result. Loads, depends on application, require variation of voltages, current and power. Once the loads changes, there is possibility for the changes of voltage, current and power. Increment of load, need increment of input. When low loads attached, the system should react to decrease the input according to reference value.

The problem of power transfer control will be the main focus. A BTB converter will be used because it allows better control of the power flow [3]. The loads will receive the level of power needed. Paper [3] purposed a BTB converter with two VSC connected with DC-link. Both of these converters can be control independently. The PI controller is used to control those VSC. With this control structure of BTB converter, the system becomes very complicated. Both of VSC need proper PI tuning to outputs a stable power transfer. These control structure is suitable for those need power from source to load and load to source as in electric train application.

Although highly developed control concepts have been introduced such as Artificial Intelligence, the PI (Proportional-Integral) controller is yet the preferred choice in industry processes [3].  The PI controller have been implemented in papers [4] and [3]. The proper tuning of the PI controllers is an important factor to the successful of the BTB converter. This factor could end up with complicated system and tuning mechanism and also could lead to slow response to the system if improper tuning imposed. Tuning of PI system is also time-consuming. User need to monitor the system response once the tuning done. In industries such as oil & gas sector, a fast and reliable control needed. For control valve application instead, if the process variable (feedback to the system such as pressure of gas in pressure vessel) have reach the set point, this valve (usually pneumatic controlled) must be close. If there is time delay, it could lead to safety issue such overpressure and explosion.

In paper [5], an FPGA-Based is utilized to control a full-bridge inverter. An Altera DE2-70 (Cyclone II EP2C35F672C6) has been employed to the system. FPGA is known to its fast switching and reliable outputs but in term of cost, FPGA are quite high in cost. To utilize the Altera DE2-70, user need to learn VHDL programming using Quartus software. For entry level user, this could be the major resistance to learn the VHDL programming. Furthermore, the VHDL code getting more complex if the system getting complex too.

**1.3 Objectives of Project**

To solve the problem stated in the problem statement, there are four objectives to be achieved:

i.  To develop single phase uncontrolled rectifier and a three phase controlled inverter.

ii.  To develop three-phase MOSFET's gate driver for inverter.

iii.  To design hysteresis band controller for power transfer control using MATLAB-Simulink R2014a.

iv.  To verify interface between MATLAB R2014a with Simulink and Raspberry Pi in-term of hardware and software.

**1.4 Scope of Project**

There are four (4) scopes of this project which is:

i.  A back to back converter consist will be develop with constant power supply of 40V will be used. MOSFET with maximum current of 21A, 600V will be utilized with resistive load attached.

ii.  To operate the MOSFET, a gate voltage of 10V – 20V is needed. This doesn't meet the output of Raspberry Pi which is 3.3V and 5V. This circuit will amplify the output from Raspberry Pi to required level of voltage to drive the MOSFET.

iii.  The control scheme of this project will be develop using MATLAB-Simulink R2014a. Hysteresis band controller will be embed in the Simulink function block to produce PWM signal for the MOSFET.

iv.  The intention of this project is to make use of readily available Simulink support package for Raspberry Pi will be used to interface between Simulink function block to Raspberry Pi. At the time of this project develop, there are only 10 block available.

**CHAPTER 2**

**LITERATURE REVIEW**

## 2.1 Introduction

Researches in related field are compulsory in initial stage and continuously until final stage. Studies on related topic will come out with proper design, at the end, result on time and cost saving.

## 2.2 Back-to-back converter.

Back-to-back power topology has an important role in a wide variety of processes. It allows a better control of the power flow that needed by industry [3]. There are several electric applications where energy flow must to be reversed during normal operation of the systems. [4]. A back-to-back converter consists of two Voltage Source Converters (VSC) connected by a common DC-link as in Figure 2.1. The power flow can change direction at any moment indicate by arrows in Figure 2.1.
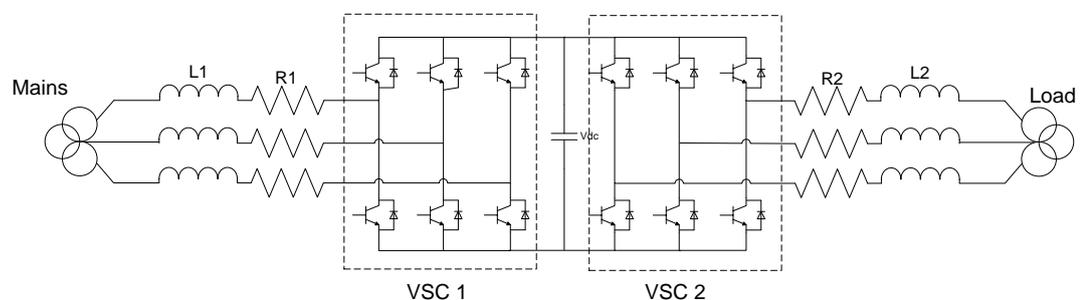
Figure 2. 1: Back-to-back power topology [3]

The use of line-commuted rectifiers on the line side converter causes the generation of harmonics, low power factor and bulky dc-link capacitor. Therefore, the power density is reduced and cost is raised; the capacitor is also a dominant factor in system reliability. Some of these drawbacks can be reduced changing the line-commuted converter by a voltage-sourced converter (VSC). VSC using the pulse-width modulation (PWM) allows fast and independent control of active and reactive power in all four quadrants of the P-Q plane. Control of both active and reactive power is bidirectional [4]. The energy transfer also not reversible hence it cannot meet the needs for fast start-up, braking and frequently reversible operation [6].

On the control system of back-to-back converter, it will measure currents and voltages which will generate the required system signals. These measurements are used to provide information for the control loops. On the controller side, it is critical to select and design proper controller. This controller will used to achieve the control objectives and regulate the state variable towards its references.

## 2.3    Single Phase Rectifier (Full-wave bridge rectifier)

Rectifier is one of component in a power supply. This converter converts AC supply to constant voltage. The advantages of common single-phase diode rectifier are simplicity, reliability, and cheapness [7]. This will help to simplify the BTB compared to the proposed system in paper [3]. A full wave bridge rectifier consists of 4 diodes and will rectify the positive and negative cycle of A.C waveform. A bridge rectifier can be made using four individual diodes, but it is also available in special packages containing the four diodes required. It is called a full-wave rectifier because it uses the entire AC wave (both positive and negative sections). 1.4V is used up in the bridge rectifier because each diode uses 0.7V when conducting and there are always two diodes conducting, as shown in the diagram below. Bridge rectifiers are rated by the maximum current they can pass and the maximum reverse voltage they can withstand (this must be at least three times the supply RMS voltage so the rectifier can withstand the peak voltages).
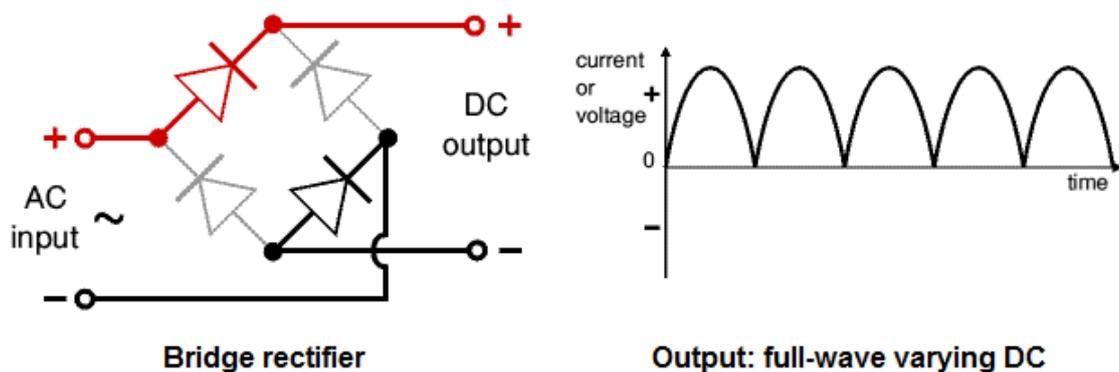
Figure 2. 2: Full wave bridge rectifier.

## 2.4    Smoothing Circuit

Smoothing circuit is used to smooth the DC from varying greatly to a small ripple. Smoothing is performed by a large value electrolytic connected across the DC supply to act as a reservoir, supplying current to the output when the varying DC voltage from the rectifier is falling.
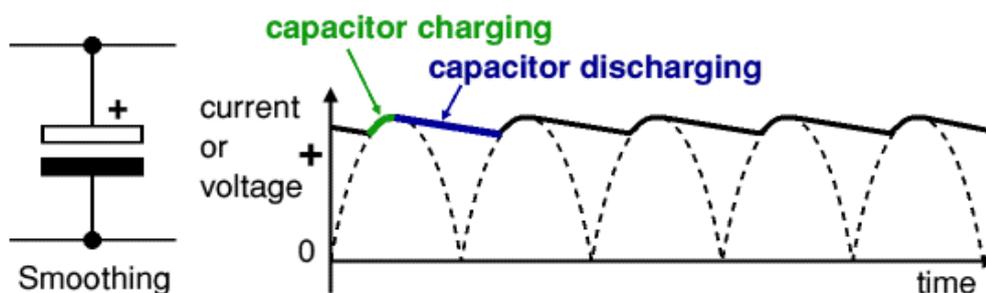


Figure 2. 3: Capacitor charging and discharging

Figure 2.3 shows the unsmoothed varying DC (dotted line) and DC, and then discharges as it supplies current to the output.The smoothing significantly increases the average DC voltage to almost the peak value . The DC voltage can be calculated as follows:

$$V_{DC} = 1.4 \ \times RMS \tag{2.1}$$

## 2.5 Three Phase Controlled Inverter

The main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications [8].
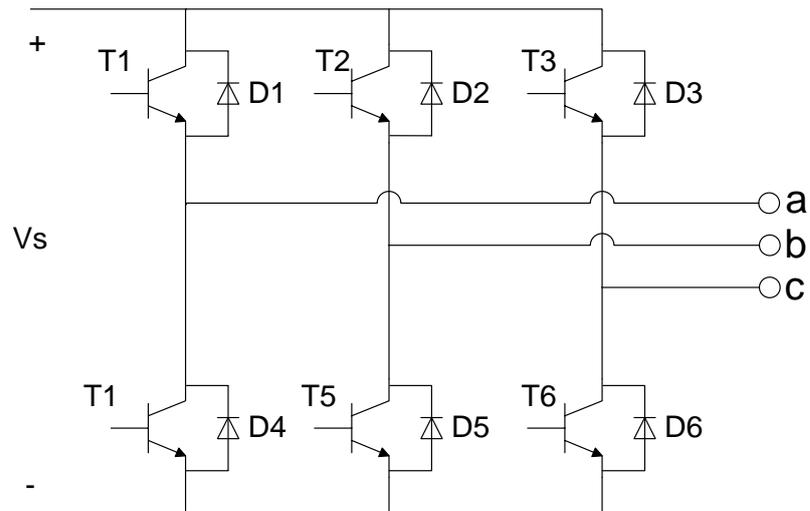


Figure 2. 4: Three phase transistor controlled inverter.

Figure 2. 4 show the circuit for three phase transistor controlled inverter. A bridge configuration is typically used to eliminate the use of transformer. Six transistors are used to conduct in sequence of T1, T6, T2, T4, T1, T5. Each leg is delayed by $120^{\circ}$. There are a few techniques to perform the switching of this inverter; one of it is the Sinusoidal Pulse Width Modulation (SPWM) techniques. SPWM provides a way to reduce the total harmonic distortion [5].
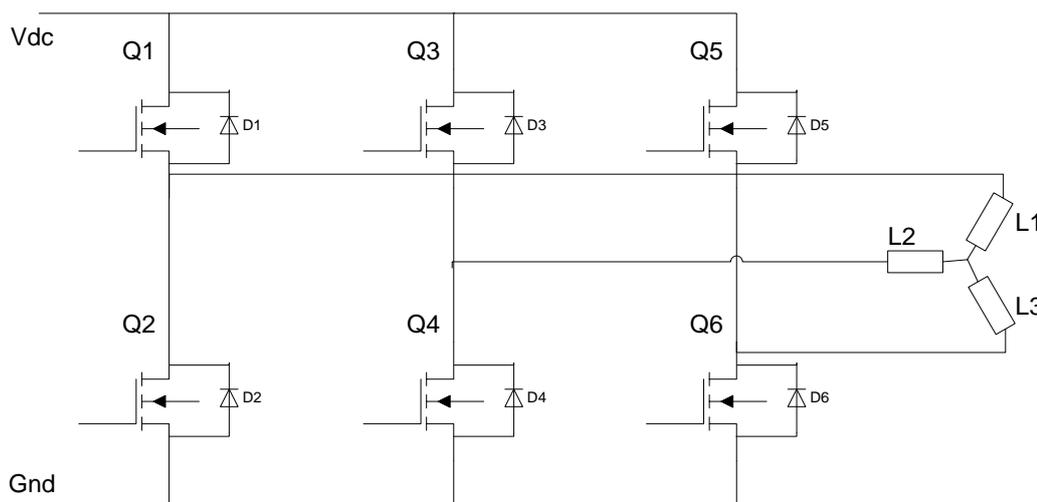
Figure 2. 5: 6-pulse MOSFET controlled inverter.

For a high power application, MOSFET is used to replace the BJT as in Figure 2. 5. MOSFET does not depend on current triggers as BJT does. Therefore the MOSFET is fully triggered even with minutest current at its gate. Each of these MOSFET is triggered by PWM signal generated by the HB controller through gate driver circuit.

## 2.6    Three Phase Gate Driver

There are numerous IC gate drives that are commercially available for gating power converters. These include pulse-width modulation (PWM) control, power factor correction (PFC) control, combined PWM and PFC control, current mode control, bridge driver, servo driver, hall-bridge drivers, stepper motor driver and thyristor gate driver [8].

Recently, the interest with solid state pulsed power modulator has been growing because of many advantages such as long life span, rectangular pulse waveforms and easiness of controlling the pulse width and repetition rate [9]

Efficiency is one of the most important issues among high power converters where IGBTs are widely used, and the gate drive circuit serving as the interface between the IGBT power switches and the logic-level signals can be optimized to achieve low losses. Conventional Gate Driver (CGD) circuits have employed fixed gate voltage and resistor networks, which are selected to minimize switching losses,

suppress cross-talk and EMI noise, and also limit the power device stresses at switching transients. However, these conflicting requirements are difficult to be realized in a conventional gate driver [10].

Basically, the purpose of using a gate driver is the application of to charge pump circuit to the gate of the MOSFET in the rectifier circuit. The gate requirements for a MOSFET or an IGBT switch are satisfy as follows; i) Gate voltage must be 10V to 15V higher than the source or emitter voltage. Because the power drive is connected to the main high voltage rail +Vs, the gate voltage must be higher than the rail voltage. ii) The gate voltage that is normally referenced to ground must be controllable from the logic circuit. Thus, the control signals have to be level shifted to the source terminal of the power device, which in most applications swings between the two rails $V^+$. iii) A low-side power device generally drives the high-side power device that is connected to the high voltage. Thus, there is one high-side and one low-side power device. The power absorbed by the gate drive circuitry should be low and it should not significantly affect the overall efficiency of the power converter [8].

## 2.7 Controller

Controller can be divided into two; adaptive and passive controller. PID, Fuzzy and Neural Network are in adaptive category while Hysteresis, Relay and Sliding Mode Control are in passive categories. All of this controller have their own disadvantage. For example, the disadvantage of sliding mode control method is chattering of the system states due to high control activity [11] .

### 2.7.1 Proportional-integral-derivative Control

PID controller is one of the adaptive controllers. It is a combination of proportional, integral and derivate controller. Combining all three modes of control enables a controller to be produced which has no offset error and reduces the tendency for oscillations. Such a controller is known as a three mode controller. The equation describing its action is:

$$P_{out} = K_p \left( e + K_I \int e\,dt + K_D \frac{de}{dt} \right) + P_o \qquad (2.2)$$

Where $P_{out}$ is the output from the controller when there is an error $e$ which is changing with time $t$, $Vo$ is the set point output when there is no error, $K_P$ is the proportionality constant, $K_I$ the integral constant and $K_D$ the derivative constant. One way of considering a three controller is as a proportional controller which has integral control to eliminate the offset error and derivative control to reduce time lag [12].
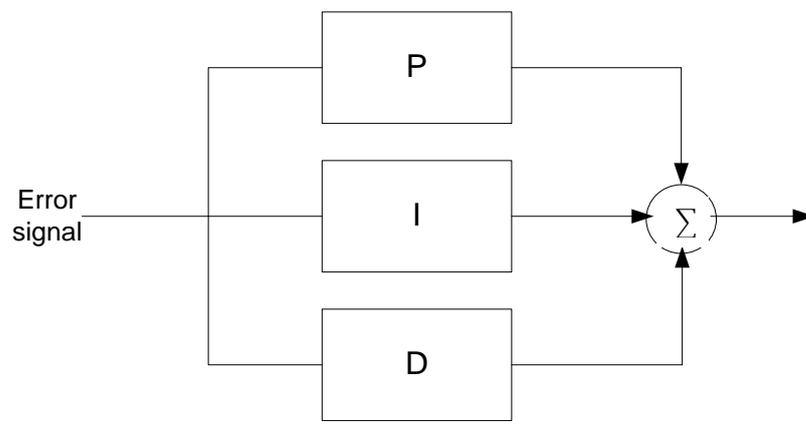


Figure 2. 6: A PID controller

Figure 2. 6 show the block diagram of a PID controller. The error signal is the difference between reference/set point and the feedback.

### 2.7.2   Sliding Mode Control

Sliding mode control (SMC) has been known for several decades and is still, due to its simplicity interest among application engineers and researchers [13]. SMC is known to be a robust control method appropriate for controlling uncertain systems. High robustness is maintained against various kinds of uncertainties such as external disturbances and measurement error. It is also straightforward to implement the resulting algorithms. Sliding mode control has long been considered for control of dynamic nonlinear systems. The need of SMC is to use a high speed switching control to move system's state trajectories onto specified and user chosen surface in

the state space, known as the sliding surface or switching surface which keep the system's state trajectory along the surface.
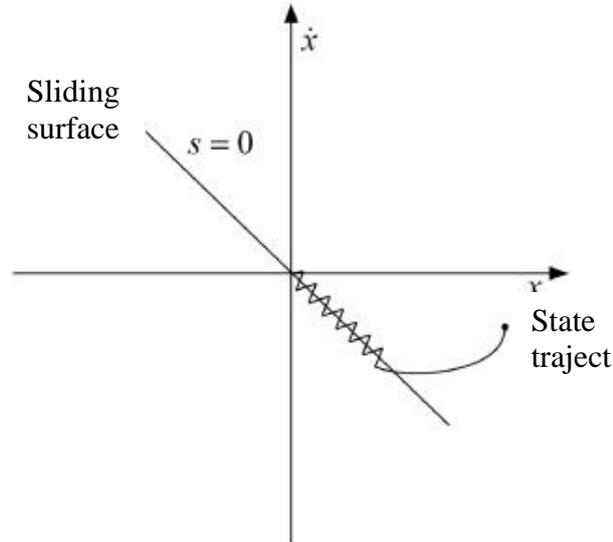


Figure 2. 7: State trajectory and sliding surface in SMC

Figure 2.7 shows the state trajectory and sliding surface in SMC. Once the state trajectory intercepts the sliding surface, it remains on the surface for all time and sliding along the surface, hence the term sliding mode. In the design of sliding mode controller the first stage is a design of sliding surface while the second is forces the state to approach the sliding surface from any other region of the state space, and remains on it [14].

Paper [14] purpose the design and implementation of sliding mode control for level control. The control problem is to find a suitable control input *u(t)* such that the output tracks a desired command asymptotically in the presence of model uncertainties and disturbances. The tracking error e(t), in terms of the command signal, $y_r(t)$ and measured output signal, $y_m(t)$, is defined as:

$$e(t) = y_r(t) - y_m(t) \qquad (2.3)$$

The sliding surface s(t) which depend of tracking error e(t) and derivatives(s) of tracking error given as:

$$s(t) = \left(\frac{d}{dt} + \lambda_c\right)^{n-1} e(t) \qquad (2.4)$$

The $n$ indicates the order of uncontrolled system, $\lambda_c$ is the positive constant and the control input u(t) can be given as:

$$u(t) = u_{eq}(t) + u_{sw}(t) \qquad (2.5)$$

Where the $u_{eq}(t)$ is the equivalent control and $u_{sw}(t)$ is the switching control.
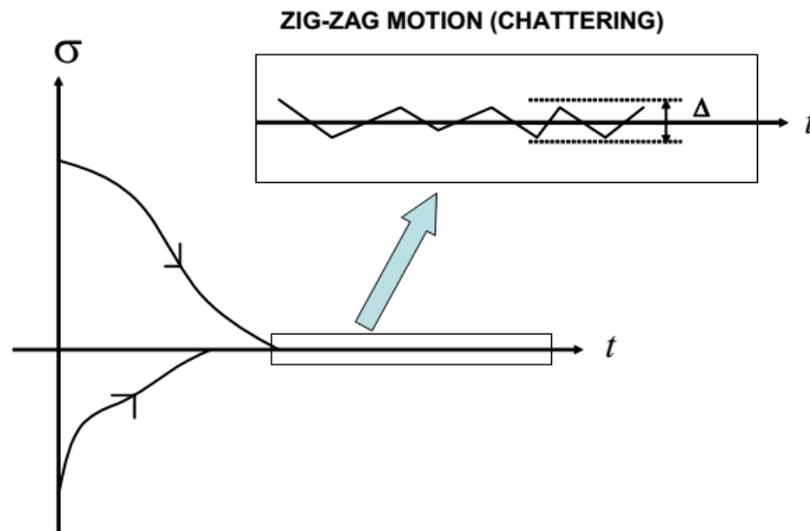


Figure 2. 8: Chattering on the output.

Disadvantage of sliding mode control method is chattering of the system states due to high control activity as shows in Figure 2. 8 [15]. To overcome this problem, a PI or PID can be implemented into the system.

### 2.7.3 Hysteresis Band

Hysteresis band controller is one of the passive controllers. The HB PWM technique is widely used because of its simplicity of implementation, and fast control [16]. Besides being simple, hysteresis controller provides higher tracking ability for the inverter [17].
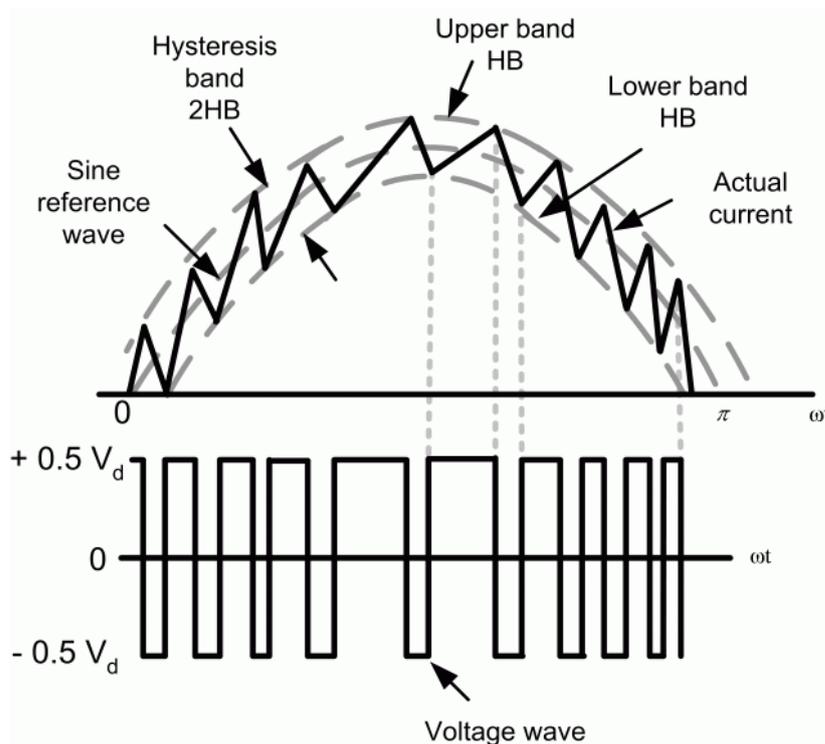


Figure 2. 9: Hysteresis Band Controller [18]

The hysteresis modulation is a feedback current control method where the load current tracks the reference current within a hysteresis band. Figure 2.9 shows the operation principle of the hysteresis modulation.

The controller generates the sinusoidal reference current of desired magnitude and frequency that is compared with the actual motor line current. If the current exceeds the upper limit of the hysteresis band, the upper switch of the inverter arm is turned off and the lower switch is turned on. As a result, the current starts to decay. If the current crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. Hence, the actual current is forced to track the reference current within the hysteresis band [18].

Paper [19] purposed basic structure of a single phase current hysteresis control loop of a voltage source chopper while paper [20] HB pulse with modulated current controller applied to a three phase VSI inverter. It apply HB controller with the band of hysteresis maintained constant all the period of fundamental. The algorithm for the scheme is given as:

$$i_{ref} = Imax \sin(\omega t) \tag{2.6}$$

Upper band: $\quad (i_u)\ i_{ref} + \Delta i = i_{ref} + h/2$ $\qquad\qquad$ (2.7)

Lower band: $\quad (i_l)\ i_{ref} + \Delta i = i_{ref} - h/2$ $\qquad\qquad$ (2.8)

Where $i_{ref}$ is the reference current, $i_u$ and $i_l$ is the upper and lower band current respectively while $\Delta i$ is the hysteresis band limit [19].

## 2.8 Power transfer control of Back-to-back converter
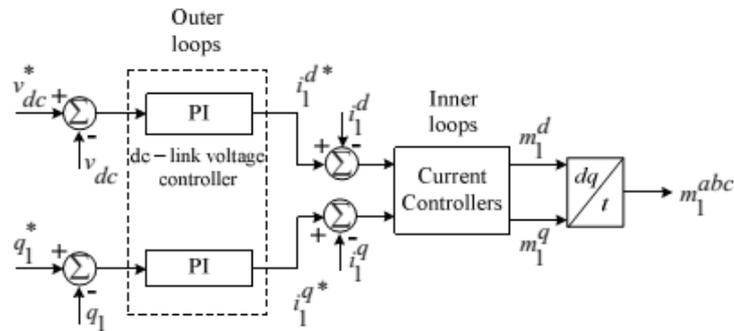


Figure 2. 10: Control block diagram for VSC1

The control-block for BTB converters typically consist of two converters (VSC1 and VSC2). The control scheme for BTB converter shows in Figure 2. 10. The control blocks contain two blocks connected in cascade, called outer and inner loop. The inner loop is used to ensure an asymptotical tracking and the outer loop to control the DC-link for VSC1 [3].

The VSC1 will control the amount of voltage in the DC-link while VSC2 control the active power flow to the load. Each VSC has similar control structure;

inner loop for current control and outer loop for DC-link voltage and active/reactive power control as show in Figure 2.11.
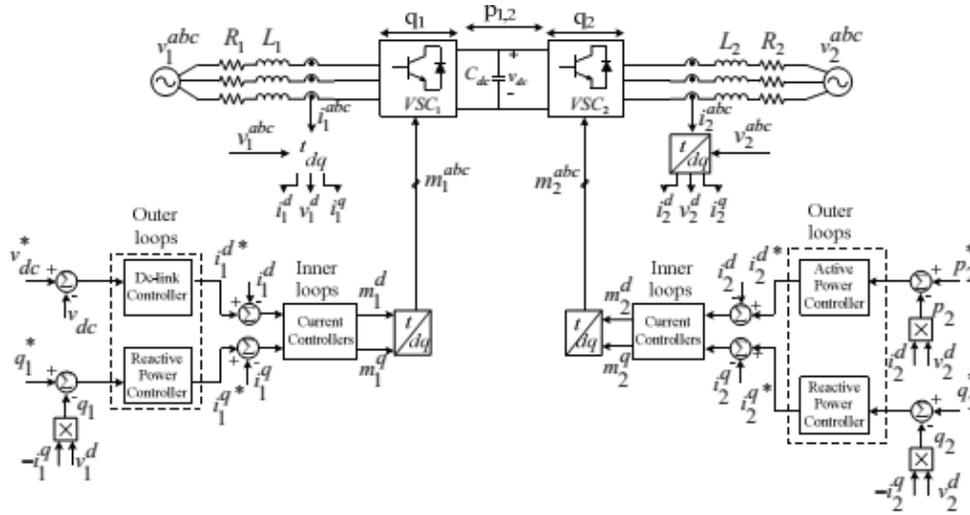


Figure 2. 11: Complete BTB control structure.

Part of the control technique of VSC2 will be implemented in this project to control active/real power of the inverter. Y connected load is used in this system. For this type of load, the power consumed is given by:

$$P = 3V_{\emptyset}I_{\emptyset}\cos\theta \qquad (2.9)$$

The $I_L = I\emptyset$ and $V_{LL} = \sqrt{3}\,V_{\emptyset}$, hence the power consumed by the three phase load can also be expressed as [21]:

$$P = \sqrt{3}V_{LL}\,I_L\cos\theta \qquad (2.10)$$

This equation will be utilized in developing the control scheme for power transfer control.

## 2.9    MATLAB-Simulink Software

Simulink is a software package for creating, editing and simulating dynamical systems on MATLAB from Mathworks. It enables rapid construction of virtual prototypes to explore design concepts at any level of detail with minimal effort. For modelling, Simulink utilizes a graphical user interface (GUI) for building models where models are created as block diagram [22]. It includes a comprehensive library of predefined blocks to be used to construct graphical models of systems using drag-and-drop mouse operations.

User is able to produce an "up-and-running" model that would otherwise require hours to build in the laboratory environment. It supports linear and nonlinear systems, modelled in continuous-time, sampled time, or hybrid of the two. Since students learn efficiently with frequent feedback, the interactive nature of Simulink encourages you to try things out, you can change parameters "on the fly" and immediately see what happens, for "what if" exploration. Lastly, and not the least, Simulink is integrated with MATLAB and data can be easily shared between the programs [23].

## 2.10    Raspberry Pi

The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. RPI is developed in the UK by Raspberry Pi foundation with the intention of stimulating the teaching of basic computer science in schools [24]. The comparatively low price and the relatively large possibilities of the central unit resided in, caused the Raspberry Pi being often used not only for educational purposes but also (individually or in sets) in steering processes or measurement systems [25]. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python. It's capable of doing everything expect a desktop computer to do, from browsing the internet and playing high-definition video, to making spreadsheets, word-processing, and playing games [26].
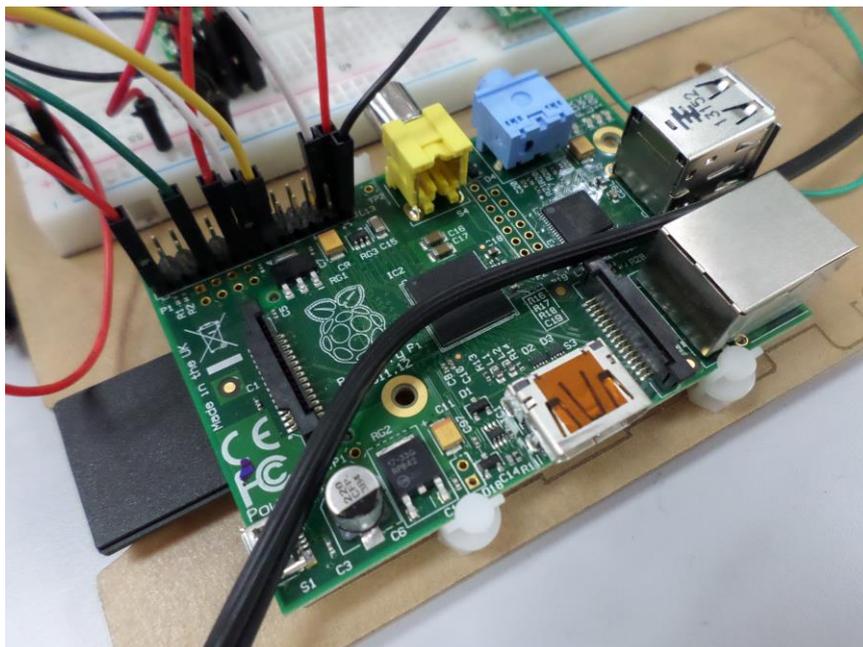
Figure 2. 12: Raspberry Pi Type B; single-board credit-card size computer

Figure 2. 12 show the RPI type B. At the time of this project, there is a newly launched model of RPI known as type B+ with some enhancement on GPIO.

Table 2. 1: Comparison between Raspberry type B and B+

| Technical | Type B | Type B+ |
|---|---|---|
| Chip | Broadcom BCM2835 SoC full HD multimedia applications processor | Broadcom BCM2835 SoC full HD multimedia applications processor |
| CPU | 700 MHz Low Power ARM1176JZ-F Applications Processor | 700 MHz Low Power ARM1176JZ-F Applications Processor |
| GPU | Dual Core VideoCore IV® Multimedia Co-Processor | Dual Core VideoCore IV® Multimedia Co-Processor |
| Memory | 512MB SDRAM | 512MB SDRAM |
| Ethernet | onboard 10/100 Ethernet RJ45 jack | onboard 10/100 Ethernet RJ45 jack |
| USB 2.0 | Dual USB Connector | 4 x USB Connector |
| Video output | HDMI (rev 1.3 & 1.4) Composite RCA (PAL and NTSC) | HDMI (rev 1.3 & 1.4) Composite RCA (PAL and NTSC) |
| Onboard storage | SD, MMC, SDIO card slot | Micro SD |
| Operating system | Linux | Linux |
| GPIO | 26 pins | 40 pins |

Table 2.1 shows the comparison between Raspberry Pi type B and B+. Raspberry Pi type B+ have nearly the same specification compared to type B. Type B+ has more GPIO's and allow more devices to be connected. Type B will be utilize in this project since the Type B+ can only be used with MATLAB 2014a and above.

The Raspberry Pi will be utilized as a controller in this project. A control scheme will be develop using MATLAB-Simulink and download to Raspberry Pi. System MATLAB-Simulink plus Raspberry Pi have an advantage of real-time control and data acquisition compared to system with MATLAB-Simulink plus Arduino.

Compared to Arduino Uno, the performance of RPI are much better in term of speed and connectivity. That is the main reason to choose this type of micro controller.

Table 2. 2: Comparison between Arduino Uno and Raspberry Pi

| Specification | Arduino Uno | Raspberry Pi |
| --- | --- | --- |
| Processor | ATMega 328 | ARM11 |
| Clock speed | 16Mhz | 700Mhz |
| RAM | 2KB | 256MB |
| Ethernet | Not available | 10/100 |
| GPU | Not available | Video Core IV |

Table 2. 2 show the comparison between Arduino Uno and RPI. RPI are excelling in these five specifications with large difference especially in term of speed and temporary storage (RAM). RPI also enable user to communicate using Ethernet [2] [27].

# CHAPTER 3

# METHODOLOGY

## 3.1    Introduction

These sections address the method on how this project carried out. All objective must be clearly stated in order to solve it with correct method. Figure 3.1 shows the project flowchart. At the first stage, the problem statement is defined with objectives and scopes of the project. Research on related field is then conducted together with review of previous research that has been made. This preliminary research will give an idea on method to solve the problem.

The initial design starts at second stage. These designs are simulated to test the performance using MATLAB-Simulink software. MATLAB-Simulink offers design and simulation on the rectifier and inverter circuit that will ease user to improve the design thus result on time and cost saving to construct the hardware. At third stage, the simulated circuits are then fabricated with the aid of software to design printed circuit board (PCB). These circuits are then tested and analyze. The hardware and software are then combined to analyze the result and further improvement can be realized within the time given to complete this project.
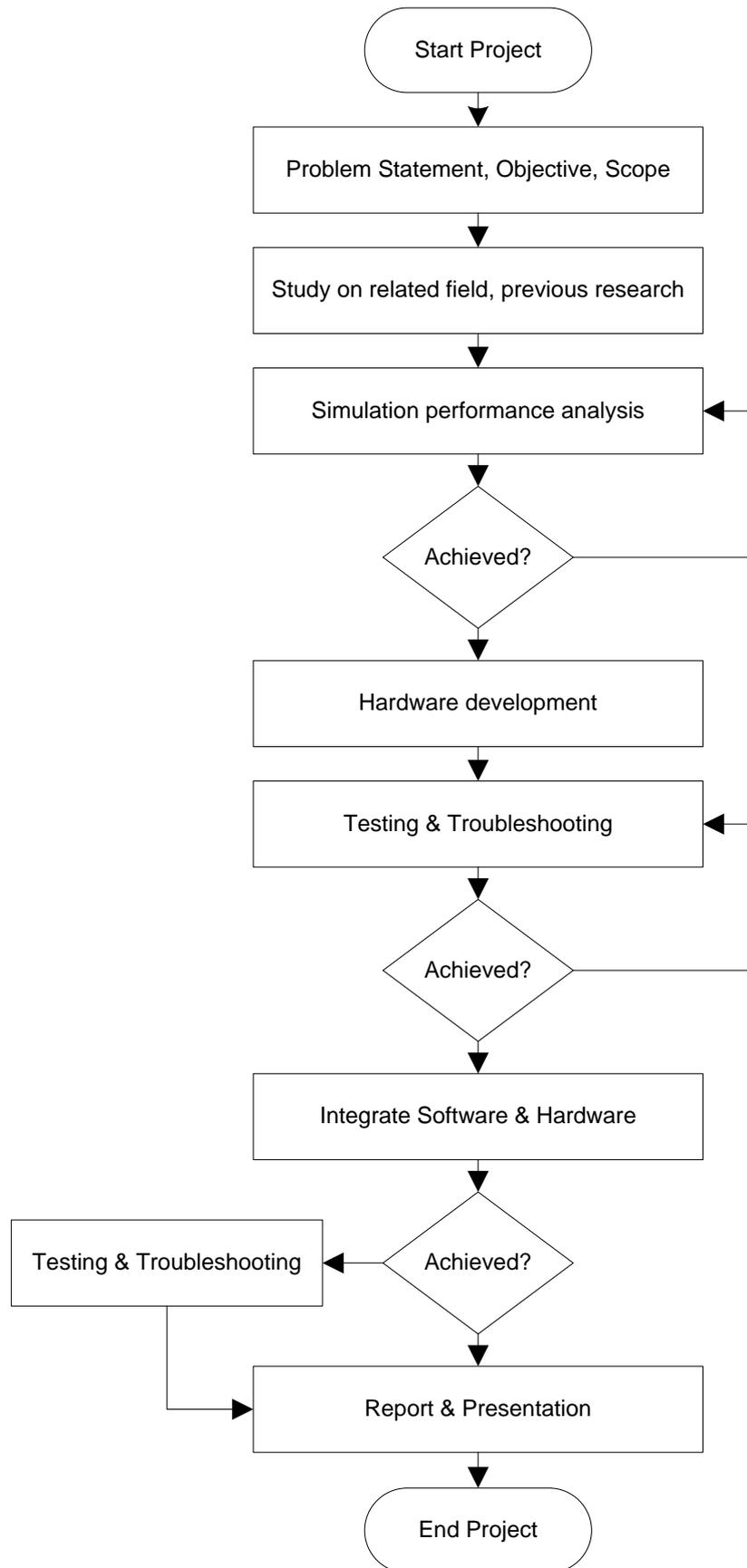
Figure 3. 1: Project Flowchart

**3.2    Specific Block Diagram of Project**
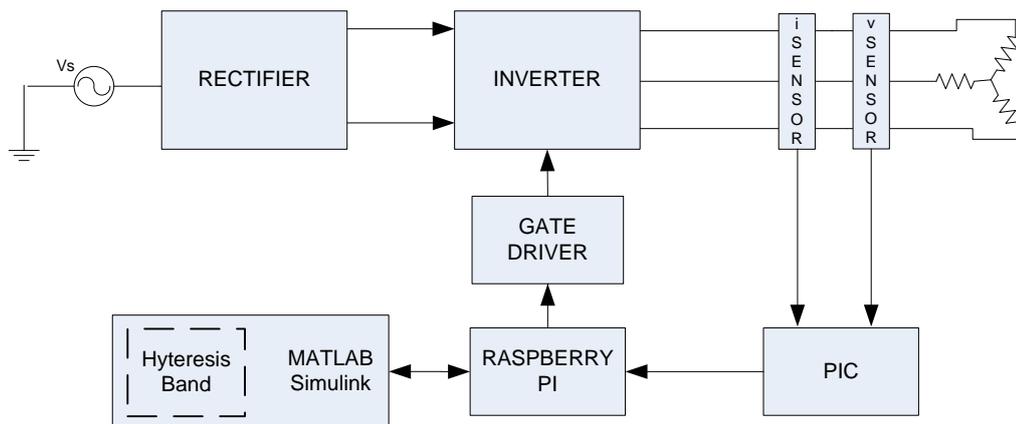


Figure 3.2: Specific Block Diagram of Project

In Figure 3.2, there are two section of this project; software development and hardware development. Hardware development consists of circuit construction for controlled rectifier, inverter, and gate driver circuit. While software development consists of Hysteresis Band controller using MATLAB-Simulink interfaced with Raspberry Pi.

Along this methodology, the aim has to remain the same which is to control the power transfer from AC source to load (resistive load). There is several testing need to be done before this project can began that related to Raspberry Pi. Raspberry Pi must able to communicate with MATLAB-Simulink. Such experiment will ensure further works can be preceded.

**3.3      Software Development**

There are two main sections in software development; development of Hysteresis Band controller and interfacing with Raspberry Pi using support package provided.

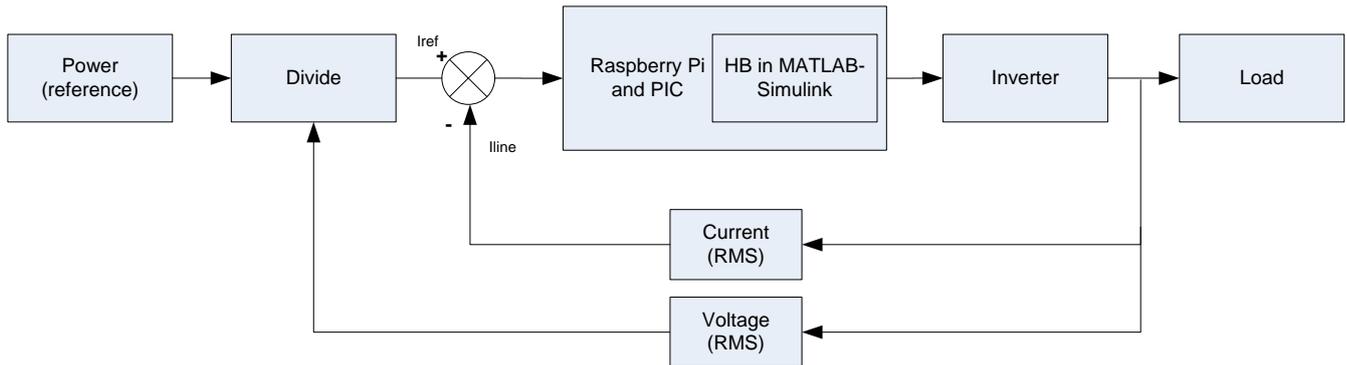**3.3.1   Proposed control strategies**



Figure 3. 3: Closed-loop of power transfer control system.

Control scheme employed to control the power transfer to the load are shown in Figure 3.3. The objective is to control power transfer to motor according to reference value. The power (reference) will divide with RMS voltage to obtain the current value. This current value will be the set point or *Iref* to the current controller. A passive controller known as Hysteresis Band controller, embed in MATLAB-Simulink to manipulate the parameters from current sensors and voltage sensor. It is known that these two parameters contribute to Power as following equation:

$$P = V \times I \tag{3.1}$$

RPI  is use as hardware/software interface between MATLAB-Simulink and MOSFET's gate. In addition, this single-board computer will be used as master controller as it can be configured to be stand-alone operation, or it can act as slave while communicating with master (server).

### 3.3.2 Hysteresis Band Controller Development

The software development which consist of Hysteresis Band controller using MATLAB-Simulink software. Figure 3.4 shows the block diagram of HB controller that will be developed using MATLAB-Simulink function block. The technique used in control scheme is using current control where *Ia* is the feedback current from current sensor while *Iref* is the reference current or set point for the system.
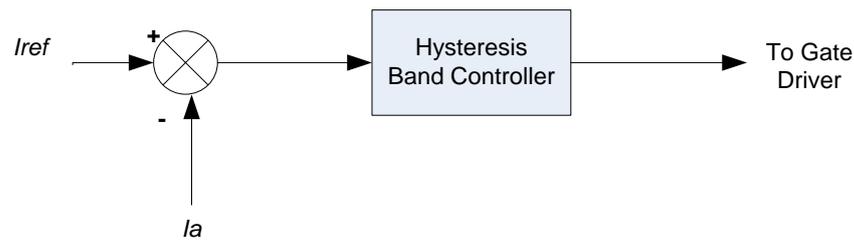


Figure 3. 4: Hysteresis Band controller.

As a basic design of HB controller, the HB must contain reference current, upper band and lower band of HB controller. As in Figure 2. 8. The error (e) is the difference between output current and reference current and can be written as below:

$$e = i - i^*$$ (3.3)

Where $i$ is the output current and $i^*$ is the reference current. In HB controller, the output voltage level depends on the error between the current set point and the real current injected by the inverter. To set the upper and lower band, the following equation is used:

$$Upper\ band = +\frac{h}{2}$$ (3.4)

$$Lower\ band = -\frac{h}{2}$$ (3.5)

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