

DEVELOPMENT OF ONE CYCLE CURRENT CONTROLLER USING  
RASPBERRY PI FOR 3 PHASE ACTIVE POWER FILTER FOR NONLINEAR  
LOAD IMPROVEMENT

MOHD HAFIZ BIN MOHAMAD SHARI

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Faculty of Electrical and Electronics Engineering  
Universiti Tun Hussien Onn Malaysia

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## ABSTRACT

Nowadays, Power distribution systems are faces more challenging problems of nonlinear load form commercial building and domestic use. The problem occurs when every single electronic appliances or electronic power supply used rectifier as a new conversion technologies such as Switch Mode Power Supply (SMPS) and it can be found virtually in every power electronic devices. The effect of nonlinear loads are create harmonic current in additional to the fundamental AC current waveform and transform the shape of the current from sine wave to some other form such as “double-hump”, and it can affect both the distribution system equipment and the loads connected to it. Therefore this study is proposing a solution by development of one cycle current control (OCC) using Raspberry Pi for 3 phases Active Power Filter where the main objective are to harmonic elimination and power quality improvement. The model was perform in MATLAB/Simulink and also implements the hardware by using Raspberry Pi as a digital signal processing system. The result and analysis of the performance were explained in this report in terms of the output current waveform and the effect of nonlinear load through the 3 phase power supply. Finally, the harmonic compensating efficiency to the typical non-linear loads of the approach presented is further verified by implementation of the One Cycle Current Controller (OCC) is designed by simulation and hardware experimental results are presented.

## ABSTRAK

Pada masa kini, sistem pengagihan kuasa berhadapan dengan masalah yang lebih mencabar iaitu beban tidak linear untuk bangunan komersil dan penggunaan domestik . Masalah ini berlaku apabila setiap perkakasan elektronik atau sumber bekalan kuasa elektronik mengaplikasikan penerus sebagai penukaran arus ulang alik (AU) kepada arus terus (AT) seperti Mod suis bekalan kuasa (SMPS) dan ia boleh didapati di hampir setiap peranti elektronik kuasa. Kesan beban tidak linear telah mewujudkan harmonik kepada bentuk asas arus ulang alik (AU) dengan mengubah bentuk semasa daripada gelombang sinus ke bentuk lain seperti dua bonggol , dan ia memberi kesan kepada peralatan bagi sistem agihan dan beban yang menghubungkan dengannya. Oleh itu kajian ini mencadangkan penyelesaian dengan pembangunan satu kitaran kawalan arus (OCC) menggunakan Raspberry Pi untuk 3 fasa penapis kuasa aktif (APF) dengan matlamat utama adalah untuk penghapusan harmonik dan peningkatan kualiti kuasa. Model ini dilaksanakan dengan menggunakan MATLAB/Simulink dan juga mengaplikasikan sistem pemprosesan isyarat digital dengan menggunakan Raspberry Pi. Keputusan dan analisis prestasi yang telah dijelaskan dalam laporan ini dari segi bentuk gelombang keluaran arus dan kesan terhadap beban tidak linear kepada sumber kuasa 3 fasa. Akhir sekali, kecekapan pampasan harmonic untuk tipikal beban tidak linear melalui pendekatan satu kitaran kawalan arus (OCC) telah dibentangkan serta disahkan keputusannya dengan pelaksanaan simulasi dan perkakasan serta keputusan eksperimen dibentangkan.

## TABLE OF CONTENTS

	<b>TITLE</b>	<b>I</b>
	<b>DECLARATION</b>	<b>II</b>
	<b>DEDICATION</b>	<b>III</b>
	<b>ACKNOWLEDGEMENTS</b>	<b>IV</b>
	<b>ABSTRACT</b>	<b>V</b>
	<b>ABSTRAK</b>	<b>VI</b>
	<b>TABLE OF CONTENTS</b>	<b>VII</b>
	<b>LIST OF TABLES</b>	<b>X</b>
	<b>LIST OF FIGURES</b>	<b>XI</b>
	<b>LIST OF SYMBOLS AND ABBREVIATIONS</b>	<b>XIII</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.0 Introduction	1
	1.1 Project Background	1
	1.2 Problem statement	2
	1.3 Aim and Objectives	3
	1.4 Limitation / Scope of Project	3
	1.5 Thesis Outline	4
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	<b>5</b>
	2.1 Introduction	5
	2.2 Nonlinear load	5
	2.3 Active Power Filter (APF)	7
	2.3.1 Harmonics in Power System Due to Nonlinear Loads:	8
	2.3.2 Brief Introduction to Active Power Filter:	8
	2.3.3 Control techniques used for Active Power Filter	9
	2.3.4 Digital Controller for Active Power Filter:	9
	2.3.5 Three Phase Inverter	9

2.4	Controller Approaches for Active Power Filter	11
2.4.1	PID controller	12
2.4.2	Fuzzy logic controller	13
2.4.3	Hysteresis control	14
2.4.4	One-Cycle Control	16
2.5	Raspberry Pi	19
<b>CHAPTER 3</b>	<b>METHODOLOGY</b>	<b>23</b>
3.1	Introduction	23
3.2	Block Diagram	24
3.3	Linear and Nonlinear Load Design	26
3.3.1	Linear Loads	26
3.3.2	Nonlinear Loads	26
3.4	Gate Driver Design	27
3.5	Controller Design	30
3.6	Current sensor	34
3.7	Inverter Circuit Design	34
3.8	Analogue to Digital converter (ADC)	36
<b>CHAPTER 4</b>	<b>DATA ANALYSIS AND RESULT</b>	<b>38</b>
4.1	Introduction	38
4.1.1	Simulation analysis	38
4.1.2	Nonlinear Load Result	39
4.1.3	One-Cycle Current Control (OCC)	41
4.1.4	Active Power Filter Simulation (Inverter)	44
4.2	Open loop Analysis of hardware	46
4.2.1	Hardware testing analysis	48
4.2.2	Raspberry Pi output analysis	48
4.2.3	Gate Driver analysis	49
4.2.4	Active Power Filter circuit analysis	51
4.2.5	Linear load Analysis	53
4.2.6	Nonlinear load analysis	56
4.2.7	Input sensor for linear load and nonlinear load	58
4.2.8	Output Inverter for linear load and Nonlinear Load	61
4.2.9	Close loop analysis	64



<b>CHAPTER 5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>67</b>
5.1	Introduction	67
5.2	Conclusion and Discussion	67
5.3	Recommendation	69
	<b>REFERENCES</b>	<b>71</b>
	<b>APPENDIX 1</b>	<b>74</b>
	<b>APPENDIX 2</b>	<b>77</b>



**PTTA UTHM**  
PERPUSTAKAAN TUNKU TUN AMINAH

**LIST OF TABLES**

2.1	Switching State for three phase inverter.	11
2.2	Raspberry Pi's specifications	21
3.1	Comparison of linear and nonlinear loads.	7
3.2	List of the components for gate driver circuit	27
3.3	List of components for three phase inverter	35
3.4	Calculation result for sensor and ADC	37



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PERPUSTAKAAN TUNKU TUN AMINAH

## LIST OF FIGURES

2. 1	Active Power Filter	7
2. 2	Schematic diagram for three phase switching	10
2. 3	One-Cycle Controlled Constant Frequency Switch [10]	16
2. 4	Switch Input $x(t)$ , Output and Switch Signal $y(t)= X(t)K(t)$ [10]	17
2. 6	Raspberry Pi Controller	19
2. 7	Raspberry Pi's hardware	20
3. 1	Block diagram of the project	24
3. 2	Circuit diagram of nonlinear load design	27
3. 3	The schematic diagram of the gate driver circuit	29
3. 4	Three-phase three-wire shunt active power filter	30
3. 5	One Cycle Current Controller (OCC) model for Phase A	32
3. 6	ACS712 Current sensor	34
3. 7	Circuit diagram of inverter (Active Power Filter)	35
3. 8	Communication Matlab and Raspberry Pi	36
4. 1	The Simulink model for One Cycle Current Controller (OCC)	39
4. 2	The Simulink diagram for Linear and Nonlinear load	40
4. 3	Current comparison waveform for linear and nonlinear load	40
4. 4	The Simulink model for One Cycle Current Controller (OCC)	41
4. 5	Current compensate result between current load harmonic, $I_a$ and current reference, $I_{a\_ref}$ .	42
4. 6	Tuning Controller result for I, PI and comparator block for I and PI	43
4. 7	PWM generator result	44
4. 8	The Simulink result for 3phase inverter circuit	45
4. 9	The OCC result for Voltage & Current Phase A (Before inject)	45
4. 10	The Simulink result for Voltage & Current Phase APF (After Inject)	46



4. 11	Diagram for open loop analysis (hardware)	47
4. 12	Matlab/Simulink reference model for open loop test	47
4. 13	Diagram for Raspberry Pi output	48
4. 14	Result for Raspberry Pi output	49
4. 15	Diagram for gate driver output	49
4. 16	Result for gate driver output pulses (6 pulses)	51
4. 17	Diagram for APF output	51
4. 18	Result for APF circuit output for line to line voltage, $V_{AB}$ .	52
4. 19	Diagram for linear load	53
4. 20	Voltage Vs Current for linear load	54
4. 21	Three phase current for linear load	55
4. 22	Diagram for nonlinear load	56
4. 23	Result for analysis single phase current nonlinear load	57
4. 24	Result for analysis 3 phase current for nonlinear load	57
4.25	Diagram input sensor for linear load,	59
4.26	Diagram input sensor for nonlinear load	59
4. 27	Result ADC input sensor for linear load,	60
4. 28	Result ADC input sensor for nonlinear load	61
4. 29	Diagram for 3 phase current output inverter with linear load	62
4. 30	Diagram for 3 phase current output inverter with nonlinear load	62
4. 31	Result for 3 phase current output inverter for linear load,	63
4. 32	Result for 3 phase current output inverter for: Nonlinear load	63
4. 33	Closed loop diagram with one-cycle current controller for 3 phase APF with nonlinear load	64
4. 34	Result for closed loop diagram with One Cycle Current Controller (OCC) controller for phase-AB of APF before injected to power supply.	65
4. 35	APF current after inject current main supply	66

**LIST OF SYMBOLS AND ABBREVIATIONS**

APF	-	Active Power Filter
PID	-	Proportional Integral Derivative
PI	-	Proportional Integral
I	-	Integral
VFD	-	Variable Frequency Drives
SMPS	-	Switch-mode Power Supply
SPWM	-	Sinusoidal Pulse Width Modulation
UPS	-	Un-interruptible Power Supply
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
IGBT	-	Insulated-Gate Bipolar Transistor
VSI	-	Voltage Source Inverter
CSI	-	Current Source Inverter
VSAFs	-	Voltage Source Active Filter
CSAFs	-	Current Source Active Filter
DC	-	Direct Current
AC	-	Alternative Current
VDC	-	Voltage DC
VAC	-	Voltage AC
THD	-	Total Harmonic Distortion
PWM	-	Pulse Width Modulation
FLC	-	Fuzzy Logic Controller

## CHAPTER 1

### INTRODUCTION

#### 1.0 Introduction

This chapter will introduce about project background, problem statement, aim, objectives and scopes of the development of One Cycle Current Controller (OCC) using Raspberry Pi for 3 phase Active Power Filter (APF) for nonlinear load improvement

#### 1.1 Project Background

Power distribution system are faces a more challenging problem for nonlinear load, rectifier is a nonlinear load device which generates harmonics and the major problem in commercial building or domestic usage. [1][2] This is due primarily to new power conversion technologies, the Switch-mode Power Supply (SMPS) is an excellent power supply and also a highly contribution to nonlinear load, which can be found in almost every power electronic device such as computers, servers, telecom systems, broadcasting equipment, banking machines and other thing [1][2]. These harmonics cause an increase in level of RMS supply current, which results an increase of power loss, heating of equipment and voltage sags [1]. APF is designed to eliminate the majority of the harmonic current orders. IEEE 512-1992, harmonic voltage is formed when harmonic current travels through the impedance of the electrical system toward the lowest impedance point [3].

Nowadays the controllers that had been widely used to overcome this problem are from adaptive and passive controller [9][12]. For an example,

Proportional Integral Derivatives (PID), Fuzzy Logic, Artificial Neural Network (ANN), Sliding Mode Control (SMC), Hysteresis and One cycle current controller. The current regulation has played an important role in current controlled pulse-width-modulated (PWM) APF that is widely applied in high performance ac drives [6][7]. Beside that there are several parameters that must be considered, such as the current control technique to the nonlinear load and for this situation the One Cycle Current Control methods is to be used. Recently, an embedded microcontroller system such as Raspberry pi is quickly developed in many applications because it is an open source, the price is reasonable and performs as microcomputer. The other characteristic of Raspberry Pi it is directly interfaces to the MATLAB / Simulink by using the Target Installer. The model will perform in MATLAB / Simulink and also implements the simulation and hardware of one cycle Current Control method by using Raspberry Pi as a digital signal processing system. As a result the performance characteristics will be observed in terms of output current and effect to the nonlinear load.

## 1.2 Problem statement

Rectifier in a every single electronic appliance or electronic power supply typically one example of nonlinear load on a power system, arc discharge device such as florescent lamp, electric welding machine or heater it will cause current in the power system is interrupted by a switching action and the current contains frequency component that are multiples of the power system frequency [2][5]. Distortion power factor is a measure of how much the harmonic distortion of a load current decreases the average power transferred to the load. The effect of nonlinear loads are create harmonic current in additional to the fundamental AC current waveform and change the shape of the current from sine wave to some other form such as “double-hump”, and it can affect both the distribution system equipment and the loads connected to it.

If these scenarios happen it will create a problem to the power distribution and consumer such as overheating of electrical distribution equipment and rotating equipment, such as cables, transformers, standby generators and electric motors,

High voltages and circulating currents caused by harmonic resonance, Equipment malfunctions due to excessive voltage distortion, Increased internal losses in connected equipment resulting in component failure and shortened lifespan, False operation of protection equipment and metering errors, Lower system power factor preventing effective utilization, Voltage regulator problems on diesel generators, Inability of automatic transfer switches to operate in closed transition [4].

### **1.3 Aim and Objectives**

The main objective in this project is to implement a Active Power Filter (APF) based One Cycle Current Controller (OCC) in order to reduce harmonic distortions for the system with nonlinear load. Other proposed objectives of this project are listed below:

1. Develop and implement an One Cycle Current Controller (OCC) method to solve the nonlinear load affect to three phase supply.
2. Interface the MATLAB Simulink and the Raspberry Pi.
3. To control the current that supply into the three phase nonlinear load.
4. To built a low cost controller for three phase nonlinear load by using Raspberry Pi.

### **1.4 Limitation / Scope of Project**

The limitation and scope of this project is to study the characteristic and effect of the harmonic of 3 phase nonlinear load and to evaluate the performance of Active Power Filter (APF) based One Cycle Current Controller (OCC). In this project the other scope of this project are:

1. Study of the one cylce current control technique by using Matlab/Simulink software for the simulation and hardware development.
2. Construct the 600W APF circuit, where the maximum Voltage 60Vdc and the maximum current 10A, in order to reduce the harmonic distortion.
3. Interface the Active Power Filter (APF) by using Matlab/simulink using Raspberry Pi board as main controller.

4. Applied 3 phase rectifier as prototype of Nonlinear load with  $10 \Omega$  50W (Wire Wound resistor).
5. Maximum Voltage and current supply able to handle by APF are 60 V and 5A.
6. Test the APF circuit and Analysis the result.

## 1.5 Thesis Outline

This thesis is organized into 5 chapters which are introduction, literature reviews, methodology, result and analysis, conclusion and recommendation.

This chapter is only the introduction of this proposed project; the chapter covers the brief idea about problem area, aim, objective and limitation to solve the problem.

Chapter 2 will cover all the literature review about the principles of technique implemented in the Active Power Filter (APF) methods, the brief control strategy used in the proposed filter, commercial product and project that have been done before.

Chapter 3 will cover the methodology of this project. The methodology is on the work that must be done and focus in order to achieve the aim and objective specified before.

Chapter 4 covers the simulation and experiment result using Matlab/Simulink and Raspberry Pi and analyse the compensation performance of the proposed filter subject to rectifier of nonlinear load. The simulation and experiments result of the system performance have been observed.

The last chapter will summarize all the works that has been done in this project. This chapter will summarize the problems faced during the project as well as the solution found to handle the problems occurred for future works that can be done to improve the system.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

This chapter will introduce about the previous project or research done before about nonlinear load, Active Power Filter, Three phase inverter Design, Raspberry Pi as controller. The research covers the usage of Matlab and Raspberry Pi for testing and the acquire result. This chapter will emphasize the importance of this project and the differences between it with other projects.

#### 2.2 Nonlinear load

Nonlinear load are the biggest problem to solve because it create harmonic currents in addition to the fundamental frequency (original) AC current [2][4]. The current waveform does not conform to that the applied voltage or where a change is not proportional to change in applied voltage and it considered nonlinear load if its impedance changes with the applied voltage. The changing impedance that means the current drawn by the nonlinear load will not be sinusoidal even when it is connected to sinusoidal voltage. These non-sinusoidal currents contain harmonic currents that interact with the impedance of the power distribution system to create voltage distortion that can affect both the distribution system equipment and the loads connected to it exactly consumer [4].

The most common form of distorted current is a pulse waveform with a high crest factor inside fundamental frequency. The SMPS is one such load since it consists of a 2-pulse rectifier bridge to convert AC to DC and a large filter capacitor

on its DC bus. The SMPS draws current in short, high-amplitude pulses that occur right at the positive and negative peaks of the voltage. Typically these high current pulses will cause clipping or flat-topping of the 230VAC supply voltage. The “double-hump” current waveform of the 6-pulse rectifier in a VFD also will cause clipping or flat-topping of the 415V distribution system.[4]

Harmonics produce an increase in the resistance of the conductor and in turn, an abnormal common mode (neutral-ground) voltage difference and this will cause undesirable ground loops to occur. The electronic power supply is to transform an AC into a DC, their power source takes its current as portions of the 50 Hz sine wave to become deformed and multiple frequencies of 50 Hz are formed. Often, single phase loads produce triplets (3rd, 9th, etc.), while three phase loads produce 5th and 7th harmonics. Therefore, electric equipment and installations which are designed to operate at 50 Hz, can become damaged or unbalanced due to these harmonic frequencies which are different than the fundamental (50 Hz). The principal problem that arises is the overheating of equipment or conductors.[4]

In an electric circuit, a nonlinear element or nonlinear load device is an electrical element which does not have a linear relationship between current,  $i$  and voltage,  $V$ . Diode is a simple example, the current  $i$  through a diode is a nonlinear function of the voltage,  $V$  across of its terminal. Nonlinear elements are avoided in some electronic circuits, called linear load circuit, because they have the potential to distort electrical signal. Other examples of nonlinear elements are transistor and other semiconductor devices, vacuums tube and iron core inductors and transformers when operated above their saturation current. Examples of nonlinear loads devices are rectifiers (power supplies, UPS units, discharge lighting); adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment.



Table 2. 1 Differences of linear and nonlinear loads.

No	Linear Loads	Nonlinear Loads
1	Examples; Power Factor Improvement Capacitor, Heaters, Incandescent Lamps. Etc	Examples; Computer, Laser Printer, SMPs, Rectifier, Refrigerator etc
2	Ohms law is valid	Ohms law is not valid
3	Load current does not contain harmonics.	Load current contains all odd harmonics
4	Could be inductive or capacitive.	Can't be categorized as leading or lagging loads.
5	Zero neutral current, if 1-Phase loads are equally balanced on 3-Phase Mains (Vector sum of line current)	Even if single phase loads are equally balanced on 3-phase neutral current could be 2.7 times the line current
6	May not demand high inrush currents while starting.	Essentially very high inrush current (20 time of Normal) is drawn while starting for approximat One cycle.

### 2.3 Active Power Filter (APF)

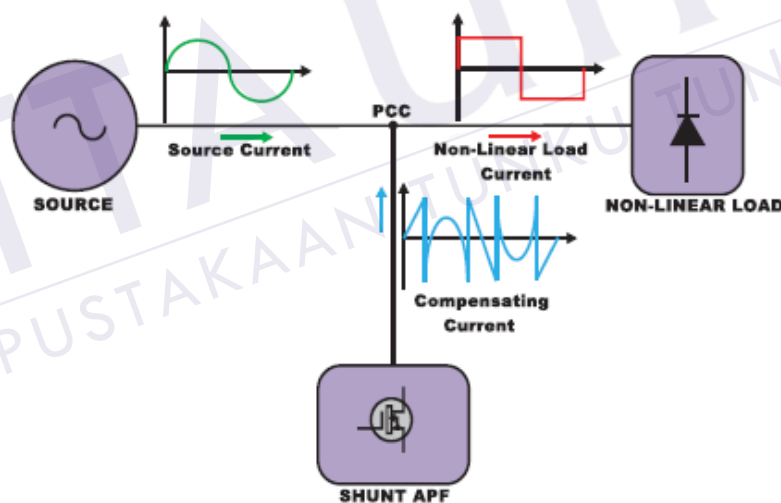


Figure 2. 1 Active Power Filter

Figure 2.1 shows the Active Power Filter (APF) is well-known as the active power line conditioner; APF is an innovative concept that has been mentioned in the literature review over the past several years. The common structure of APF included inverters interfacing with the energy storage elements. The simple terms of APF are generate and inject harmonics equal but opposite to those created by nonlinear loads, cancelling the distortion current and improving the power quality of the power

system [5]. The principle was proposed in 1970's [6][7] Active Power Filter in three-phase system can be subdividing into two classes. In one class, the neutral is not present for examples are three-phase or three-phase wire filters. The other class, present of the neutral conductor and available for use for example three-phase for wire system or three phase four legs.

### **2.3.1 Harmonics in Power System Due to Nonlinear Loads:**

The study begins with the detection of the harmonics arising due to the use of nonlinear loads. The main sources of voltage and current harmonics are due to control and energy conversion techniques involved in the power electronic devices such as chopper, rectifier, cyclo-converter etc. The harmonic sources are energy conversion devices such as power factor improvement and voltage controller devices of motor, high-voltage direct-current power converters, traction and power converters, battery-charging systems, static-var compensators, wind and solar-powered dc/ac converters, direct energy devices-fuel cells, storage batteries which require dc/ac power converters, control of heating elements[10]. The current and voltage harmonics were measured using a dynamic signal analyzer by M. Etezadi-Amoli, and plotted at for different substations [11]. Due to use of nonlinear loads like rectifier, chopper etc. the load current gets distorted, which is explained nicely by Robert considering harmonic study [12].

### **2.3.2 Brief Introduction to Active Power Filter:**

To reduce the harmonics conventionally passive L-C filters were used and also capacitors were employed to improve the power factor of the ac loads. But the passive filters have several drawbacks like fixed compensation, large size and resonance problem. To mitigate the harmonics problem, many research work development are developed on the active power (APF) filters or active power line conditioners [13][14].

### 2.3.3 Control techniques used for Active Power Filter

Designing a suitable controller for an APF is very important. A number control strategies such as instantaneous reactive power theory initially developed by Akagi et al. [15], synchronous frame d–q theory [16], synchronous detection method [17], notch filter and fuzzy logic controller method are used in the development of three-phase APFs and the gate pulses are generated by current control technique like sinusoidal pulse width modulation (SPWM), triangular PWM, hysteresis current control technique [18].

### 2.3.4 Digital Controller for Active Power Filter:

Advancement in microelectronics has motivated new directions for APF design starting from the use of analogue and digital components to microprocessors, microcontrollers, digital signal processors (DSP's) [17][18] and FPGA implementation [19][20]. Further, these developments have made it possible to use different control algorithm such as proportional integral (P-I), fuzzy logic etc. for improving the steady state and dynamic performance of APFs. By implementing this performance, response as well as the cost is efficient compare to the analogue one.

### 2.3.5 Three Phase Inverter

Inverter is a device that transforms Direct Current (DC) to Alternating Current (AC), by switching the DC input supply (voltage or current).in predetermined sequences to generate AC (voltage or current). Inverters function as electrical controller equipment from the power produced by a renewable energy source such as solar panel, wind turbine, hydroelectric, tidal wave turbine and etc. The typical applications of an inverter are un-interruptible power supply (UPS), tractions and VHDC, industrial (induction motor) drives. There are 3 major circuit or components to complete inverter as a device; DC supply is storage energy, Gate circuit is an isolated circuit to protect controller being damage from surge, overload voltage or

current and switching circuit is to perform a DC supply switching follow controller output form.

The purpose of these topologies is to produce a three phase voltage where the amplitude, phase and frequency can be controlled. The three phase inverter DC/AC voltage sources are extensively being used in induction motor driver, active filter and unified power flow controllers in power system and uninterrupter power supplies to generate controllable frequency and AC voltage magnitudes using various pulse width modulation (PWM) strategies. The standard application for three phase inverter shown in Figure 2.2 has six switches (MOSFET or IGBT) the switching of which depends on the modulation scheme. The input DC is usually obtained from a single-phase or three phase utility power supply through a diode-bridge rectifier and LC or C filter.

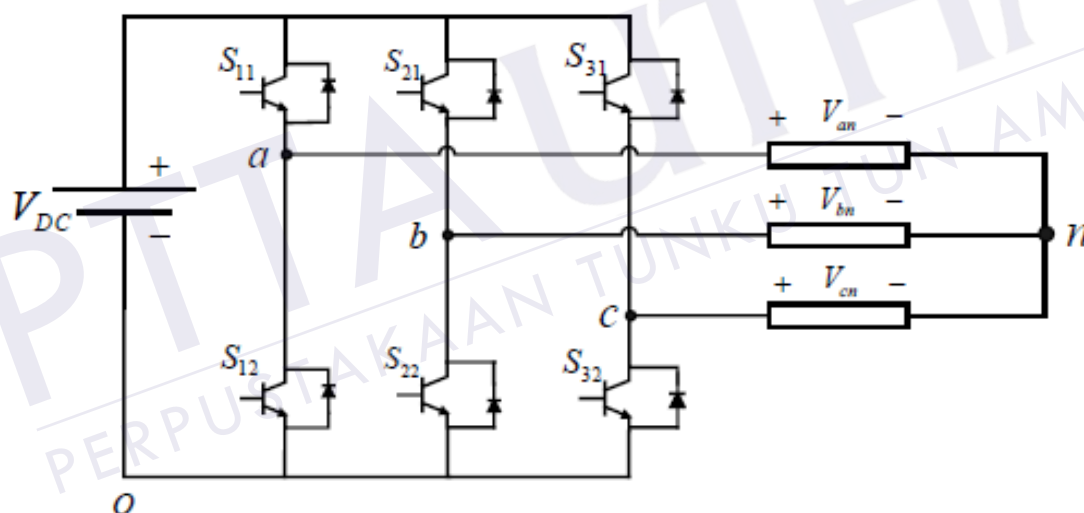


Figure 2. 2 Schematic diagrams for three phase switching

There has eight switch state for three phase inverter given in table 2.1 in order the circuit are satisfied with Kirchhoff Voltage Law (KVL) and the Kirchhoff current Law (KCL), the important thing are both of switch cannot be turn ON at the same time cause it will shorten to the input voltage. Thus the nature of two switches in the same leg is complementary [21].

Table 2. 1 Switching States for three phase inverter.

$S_{11}$	$S_{12}$	$S_{13}$	$V_{ab}$	$V_{bc}$	$V_{ca}$
0	0	0	0	0	0
0	0	1	0	$-V_{DC}$	$V_{DC}$
0	1	0	$-V_{DC}$	$V_{DC}$	0
0	1	1	$-V_{DC}$	0	$-V_{DC}$
1	0	0	$V_{DC}$	0	$-V_{DC}$
1	0	1	$V_{DC}$	$-V_{DC}$	0
1	1	0	0	$V_{DC}$	$-V_{DC}$
1	1	1	0	0	0

From the eight switching states as shown in Table 2.1, two of them produce zero ac line voltage at the output. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states produce no zero ac output line voltages. In order to generate a given voltage waveform, the inverter switches from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages, which are  $-V_{DC}$ , 0, and  $V_{DC}$ . The selection of the states in order to generate the given waveform is done by the modulating technique that ensures the use of only the valid states [21].

#### 2.4 Controller Approaches for Active Power Filter

There are a lot of methods that able to control three phase nonlinear load. They are voltage and current control methods. Both of control technique quite same in term of comprising an internal voltage or current feedback loop and correct the error occurs using the passive or active controller to make the correction in terms to control the performance of the nonlinear load. The controller method has divided into two criteria which are Passive and Adaptive. The example of passive controller contains of Hysteresis, Relay and Sliding Mode Control (SMC). While for the adaptive controller are Fuzzy Logic, PID, and Neural Network.

### 2.4.1 PID controller

PID controller can be attributed partly to their robust performance in a wide range of operating conditions and partly for their practicality engineers can operate them in a simple and straightforward manner. Proportional-Integral-Derivative (PID) controller is prominent for its simplicity. [29]. A PI controller is a common mechanism used in industrial control applications. A PID controller is capable used for regulation of temperature, pressure, flow, speed and other process variables. PID controlled system is a combination of three elements which are proportional, integral and derivative. Equation 2.1, describing  $u(t)$  as the controller output, the final form of the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \quad (2.1)$$

WHERE,

$e = \text{error}$

$\tau = \text{time or instantaneous time}$

Tuning parameter

$K_p = \text{proportional gain}$

$K_i = \text{integral gain}$

$K_d = \text{derivative gain}$

Figure 2.3 shows the block diagram of a PID controller in a feedback loop. The theory of proportional is the error is multiplied by a negative (for reverse action) proportional constant P, and added to the current output. P represents the band over which a controller's output is proportional to the error of the system. For integral, the error is integrated (averaged) over a period of time, and then multiplied by a constant I, and added to the current control output. I represent the steady state error of the system and will remove measured value errors. Derivative is the rate of change of the error is calculated with respect to time, multiplied by another constant D, and added to the output. The derivative term is used to determine a controller's response to a change or disturbance of the process temperature. The larger the derivative term, the more rapidly the controller will respond to changes in the process value.

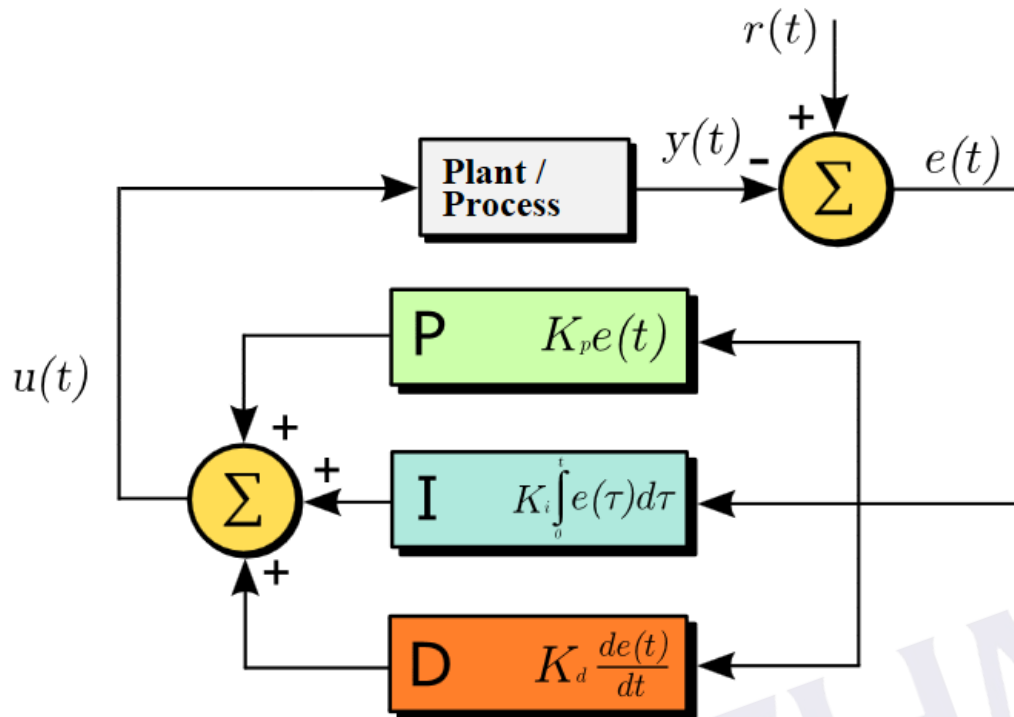


Figure 2. 3 A block diagram of a PID controller in a feedback loop

Relate the system to APF, conventional PID controllers used to extract the fundamental component of the load current thus facilitating reduction of harmonics and simultaneously controlling dc-side capacitor voltage of the voltage source inverter because of their benefit to the system that PID controller gives better speed response in terms of settling time, rise time and steady state error.

#### 2.4.2 Fuzzy logic controller

Fuzzy logic controller (FLC) has been significance a good alternative solution in many applications. [28] The advantages of fuzzy logic controllers are more robust than conventional controllers; there is no specific requirement a mathematical model and able to handle non-linearity. FLC is the evaluation of a set of simple linguistic rules to determine the control action [28] [27]. Fuzzy Logic incorporates a simple rule-based, for example IF X AND Y THEN Z approaches to a solving control problem rather than attempting to model a system mathematically. The FLC model is empirically-based, relying on an operator's experience rather than their technical understanding of the system.

The desired inverter switching signals of the shunt active filter are determined according to the error between the compensate currents and reference currents. According [27] produced a paper on Fuzzy Logic controller for shunt Active Power Filter; the paper presents Active Power Filter based in detection load current and harmonic voltage at the point of installation by using the fuzzy logic method and to improve compensation capability of APF. The shunt APF is implemented with PWM current controlled voltage source inverter and switching patterns are generated through a fuzzy logic control. A fuzzy logic-based PWM control technique is used to generate the gating signals. Switching signal obtained [27] after proper amplification and isolation are given to the switching devices of the PWM converter. The DC link capacitor voltage is maintained constant by a fuzzy logic controller. Fuzzy logic is characterized by seven sets of membership function for each input and output variable by using Mamdani-type min operator and defuzzification using the centroid method. The performance of fuzzy logic controller is found to be excellent, total harmonic distortion is (THD) reduced and improve by tuning the fuzzy rule based using an expert view to produce more effectiveness and accuracy of controller.

### 2.4.3 Hysteresis control

Hysteresis current control method is the most usually suggested control method in time domain. This method provides instantaneous current corrective response, good accuracy, extreme robustness, good stability and allows fast current control [30][31][32]. The basic principle of current hysteresis control technique is that the switching signals are derived from the comparison of the current error signal with a fixed width hysteresis band. As long as the error is within the hysteresis band, no switching action is taken. Switching occurs whenever the error hits the hysteresis band. This control scheme is shown in Figure 2.4. The outputs of the comparator are switching gating signals to the inverter.



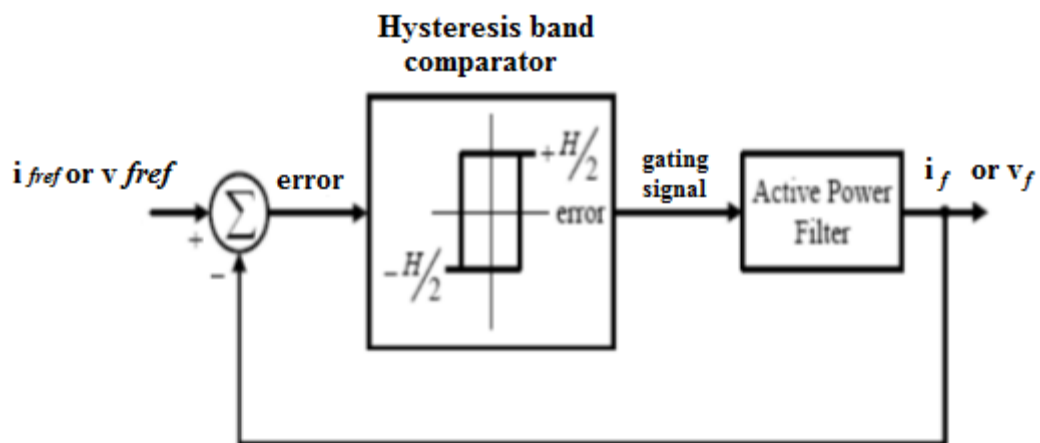


Figure 2. 4 Hysteresis Control Techniques

The APF is therefore switched in such a way that the peak-to-peak compensation current/voltage signal is limited to a specified band determined by upper band and lower band as demonstrated by Figure 2.5. To acquire a compensation current with switching ripples as small as possible, the value of upper band and lower band can be reduced. However, doing so the results in high switching frequency. Thus, increases losses on the switching transistors [31][32].

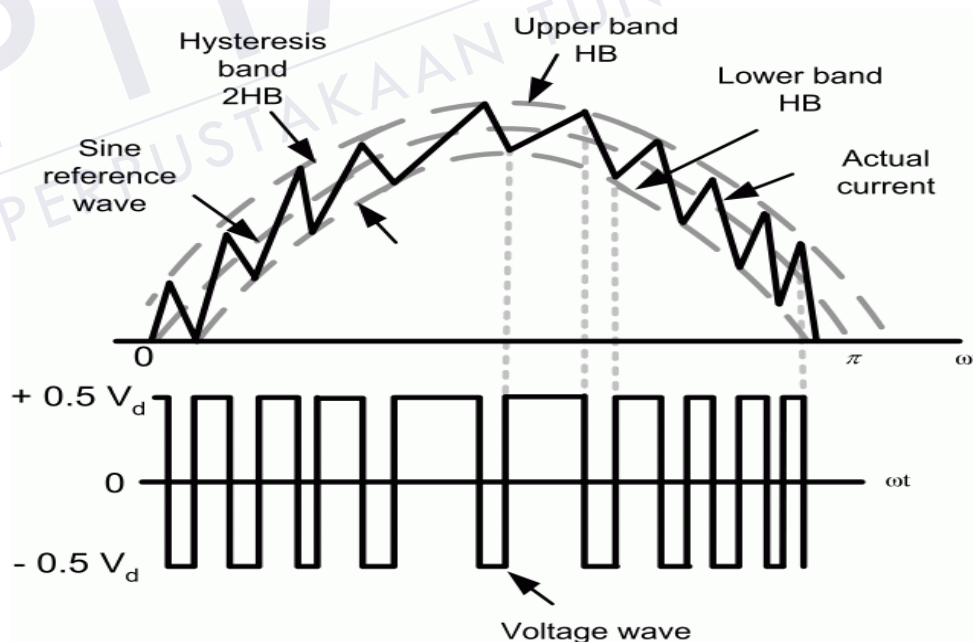


Figure 2. 5 Gating signal generation

### 2.4.4 One-Cycle Control

One Cycle Control (OCC) is the term used to describe a nonlinear control technique invented by Keyue Smedley and Slobodan Cuk because switches are nonlinear systems, the idea is that a pulsed nonlinear control should provide faster dynamic response and reject input perturbations better than linear control since the nonlinear control matches the system [23][24]. One Cycle Current Controller (OCC) technique able to be implemented under constant off time, constant on time, constant-frequency, or variable by adjustable time on and time off switches, constant-frequency is most commonly used [22]. The basic idea of One Cycle Current Controller (OCC) can be seen in Figure 2.3 below for a constant frequency switch

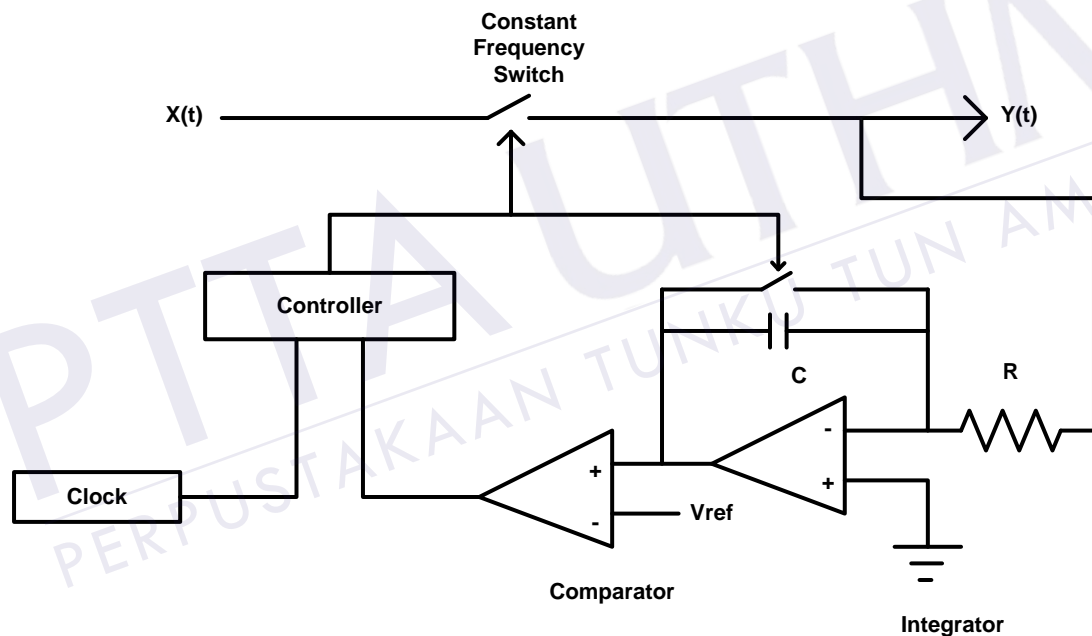


Figure 2. 6 One-Cycle Controlled Constant Frequency Switch [10]

The input signal  $x(t)$  at the input node of the switch is chopped by the switch and transferred to the output node of the switch to form a switched variable  $y(t)$  [10]. The average value of  $y(t)$  is obtained by integrating  $y(t)$  and the value is then compared with a reference. As soon as the integrated value reaches the reference, the comparator sends a signal to the controller, which turns the switch off and resets the integrator to zero [10].

A switch, constant frequency, constant *ON* time, constant *OFF* time or variable as is defined as operating under a function  $k(t)$  at frequency  $f_s = \frac{1}{T_s}$  [23]:

$$k(t) = \begin{cases} 1 & 0 < t < T_{ON} \\ 0 & T_{ON} < t < T_s \end{cases} \quad (2.2)$$

In each cycle, the switch is on for a time duration  $T_{ON}$  and is *OFF* for a time duration  $T_{OFF}$ , where  $T_{ON} + T_{OFF} = T_s$ . The duty-ratio  $d = \frac{T_{ON}}{T_s}$  is modulated by an analogue control reference  $V_{ref}(t)$ . The input signal to the switch is  $x(t)$  to produce an output  $y(t)$  with the same frequency and pulse width as  $k(t)$ , with  $x(t)$  as the envelope of  $y(t)$  as seen in Figure 2.4

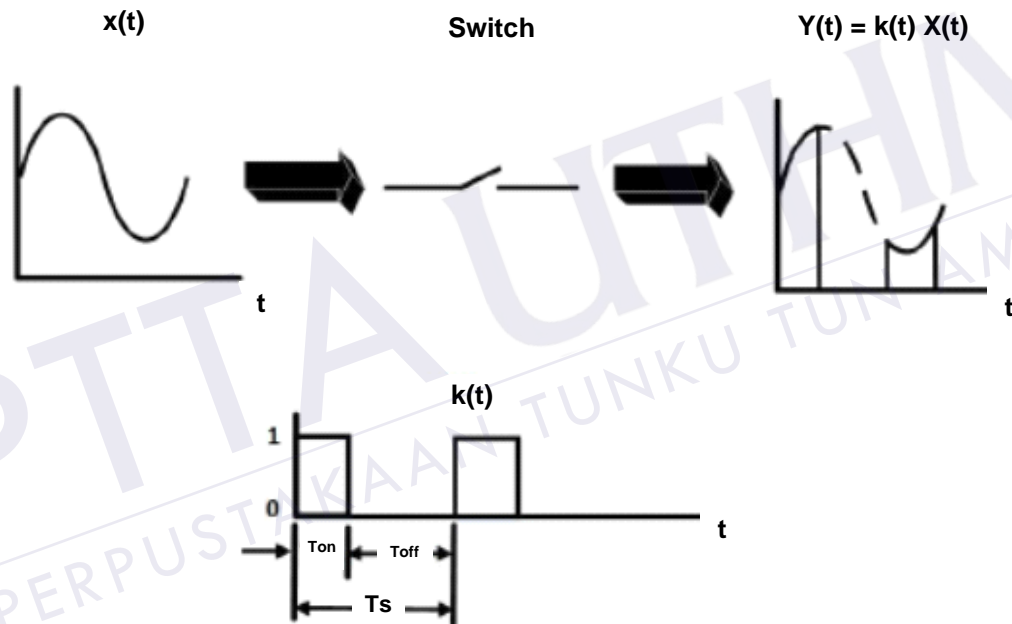


Figure 2. 7 Switch Input  $x(t)$ , Output and Switch Signal  $y(t) = X(t)K(t)$  [10]

Assuming that the switch frequency  $f_s$  is much higher than the frequency bandwidth of  $x(t)$  or  $V_{ref}(t)$ , the effective output value  $y(t)$  is equal to the average value over a switch cycle:

$$y(t) = \frac{1}{T_s} \int_0^{T_s} x(t) dt \approx x(t) \frac{1}{T_s} \int_0^{T_{on}} dt = x(t) \frac{T_{on}}{T_s} = x(t) V_{ref}(t) \quad (2.3)$$

Thus, the output signal  $y(t)$  is a product of the input signal  $x(t)$  and the control  $V_{ref}(t)$  making the switch nonlinear. If the control signal is constant, for example  $V_{ref}(t) =$

$D$ , then the output becomes  $Dx(t)$ , as is the case in digital signal processing. For power processing applications,  $x(t)$  usually represents the power, while  $V_{ref}(t)$  is the signal to be amplified. Ideally, the input power  $x(t)$  is constant, but in reality there are perturbations causing disturbances to the output  $y(t)$  also. If the switch duty ratio is modulated such that in each cycle the integration of the chopped waveform at the switch output is exactly equal to the integration of the control signal, i.e.:

$$\int_0^{T_{on}} x(t)dt = \int_0^{T_{on}} V_{ref}(t)dt \quad (2.4)$$

Then the output signal becomes instantaneously controlled within one cycle:

$$y(t) = \frac{1}{T_s} \int_0^{T_{on}} x(t)dt = \frac{1}{T_s} \int_0^{T_s} V_{ref}(t)dt = V_{ref}(t) \quad (2.5)$$

Since the switching frequency  $f_s$ , is much higher than the time-varying reference voltage, the reference can be seen as constant in one period, thus simplifying the above equation to:

$$y(t) = V_{ref} \quad (2.6)$$

Thus, the switch is able to reject any input disturbances since it does not depend on  $x(t)$  and is able to linearly pass  $V_{ref}$ , turning a nonlinear switch into a linear switch.[23]



## 2.5 Raspberry Pi

A Raspberry Pi is a small, credit-card sized microcomputer developed by Raspberry Pi Foundation, UK. This single boarded computer was developed with aim of teaching the basics of computer science and programming to school students all around the world. Although a microcontroller, like Arduino, is trendy for prototyping projects, a Raspberry Pi is quite different from the popular microcontroller. Actually, it is more like a computer than an Arduino.

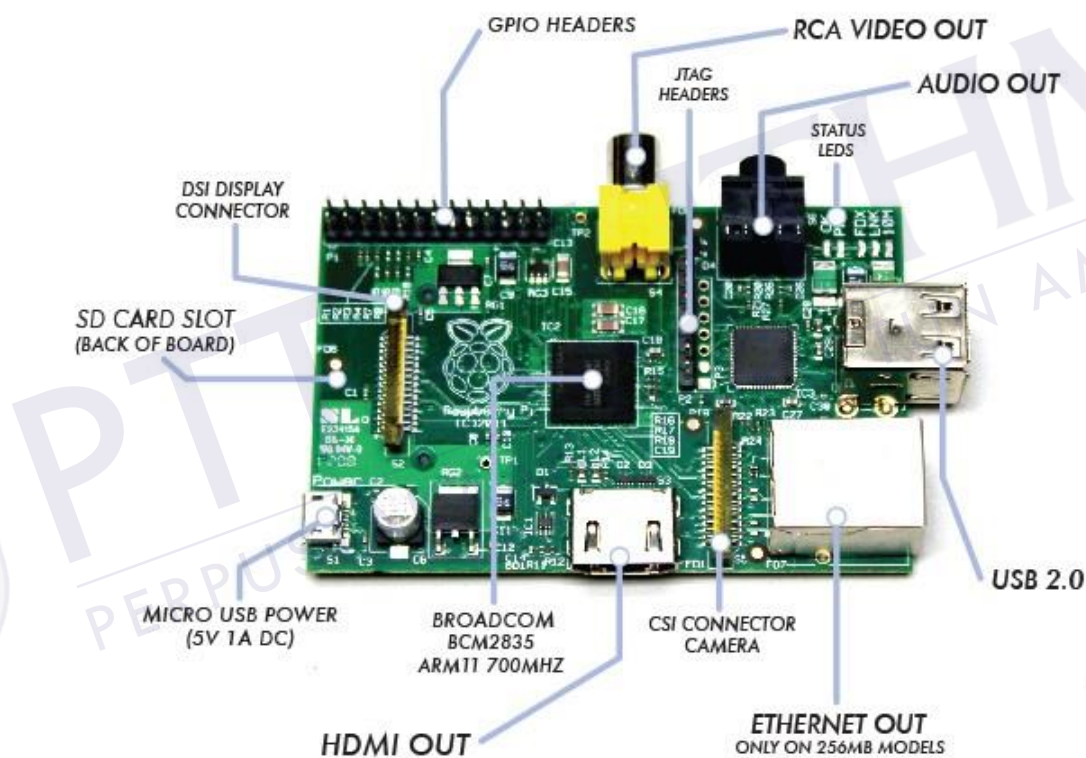


Figure 2. 8 Raspberry Pi's Controller

### 2.5.1 Hardware and specifications

Raspberry Pi is found in two versions. Model A and Model B. Although Model A is cheaper than Model B, there are some other differences in these two versions of Raspberry Pi. Model A has a 256MB memory, comes with a single USB port and

does not have any Ethernet port whereas model B has a 512MB memory, 2 USB ports, and an Ethernet port as well.

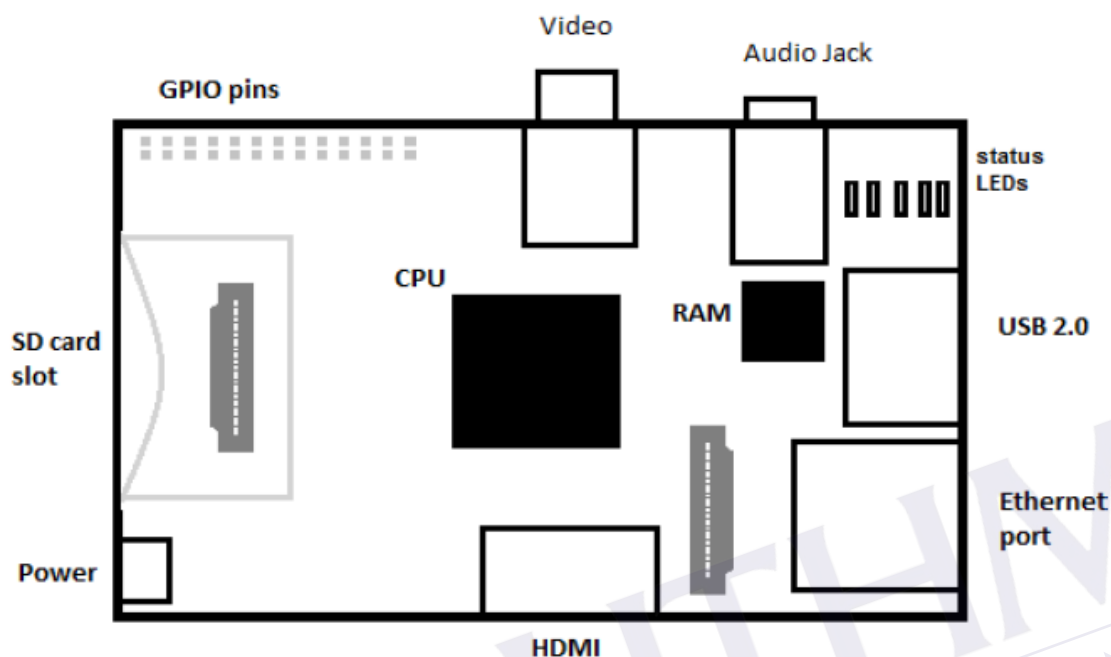


Figure 2.9 Raspberry Pi's hardware

A Raspberry Pi consists of many important hardware parts with some useful functions. The main part of a Raspberry Pi is its Processor. Every Raspberry Pi has a Broadcom BCM2835 chip which embodies an ARM1176JZF-S CPU core. The chip has a clock speed of 700MHz and it is a 32-bit System. A Raspberry Pi has a SD card slot for a SD card which acts as the storage media for it. Everything including the operating system and other files are stored in the SD card. The HDMI port is used as audio and video output. A HDMI to DVI (Digital Visual Interface) converter can be used to convert the HDMI signals to DVI which is normally used by monitors. The Raspberry Pi has the Status LED which provides the visual information. For instance, the first green light (marked as ACT on Raspberry Pi board) indicates that the SD card is accessed, the second green LED (marked as FDX) indicates the full duplex network and the third green LED (marked as LNK) indicates the link activity. Similarly, the red light (marked as PWR) announces the power of 3.3v and the yellow LED (marked as 100) hints the 100Mbps network connection. The 5v DC through a micro USB powers up the Raspberry Pi. This device also has a RCA

composite video connector for video output as well as a 3.5mm stereo jack for audio output. The Raspberry Pi has 26 GPIO pins which help to connect to low level peripherals and expansion boards.

### 2.5.2 Raspberry Pi's specifications

Raspberry Pi's specifications (Raspberry Pi Model A & Model B Comparison 2013). The Raspberry Pi used for this thesis study uses Raspbian Wheezy as an operating system. Raspbian is a Debian based free OS (operating system) for Raspberry Pi.

Table 2.2 Raspberry Pi's specifications

Technical Feature	Model A	Model B
SOC (System On Chip)	Broadcom BC2835	
CPU	700 MHz Lower Power ARM1176JZ-F	
GPU	Dual Core Video Core IV multimedia Co-processor	
Memory	256MB SDRAM	512MB SDRAM
USB 2.0	1	2
Video Out	Composite RCA(PAL and NTSC), HDMI	
Audio out	3.5mm jack, HDMI	
Storage	SD/MMC/SDIO card slot	
Network	No Port	RJ45 Ethernet
Peripheral Connectors	8xGPIO, UART,PC bus, SPI bus	
Power Source	5Volt DC via Micro USB or GPIP headers	

The advantages of the Raspberry Pi's are stated below: [26]

- A Raspberry Pi is a small, credit-card sized microcomputer developed by Raspberry Pi Foundation, UK with aim of teaching the basics of computer science and programming to school students all around the world. Actually, it is more like a computer than an Arduino.
- Inexpensive – Raspberry Pi embedded devices are inexpensive compared to other microcontroller embedded devices.
- Can be programmed using variety of programming languages – The Raspberry Pi programming environment is easy to use for beginners.
- Entire Linux software stack is available – It can run a full Linux based operating system and has hardware support for SPI, I2C and Serial.

- It is very easy to connect to internet
- Open source – The Raspberry Pi software is published as open source tools, so the user easy to get the information experienced programmers.





## CHAPTER 3

### METHODOLOGY

#### 3.1 Introduction

This chapter will introduce about methodology of the doing this project has been outlined so that the satisfied result will acquired. This methodology divide into FIVE basic research, nonlinear load problem, One Cycle Current Controller (OCC) Design, Gate Driver circuit design, current sensor design and Active Power Filter Design. This project research diving into two task, which are simulation and hardware analysis. For simulation analysis, whole simulations are using software called Matlab / Simulink and all the five basic research are constructed, simulated and verify the result thru basic concept of One Cycle Current Controller. For the hardware implementation, the model has been developing based on five basic research prototypes due to apply the controller method and analysis the performance of each part.



### 3.2 Block Diagram

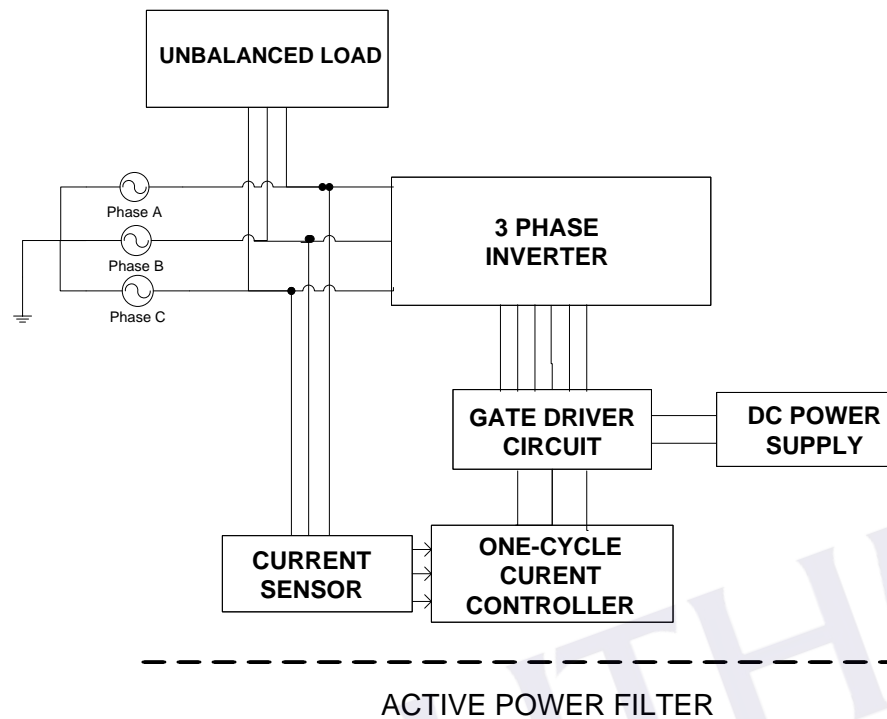


Figure 3. 1 Block diagram of the project

Figure 3.1 shows the block diagram of the whole project of development of One Cycle Current Controller OCC using Raspberry Pi. This development of Active Power Filter (APF) consists of FIVE main parts which are the DC power supply as the input, gate driver circuit as an isolator circuit and PWM signal generator, three phase inverter, and current sensor as a feedback input current to the controller and One Cycle Current Controller (OCC). The power supply is generated by dropping the voltage from 3 phases 415V to 3 phases 24V and connects it to the three phase nonlinear load. For the load component consist of six power diode and power resistor with the rating of load 10 $\Omega$ , 50 W and the diode characteristic will interrupt the fundamental waveform of current from supply and form “double hump” waveform to the load.

The first part is an input which is the DC voltage that fed to a three phase inverter and performs as Active Power Filter (APF). The gate drivers use a 5 Vdc while the inverter input voltage depends on the loads that need to be powered. Second part is the gate driver circuit which has a function that to double up the PWM signal from the Raspberry Pi and also perform as isolator circuit. The gate driver will

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