

P-3537



**Power Factor Improvement in Three Phase  
AC-AC Converter Through Modified SPWM**



**A Project Report**

*Submitted by*

**P.VASUKI - 0920105016**

*in partial fulfillment for the award of the degree*

of

**Master of Engineering**

in

**Power Electronics and Drives**

**DEPARTMENT OF ELECTRICAL & ELECTRONICS  
ENGINEERING**

**KUMARAGURU COLLEGE OF TECHNOLOGY  
COIMBATORE – 641 049**

(An Autonomous Institution Affiliated to Anna University of technology, Coimbatore.)

**ANNA UNIVERSITY OF TECHNOLOGY, COIMBATORE**

**APRIL 2011**

# ANNA UNIVERSITY: COIMBATORE

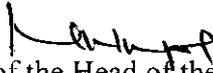
## BONAFIDE CERTIFICATE

Certified that this project report entitled “**Power Factor Improvement in Three Phase AC-AC Converter through Modified SPWM**” is the bonafide work of

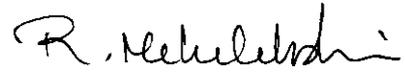
P.Vasuki

Register No. 0920105016

Who carried out the project work under my Supervision



Signature of the Head of the Department



Signature of the Supervisor

Certified that the candidate with university Register No. 0920105016 was examined in  
project viva voce Examination held on 27.04.2011

  
Internal Examiner  
External Examiner

**DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING**  
**KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE 641 049**  
(An Autonomous Institution Affiliated to Anna University of Technology, Coimbatore.)



# Certificate

This is to certify that

P. Vasuki of  
Kumaraguru College of Technology

has Participated/Presented a Research Paper titled  
Power Factor Improvement in Three phase  
AC-AC Converter Through Modified Sinusoidal  
Pulse Width Modulation

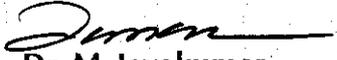
in the

*Third National Conference on Recent Trends in  
Communication, Computation and Signal Processing,*  
organized by the

Department of Electronics and Comunication Engineering,  
Amrita Vishwa Vidyapeetham, Coimbatore on March 01 - 02, 2011.

  
N. Mohankumar  
Secretary

  
B. Sabarish Narayanan  
Treasurer

  
Dr. M. Jayakumar  
Convenor



## ACKNOWLEDGEMENT

I humbly submit all the glory and thanks to the almighty for showering the blessings and giving the necessary wisdom for accomplishing this project.

I would like to express my heartfelt thanks to our beloved Principal **Dr.S.Ramachandran**, for his support.

I take immense pleasure in thanking **Dr.Rani Thottungal, HOD** Department of Electrical and Electronics Engineering, Kumaraguru College of Technology, for her constant encouragement and support

I would like to express my deep sense of gratitude and profound thanks to my guide **Dr.R. Mahalakshmi**, Associate Professor, Electrical and Electronics Engineering Department, for her valuable guidance, support, constant encouragement and co-operation rendered throughout the project.

I am also thankful to all my **teaching and technical supporting staffs** of Electrical and Electronics Engineering department, for their kind help and encouragement.

Finally, I thank my parents for giving me the moral support and abundant blessings in all of my activities and to my dear friends who made me endure my difficult times with their unfailing humor and warm wishes.

# CONTENTS

<b>TITLE</b>	<b>Page No</b>
ABSTRACT	i
LIST OF TABLES	ii
LIST OF FIGURES	iii
ABBREVIATIONS	v
LIST OF SYMBOLS	vi
<b>1. INTRODUCTION</b>	
1.1 Introduction of AC PWM Chopper	1
1.2 Objectives of project	2
1.3 Organization of the thesis	2
<b>2. AC VOLTAGE REGULATORS</b>	
2.1 Introduction	4
2.2 Single Phase AC Voltage Regualtors	4
2.3 Three Phase AC Voltage Regualtor	6
<b>3. SINGLE PHASE AC PWM CHOPPER</b>	
3.1 Introduction	9
3.2 Block Diagram	9
3.3 PWM Control Strategies	10
3.3.1 Sinusoidal Pulse Width Modulation	11
3.3.2 Modified Sinusoidal Pulse Width Modulation	12

3.4 Circuit Diagram of Single Phase AC PWM Chopper	13
3.5 Simulation Diagram	
3.5.1 Matlab	14
3.5.2 SIMULINK	14
3.5.3 Power System Block Set	14
3.5.4 Overall System Structure	15
3.5.5 Control Circuit	16
3.5.6 Simulation Results and Discussions	16

#### **4. THREE PHASE AC-AC CONVERTER THROUGH MODIFIED SPWM**

4.1 Introduction	19
4.2 Block Diagram	19
4.3 Circuit Diagram of three phase ac PWM chopper	20
4.4 Principle of Operation	21
4.4.1 Active Modes	22
4.4.2 Freewheeling Modes	22
4.5 Simulation Results and Discussions	24
4.5.1 Input Voltage and Input Current Characteristics	25
4.5.2 Output Voltage	26
4.5.3 Power Factor	26

#### **5. HARDWARE IMPLEMENTATION OF SINGLE PHASE AC PWM CHOPPER**

5.1 Block diagram of single phase ac PWM chopper	27
--	----

5.1.1 Power Supply	28
5.1.2 Modified SPWM Pulse generation	28
5.1.3 MOSFET IRFZ44	29
5.1.4 MOSFET driver IR2110	29
5.1.5 Single Phase ac PWM chopper	30
5.1.6 Microcontroller for Single Phase AC PWM Chopper	31
5.1.7 Optocoupler	32
5.2 Hardware Prototype and Results	33
<b>6. CONCLUSION AND FUTURE SCOPE</b>	
6.1 Conclusion	36
6.2 Future scope	36
REFERENCES	37
APPENDIX I Data Sheets	39
APPENDIX II PIC 16F877A Data Sheets	47
APPENDIX III PIC Programming	52

## **ABSTRACT**

The three phase ac-ac converter whose control strategy is based on modified sinusoidal pulse-width modulation switching technique is proposed in this thesis. A new generation of ac-ac three-phase power converters with more commutations per half cycle has been proposed for ac power due to the increasing availability and power capability of high frequency controlled on and off power semiconductor switching devices. As majority of the industrial loads are being inductive, the power factor is less. To improve the power factor, the delayed current is shifted to the input voltage, through a modification of the classical sinusoidal pulse width modulation switching technique. In this way, the decrease in the phase angle between the input current and voltage is feasible, and consequently, high cost compensation capacitors can be avoided. The improvement of power factor through this switching technique on the proposed converter is investigated and verified via simulation using the software Matlab/Simulink. The single phase ac-ac converter is implemented in hardware and tested. Micro controller PIC16F877A is used to generate the pulses for the switching devices of the semiconductor power switches in three phase ac-ac converter.

## LIST OF TABLES

Table No.	Title	Page No.
4.1	Switching Sequence	21

## LIST OF FIGURES

Figure No.	Title	Page No.
2.1	Single phase AC-AC voltage regulator	4
2.1 (a)	Back to Back SCR	4
2.1 (b)	A bidirectionally conducting TRAIC	4
2.2	Operation of a single phase PAC with an inductive load	5
2.3	Load current for a single phase AC-AC converter with a RL load	6
2.4	Three-phase, three-wire ac regulator	7
2.5	Waveforms for three-phase three-wire ac regulator	8
3.1.	Single Phase AC-AC Converter	10
3.2.	Conventional SPWM pulses	11
3.3	$\alpha$ -SPWM Pulses For $\alpha = 35^\circ$	12
3.4	Single Phase AC PWM chopper	13
3.5	SIMULINK model of single phase PWM ac chopper	15
3.6	Control Circuit of $\alpha$ -SPWM	16
3.7	Input Voltage and Current for Conventional SPWM	16
3.8	Input Voltage and Current Without a converter	17

### LIST OF FIGURES (Cont.,)

Figure No.	Title	Page No.
3.9	Input Voltage and current for Modified SPWM	17
3.10	Input Power Factor	17
3.11	Output Voltage	18
4.1	Block Diagram of Three Phase AC-AC Converter	20
4.2	Circuit Diagram of Three Phase AC voltage regulator	21
4.3	Active mode of Positive Half cycle	22
4.4	Active mode of Negative Half cycle	22
4.5	Freewheeling mode of Positive Half cycle	23
4.6	Freewheeling mode of Negative Half cycle	23
4.7	Simulation Circuit of Three Phase ac-ac converter	24
4.8	Input Voltage and Current for conventional SPWM	25
4.9	Input Voltage and Current for $\alpha$ -SPWM	25
4.10	Output voltage	26
4.11	Power factor	26
5.1	Hardware Block diagram	27
5.2	Block diagram of power supply	28
5.3	Schematic of rectifier	28
5.4	Schematic of PWM Generation	29
5.5	Pin diagram of IR2110	30

### LIST OF FIGURES (Cont.,)

<b>Figure No.</b>	<b>Title</b>	<b>Page No.</b>
5.6	Driver circuit of IR2110	30
5.7	Schematic of Single phase PWM ac chopper	31
5.8	Schematic of micro controller circuit	32
5.9	MCT2E Opto Coupler	32
5.10	Prototype Photo	33
5.11	Input Voltage	34
5.12	Input Current	34
5.13	Output Voltage	35

## ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
PAC	Phase Angle Control
RMS	Root Mean Square
PWM	Pulse Width Modulation
PF	Power Factor
SPWM	Sinusoidal Pulse Width Modulation
$\alpha$ – SPWM	Modified Sinusoidal Pulse Width Modulation
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
IGBT	Insulated Gate Bipolar Transistor

## LIST OF SYMBOLS

$V_s$	Source Voltage
$\alpha$	Firing Angle
$\phi$	Power Factor Angle
$i_L$	Load Current
$i_{ss}$	Steady-state component of load current
$i_{tr}$	Transient component of load current
$M$	Modulation index
$I_{in}$	Input Current
$V_{tr}$	Triangular carrier wave
$V_c$	Reference sinusoidal wave
$V_{c\alpha}$	Sinusoidal waveform, which is similar to input voltage but not in phase with $V_s$

---

---

## CHAPTER 1

---

---

# CHAPTER 1

## INTRODUCTION

### 1.1. INTRODUCTION OF AC PWM CHOPPER

Numerous modern industry applications, from low to high power areas, demand ac signals with adjustable amplitude and frequency. A converter that changes fixed ac supply to the ac supply with alternative voltage, frequency, phase or shape is an AC/AC converter. The simplest one is voltage regulator, which changes ac voltage without frequency variation. Others are direct frequency converter and a DC link converter. AC voltage regulator is discussed here. Two types of control normally employed are

- On-off control
- Phase-angle control

In on-off control the switches connect the load to the ac source for few cycles of input voltage and then disconnect it for another few cycles. The circuit configurations and performance is similar to the phase control techniques.

Phase controlled ac choppers are well known and are being widely used to obtain variable ac voltage from a fixed ac voltage source. In this type of control the switches connect the load to the ac source for a portion of each cycle of input voltage. The power flow to the load is controlled by delaying the firing angle of switches. This technique offers the advantages of simplicity and ability of controlling large amount of power economically. However, significant harmonics in both the output voltage and current is introduced, and a discontinuity of power flow appears at both the input and output sides. Also the retardation of firing angle causes a lagging power factor (PF) at the input side even for a resistive load.

The above problems can be partially solved by using more advanced control methods such as symmetrical angle control (SAC), asymmetrical angle control (AAC) and time ratio control of high frequency (TRC) or by introducing a freewheeling path in the power circuit. In development of power semiconductor devices, Pulse Width Modulation (PWM) techniques are increasingly being encouraged and will be sophisticated further. One of the main functions in the PWM methods is to eliminate the harmonic contents of the output voltage by adjusting the number of pulses per cycle and to improve the PF. AC chopper using PWM provides substantial

advantages over conventional line commutated AC controllers. There are many PWM techniques are available of which sinusoidal PWM (SPWM) is commonly used. However, the PF is less i.e., the lag between the input voltage and input current is not zero. Contrary to this, through the Modified SPWM ( $\alpha$ -SPWM) switching technique, this lag can almost become zero, and consequently, the PF will be improved. As majority of the industrial loads are being inductive, the PF will be very less. This project deals with the proposed three phase AC chopper using PWM to improve PF.

## **1.2 OBJECTIVES OF THE PROJECT**

The aim of this project is

- To design and simulate three phase AC-AC PWM chopper using Modified SPWM technique so as to improve the PF.
- To simulate and compare the input voltage and current made by implementing both conventional SPWM, modified SPWM control technique in three phase AC-AC converter using MATLAB/SIMULINK.
- Hardware implementation of single phase AC-AC PWM chopper.

## **1.3 ORGANIZATION OF THESIS**

This gives an overall outline of the project report.

### **CHAPTER 1**

It describes the general introduction, objective of the project.

### **CHAPTER 2**

It describes about the single and three phase ac voltage regulators.

### **CHAPTER 3**

It describes about the single phase ac PWM chopper, modified SPWM technique, simulation diagram and results.

## CHAPTER 4

In this chapter it describes the proposed three phase ac PWM chopper, equivalent circuit, modes of operation, simulation diagram and results.

## CHAPTER 5

It includes the proposed system model and description of all components used in the hardware. It shows the schematic diagram of the hardware and output waveforms and test results.

## CHAPTER 6

Gives the conclusion and recommendations for the future work.

---

---

## CHAPTER 2

---

---

## CHAPTER 2

### AC VOLTAGE REGULATORS

#### 2.1 INTRODUCTION

AC to AC voltage converters operate on the AC mains essentially to regulate the output voltage. Portions of the supply sinusoid appear at the load while the semiconductor switches block the remaining portions. Several topologies have emerged along with voltage regulation methods, most of which are linked to the development of the semiconductor devices. The AC voltage controllers can be classified into two types

- Single Phase controllers
- Three Phase controllers

#### 2.2 SINGLE PHASE AC VOLTAGE REGULATORS

In practice most of the loads are inductive to a certain extent. A full wave controller with an RL load is shown in Fig.2.1 in which the phase angle control (PAC) technique is implemented. The firing angle of the switch is varied. It uses a low frequency switch to chop an AC sine wave. The average voltage is proportional to the area under the sine wave. Thus, the average voltage is the integral from the firing angle to the zero crossing, the cosine of the firing angle. The current builds up from zero in each cycle. It quenches not at the zero crossing of the applied voltage as with the resistive load but after that instant. The supply voltage thus continues to be impressed on the load till the load current returns to zero.

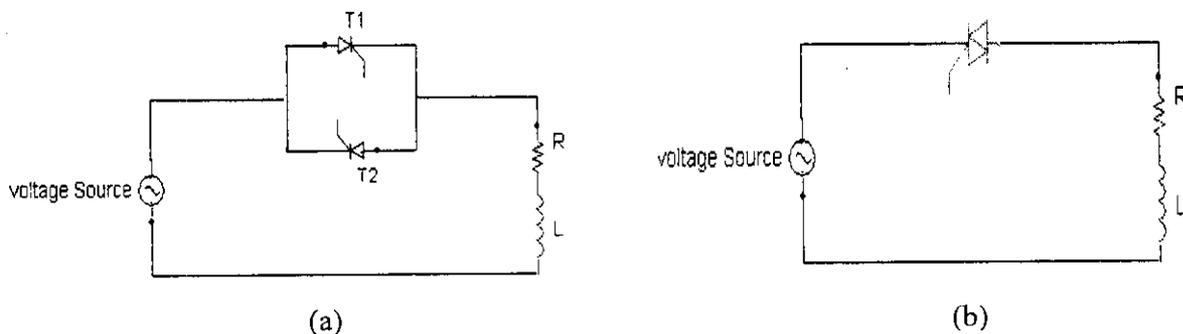


Fig. 2.1 Single phase AC-AC voltage regulator

(a) Back-to-back SCR

(b) A bi-directionally conducting TRIAC

The switches can be thyristor (Fig. 2.1(a)) or TRIAC (Fig. 2.1(b)). The TRIAC based converter may be considered as the basic topology. Being bi-directionally conducting devices, they act on both polarities of the applied voltage. The TRIAC is a low power device, used in voltage control circuits, used as light dimmers, speed control for fan motors (single-phase), etc. Some of the advantages and disadvantages of the TRIAC viz-a-viz thyristor are given.

### ADVANTAGES

- Triacs are triggered by positive or negative polarity voltages applied at the gate terminal.
- A triac needs a single heat sink of slightly larger size, whereas anti-parallel thyristor pair needs two heat sinks of slightly smaller sizes, but due to the clearance total space required is more for thyristors.

### DISADVANTAGES

- Triacs have low rating as compared to thyristors  $dv/dt$
- Triacs are available in lower rating as compared to thyristors.
- Since a triac can be triggered in either direction, a trigger circuit for triac needs careful consideration.
- The reliability of triacs is lower than that of thyristors.

A single-pulse trigger for the anti-parallel SCR (Fig. 2.1(a)) or TRIAC (Fig. 2.1(b)) has no effect on the devices if it (or the anti-parallel device) is already in conduction in the reverse direction. The devices would fail to conduct when they are intended to, as they do not have the supply voltage forward biasing them when the trigger pulse arrives. A single pulse trigger will work till the trigger angle  $\alpha > \phi$ , where  $\phi$  is the power factor angle of the inductive load. A train of pulses is required here. The output voltage is controllable only between triggering angles  $\phi$  and  $180^\circ$ . The load current waveform is further explained in Fig. 2.2

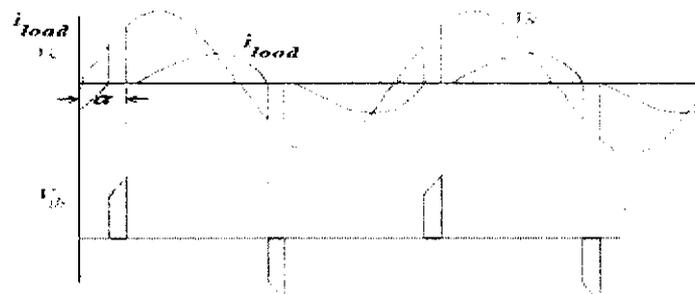


Fig.2.2 Operation of a single phase PAC with an inductive load

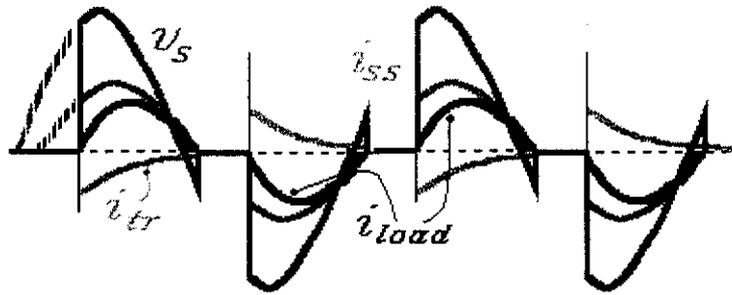


Fig.2.3 Load current for a single phase AC-AC converter with a RL load

With an inductance in the load the distinguishing feature of the load current is that it must always start from zero. However, if the switch could have permanently kept the load connected to the supply the current would have become a sinusoidal one phase shifted from the voltage by the phase angle of the load,  $\phi$ . This current restricted to the half periods of conduction is called the 'steady-state component' of load current  $i_{ss}$ . The 'transient component' of load current  $i_{tr}$ , again in each half cycle, must add up to zero with this  $i_{ss}$  to start from zero.

$$i_{load} - \text{load current} (= i_{ss} + i_{tr}) \quad (2.1)$$

This condition sets the initial value of the transient component to that of the steady state at the instant that the SCR/TRIAC is triggered. Fig. 2.3 illustrates these relations.

### 2.3 THREE-PHASE AC VOLTAGE REGULATORS

There are many types of circuits used for the three-phase ac regulators (ac to ac voltage converters), unlike single-phase ones. The three-phase loads (balanced) are connected in star or delta. Two thyristors connected back to back, or a TRIAC, is used for each phase in most of the circuits as described.

The circuit of a three-phase, three-wire ac regulator (termed as ac to ac voltage converter) with balanced resistive (star-connected) load is shown in Fig. 2.4. It may be noted that the resistance connected in all three phases are equal. Two thyristors connected back to back are used per phase, thus needing a total of six thyristors. The thyristors are fired in sequence (Fig. 2.4), starting from 1 in ascending order, with the angle between the triggering of thyristors 1 & 2 being (one-sixth of the time period ( $60^\circ T$ ) of a complete cycle). The line frequency is 50 Hz,

with  $T=1/f=20\text{ms}$ . The thyristors are fired or triggered after a delay of  $\alpha$  from the natural commutation point. The natural commutation point is the starting of a cycle with period,  $(60^\circ = T/6)$  of output voltage waveform, if six thyristors are replaced by diodes. The output voltage is similar to phase-controlled waveform for a converter, with the difference that it is an ac waveform in this case. The current flow is bidirectional, with the current in one direction in the positive half, and then, in other (opposite) direction in the negative half. So, two thyristors connected back to back are needed in each phase. The turning off of a thyristor occurs, if its current falls to zero. To turn the thyristor on, the anode voltage must be higher than the cathode voltage, and also, a triggering signal must be applied at its gate.

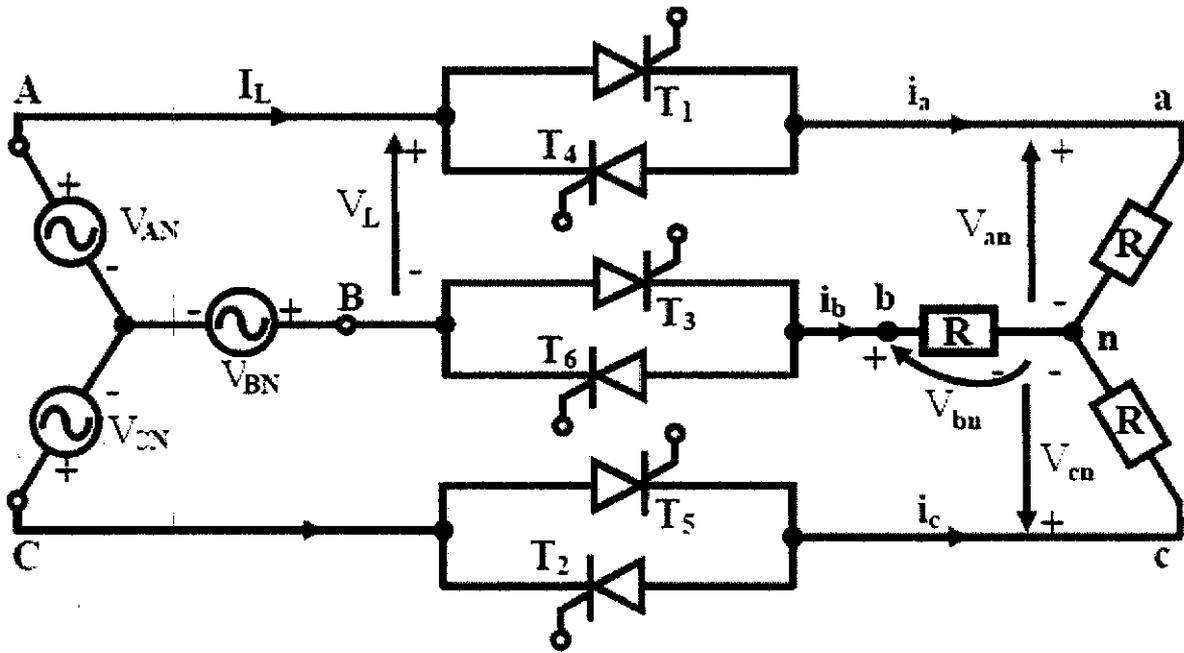


Fig. 2.4 Three-phase, three-wire ac regulator

The procedure for obtaining the expression of rms value of the output voltage per phase for balanced star-connected resistive load, which depends on range of firing angle. If the rms value of the input voltage per phase, and assuming the voltage, as the reference, the instantaneous input voltages per phase are,

At any time only two thyristors conduct for  $60^\circ < \alpha < 90^\circ$ . Although two thyristors conduct at any time for  $90^\circ < \alpha < 150^\circ$ , there are periods, when no thyristors are on. For  $\alpha > 150^\circ$ , there is no period for which two thyristors are on, and the output voltage becomes zero at  $\alpha = 150^\circ (5\pi/6)$ . The range of delay angle is  $0^\circ < \alpha < 150^\circ$ .

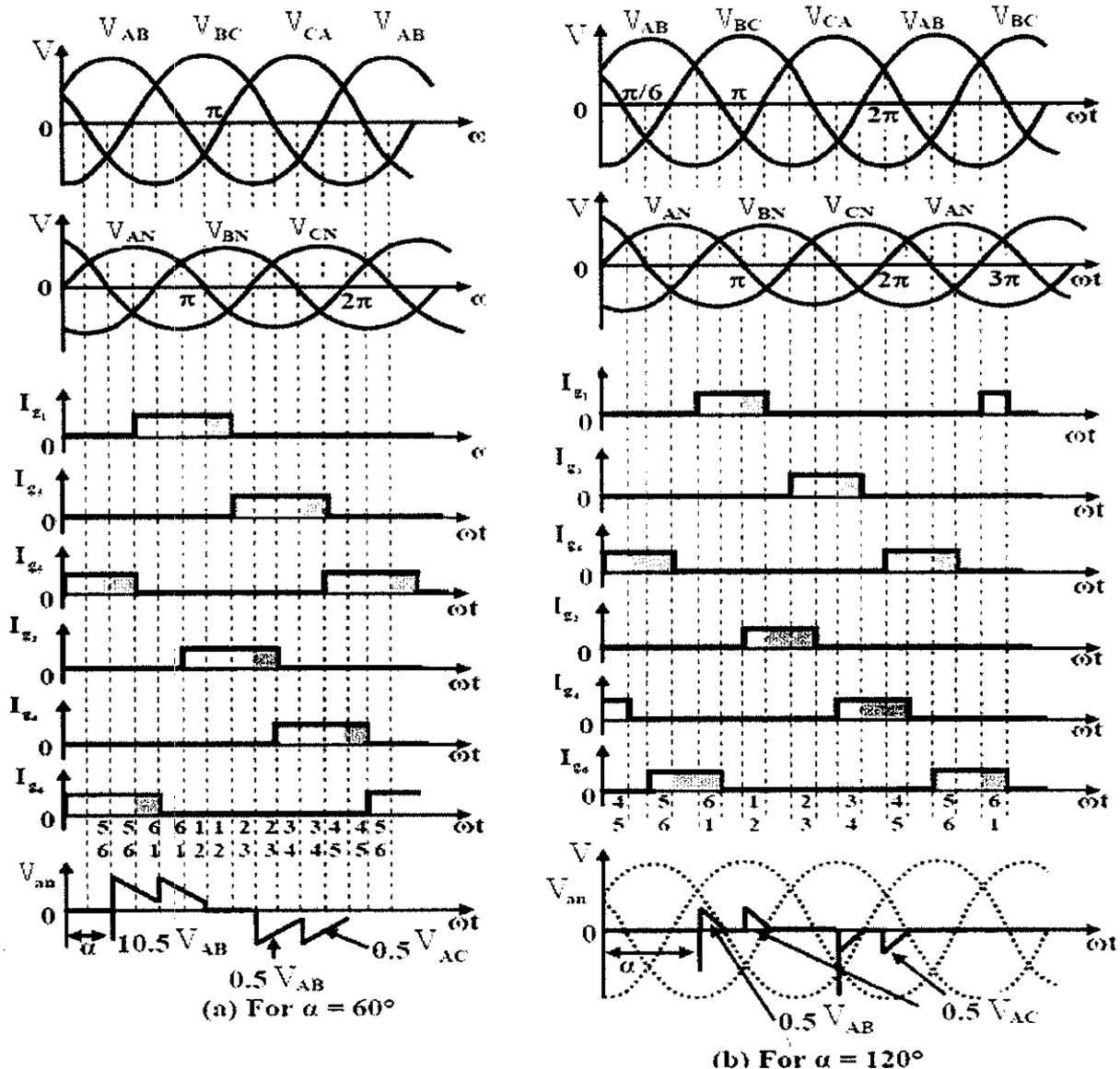


Fig. 2.5 Waveforms for three-phase three-wire ac regulator

(a) For  $\alpha = 60^\circ$

(b) For  $\alpha = 120^\circ$

**DISADVANTAGES OF PHASE ANGLE CONTROL**

- Retardation of firing angle, causes a lagging power factor at the input side even for a resistive load
- Plentiful lower order harmonics in both load and supply voltages/currents
- Discontinuity of power flow to the load appears

---

---

## CHAPTER 3

---

---

## CHAPTER 3

### SINGLE PHASE AC PWM CHOPPER

#### 3.1 INTRODUCTION

An AC-AC converter when operating with phase angle control it suffers with lot many drawbacks which can be overcome by controlling the switches using PWM technique. AC PWM chopper has many applications such as power regulators, induction motor drives and many others. They are devices, which use a semiconductor switches in a different configuration of connection. These converters are unidirectional or bi-directional power flow compatible in function used in electric configuration, elements and application. In today of power applications high-power MOSFET or IGBT-switches are used, driven by various commutation strategies and modulation techniques. The main aim is to obtain a high-quality power conversion, minimum losses, high efficiency and low cost.

The performance of the regulator can be improved if it is designed to operate as a chopper. In this case input supply voltage is chopped into segments and output voltage level is decided by the ratio between ON/OFF.

The operation of the ac voltage regulator gives the following advantages:

- Improved load power factor due to high frequency switching.
- Control range is wide in terms of firing angles regardless of load power factor.
- The low order harmonics are eliminated compared to the phase angle control.
- The order of the dominant load voltage harmonics can be controlled through changing chopper frequency.
- Linear control of the fundamental component of the output voltage.

#### 3.2 BLOCK DIAGRAM

The naturally commutated thyristor controllers introduce lower order harmonics in both the load and supply side and have low-input PF. Normally in ac choppers single pulse can be modulated to control the output or load voltage. However, the load voltage has almost square wave shapes, and therefore the load voltage and the line current has higher order harmonics. If

multiple output voltage pulses are used instead of single pulse, it significantly reduces the harmonics. So, the performance of ac voltage regulators can be improved by PWM control.

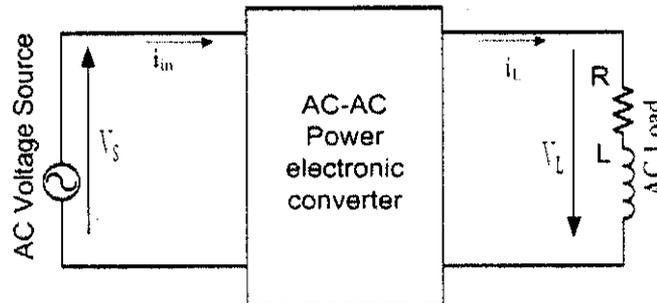


Fig. 3.1 Single Phase AC-AC Converter

The ac source supplying the RL load through power electronic converter is shown in Fig. 3.1. The switches employed are gate commutated switches, viz, MOSFET, IGBT etc. In this circuit IGBT are used. It has the highest power capabilities up to 1700kVA, 2000V, 800A. Because of the low resistance than the MOSFET the heating losses of the IGBT are lower too. Their voltage drop is 2-3 V, which is higher than that of a bipolar transistor but lower than the MOSFET has. Due to the negative temperature coefficient, when a temperature is raised, the power and heating decrease therefore the device withstands the overloading and operates in parallel well. The reliability of the IGBT is higher than that of the FET and secondary breakdown is absent. They have relatively simple voltage controlled gate driver and low gate current.

### 3.3 PWM CONTROL STRATEGIES

Pulse Width Modulation (PWM) is normally used as a controller in power conversion and motion control. There are various kinds of modulating modes available such as sinusoidal PWM, space vector PWM, current tracking PWM, harmonic elimination PWM and others. These techniques have merits and demerits but the most widely used in industrial applications are the sinusoidal PWM and space vector PWM. Digital Signal Processors (DSP) and/or Microcontrollers, where reprogramming of the carrier Frequencies are simple. The Sinusoidal Pulse Width Modulation (SPWM) is a well known wave shaping technique. For realization, a

high frequency triangle carrier signal,  $V_{tr}$ , is compared with a sinusoidal reference signal,  $V_c$ , as desired frequency. The crossover points are used to determine the switching instants.

The PWM control has the following advantages.

- The output voltage control can be obtained without any additional components.
- With this type of control, lower order harmonics can be eliminated and the filtering requirements are minimized as higher order harmonics can be filtered easily.

There are many PWM modulation techniques available of which SPWM and modified SPWM are discussed here.

### 3.3.1 SINUSOIDAL PULSE WIDTH MODULATION

Instead of maintaining the width of all pulses the same as in the case of multiple pulse width modulation, the width of each pulse is varied in proportion to the amplitude of the sine wave evaluated at the centre of the same pulse. The switching pulses for the operation of the SPWM converter are created by comparing a triangular carrier waveform ( $V_{tr}$ ) of frequency  $f_c$  with a sinusoidal waveform, according to Fig. 3.2, in which the sinusoidal waveform signal ( $V_c$ ) is absolutely similar and in phase with input voltage  $V_s$ .

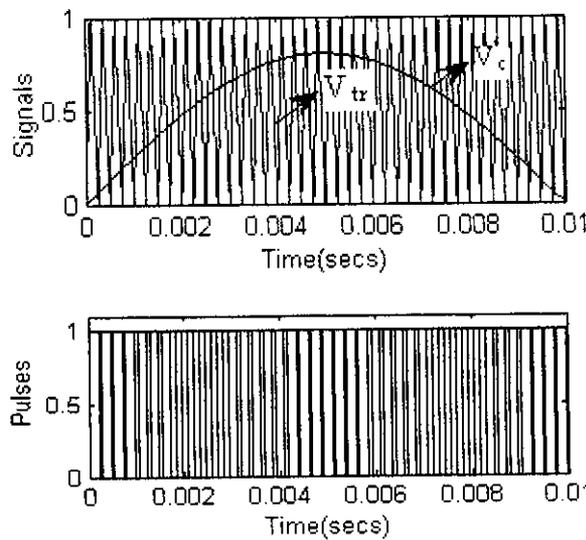


Fig. 3.2 Conventional SPWM pulses

This sinusoidal pulse width modulation is commonly used in industrial applications. The frequency of the reference signals determines the inverter output frequency and its peak

amplitude controls the modulation index  $M$ . The number of pulses per half cycle depends on the carrier frequency.

### ADVANTAGES

- Low harmonics can be eliminated or minimized.
- Higher order harmonics can be filtered. Easily the filtering requirements are minimized.
- The output voltage can be controlled internally without external components.
- Since IGBTs have low turn-off time losses are much reduced.

### DISADVANTAGES

- Power Factor is not unity

### 3.3.2 MODIFIED SINUSOIDAL PULSE WIDTH MODULATION ( $\alpha$ -SPWM)

The  $\alpha$ -SPWM is advanced form of SPWM which overcomes the drawbacks of SPWM. The gate pulses are generated by comparing a triangle waveform, i.e., triangular signal ( $V_{tr}$ ) with a sinusoidal waveform, which is similar to input voltage but not in phase with  $V_s$  ( $V_{ca}$ ) enables the generation of the switching pulses as shown in Fig. 3.3 The waveform  $V_{ca}$  is strongly similar to the sinusoidal waveform  $V_c$  but shifted to the left by an angle  $\alpha$ , so that this signal leads to the voltage  $V_c$  by an angle.

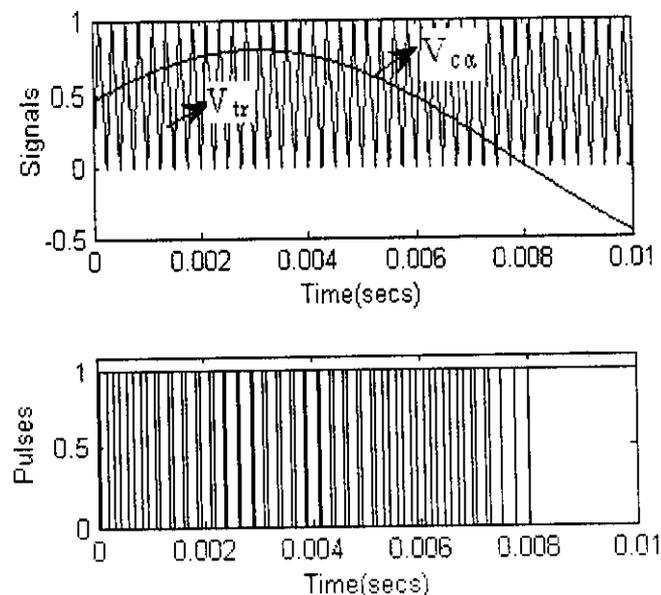


Fig. 3.3  $\alpha$ -SPWM Pulses For  $\alpha = 35^\circ$

In general, the application of such pulses (shifted to the left by an angle  $\alpha$ ) to a controlled converter consisting of metal oxide-semiconductor field-effect transistor (MOSFET) or IGBT has two advantages:

- Input current is shifted left to the input voltage, that is, the trade-off in this work
- The most high harmonics of the input current appear in the area of high order as by the conventional SPWM, which can be eliminated by the use of a small filter.

### 3.4 CIRCUIT DIAGRAM OF SINGLE PHASE AC PWM CHOPPER

The AC source offers a sinusoidal voltage  $V_s$  and has the internal impedance  $R_g-L_g$ . A small  $L_f-C_f$  input filter is used to absorb the high-order harmonics of the input current  $I_{in}$ . The switching power elements insulated gate bipolar transistor IGBT1 and IGBT2 with external antiparallel diodes control the load current  $I_L$ , which can flow bidirectionally. By using fast switching devices, PWM techniques can be applied to the ac voltage controllers for producing variable voltage with a better input PF. Single phase AC PWM chopper and its control circuit is shown in Fig. 3.4.

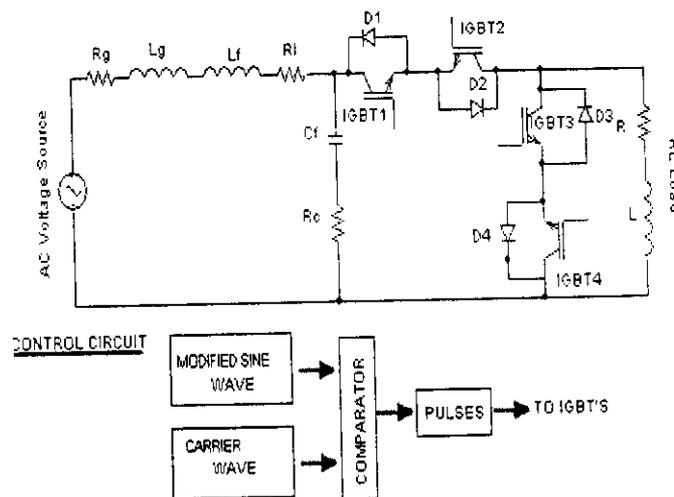


Fig. 3.4 Single Phase AC PWM chopper

When the gate pulse generated using SPWM technique is applied to the converter Fig.3.4, the lag of the current  $I_{in}$  behind the voltage  $V_s$  will decrease in comparison to those in case without converter which is verified using simulation. However, the lag of the current  $I_{in}$  to the voltage  $V_s$  cannot become zero.

## **3.5 SIMULATION DIAGRAM**

### **3.5.1 MATLAB**

The name MATLAB stands for matrix laboratory. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. In this project the modeling and simulation of the proposed system is done using MATLAB (using simulink and power system block set tool boxes).

### **3.5.2 SIMULINK**

Simulink is a software package for modeling, simulating, and analyzing non linear dynamical systems. It is a graphical mouse-driven program that allows somebody to model a system by drawing a block diagram on the screen and manipulating it dynamically. Simulink is a platform for multi domain simulation and Model-Based Design for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications.

### **3.5.3 POWER SYSTEM BLOCK SET**

The Power System Block set allows scientists and engineers to build models that simulate power systems. The block set uses the Simulink environment, allowing a model to be built using click and drag procedures. Not only can the circuit topology be drawn rapidly, but also the analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. SimPowerSystems extends Simulink with tools for modeling and simulating basic electrical circuits and detailed electrical power systems. These tools let you model the generation, transmission, distribution, and consumption of electrical power, as well as its conversion into mechanical power. SimPowerSystems is well suited to the development of complex, self-contained power systems, such as those in automobiles, aircraft, manufacturing plants, and power utility applications

### 3.5.4 OVERALL SYSTEM STRUCTURE

The power factor investigation is carried out through MATLAB/SIMULINK using a characteristic example of converter topology shown in Fig. 3.4. Simulation parameters are  $R_g = 0.0262 \Omega$  and inductance  $L_g = 30 \mu\text{H}$ , filter inductance  $L_f = 3.5 \text{ mH}$ , capacitor  $C_f = 4 \mu\text{F}$  and resistances  $R_L = R_C = 0.05 \text{ V}$  and the load values are  $R = 40 \Omega$  and  $L = 90 \text{ mH}$  ( $\phi_L \approx 35^\circ$ ). The angle by which the sine wave is shifted by  $\alpha$  is equal to  $\phi_L$ .

$$\phi_L = \arctan\left(\frac{\omega L}{R}\right) \quad (3.1)$$

Fig. 3.5 shows the overall simulation circuit. Both the conventional SPWM and Modified SPWM control technique is implemented. The input voltage, input current, output voltage, PF results are analysed using MATLAB/SIMULINK 7.8.0 ( R2009a)

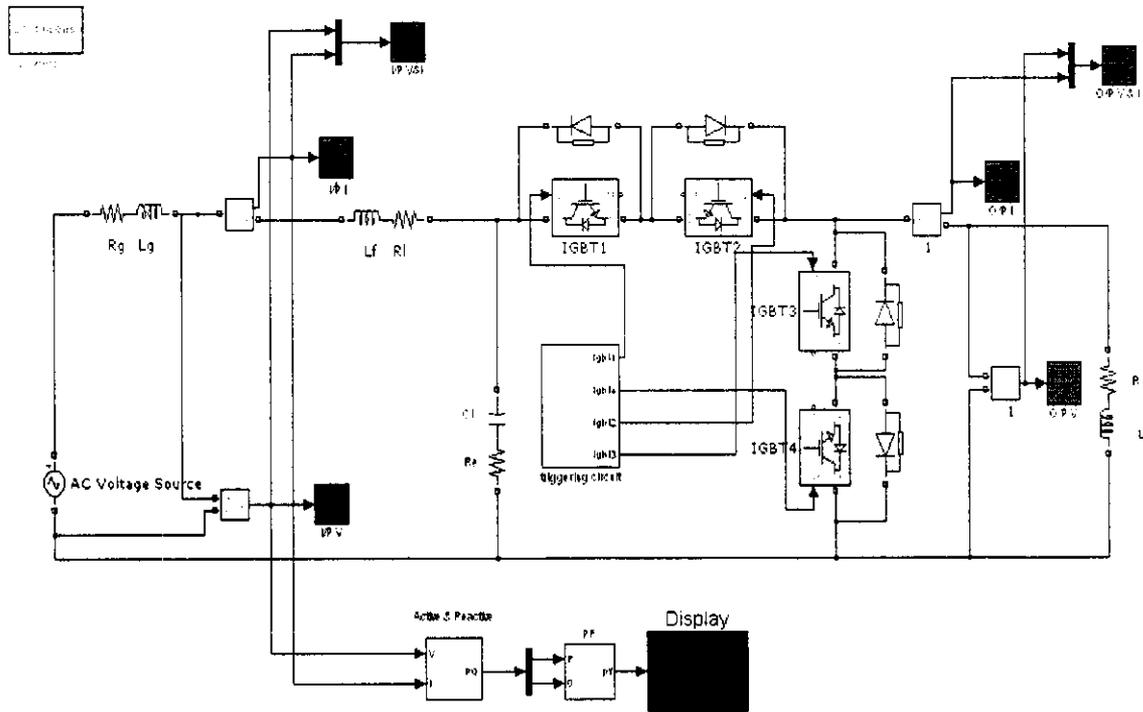


Fig. 3.5 SIMULINK model of single phase PWM ac chopper

### 3.5.6 CONTROL CIRCUIT

The sinusoidal wave shifted by angle is compared with the triangular wave and the pulses are generated. During the positive half cycle the pulses of IGBT 1 and IGBT 2 are generated and for IGBT 3 and IGBT 4 pulses are generated using negative half cycle as shown in fig.3.6

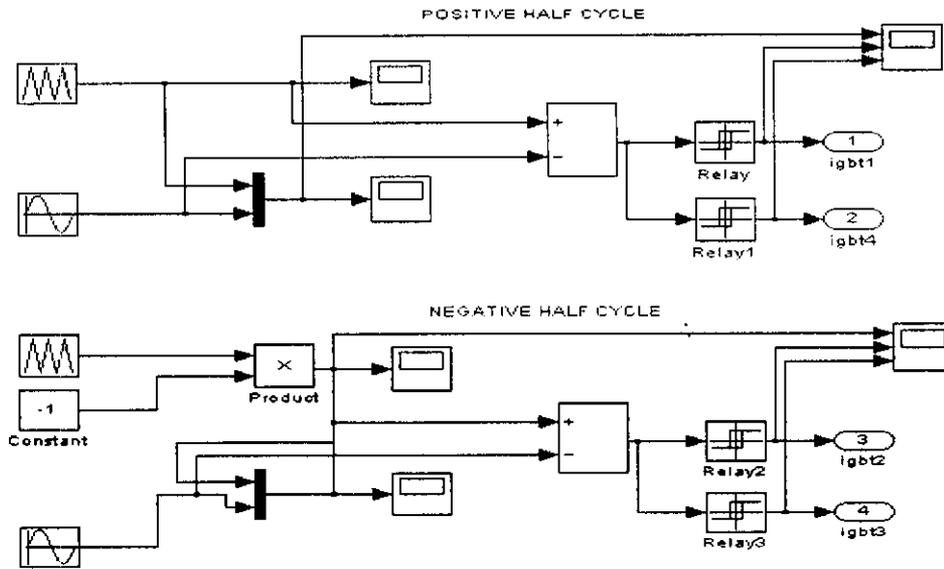


Fig. 3.6 Control Circuit of  $\alpha$ -SPWM

### 3.5.7 SIMULATION RESULTS AND DISCUSSIONS

#### INPUT VOLTAGE AND INPUT CURRENT

When the pulses from the conventional SPWM technique is applied to the IGBT switches the lag behind input voltage and current as shown in Fig. 3.7 decreases in comparison to those in case without converter as shown in Fig. 3.8. On implementing the modified SPWM technique the input voltage and current obtained is almost in phase which is inferred from Fig. 3.9

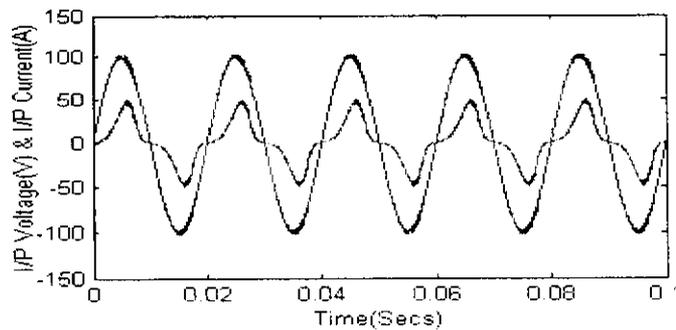


Fig. 3.7 Input Voltage and Current for Conventional SPWM

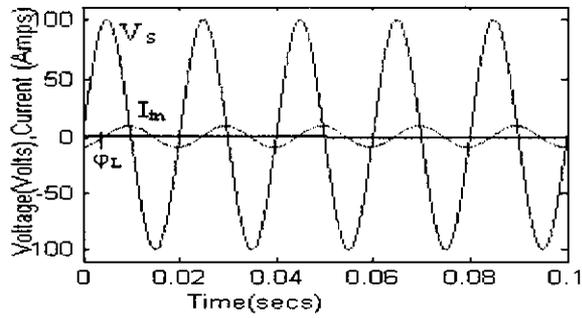


Fig. 3.8 Input Voltage and Current Without a converter

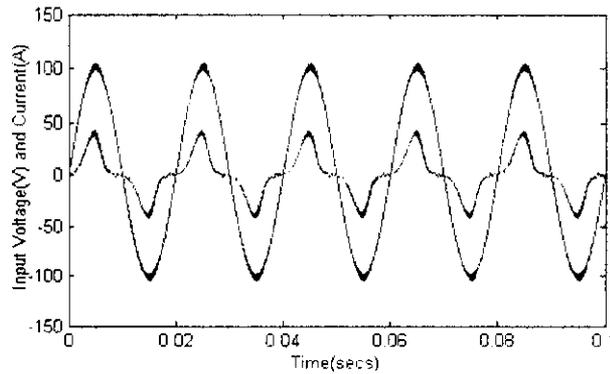


Fig. 3.9 Input Voltage and current for Modified SPWM

**POWER FACTOR**

Because of the  $\alpha$ -SPWM technique applied to the single phase ac PWM chopper the PF is maintained almost unity as inferred from Fig. 3.10

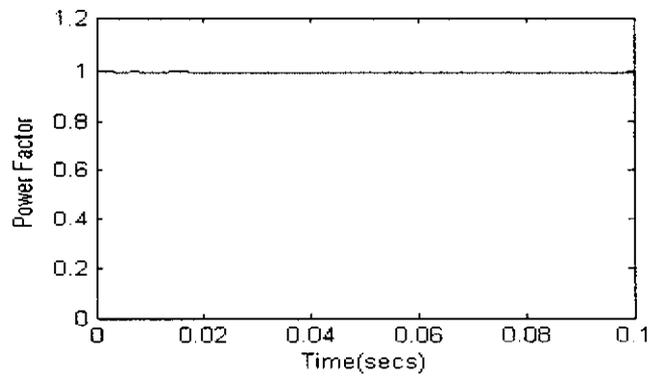


Fig. 3.10 Input Power Factor

## OUTPUT VOLTAGE

Input supply voltage is chopped into segments and output voltage level is decided by the ratio between ON/OFF. The chopped output voltage is shown in Fig. 3.11

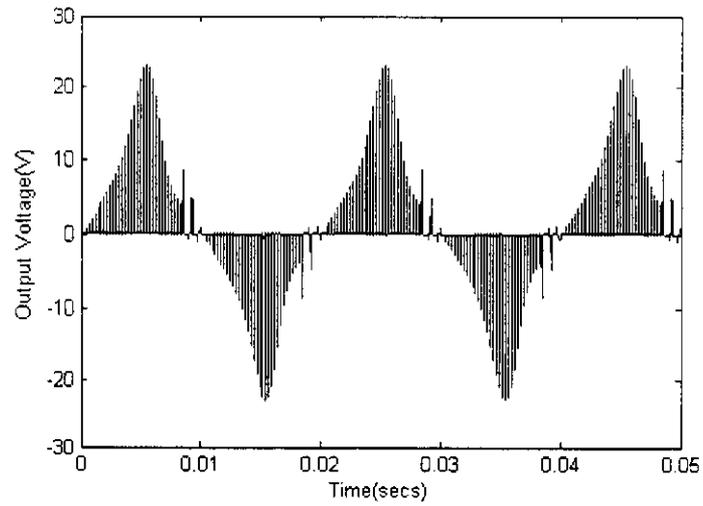


Fig. 3.11 Output Voltage

---

---

## CHAPTER 4

---

---

## CHAPTER 4

### THREE PHASE AC-AC CONVERTER USING MODIFIED SPWM

#### 4.1 INTRODUCTION

Significant advances in modern ac/ac power converter technologies and demands of industries have reached beyond standard ac/ac power converters with voltage-source inverters fed from diode rectifiers. Power electronics converters have been matured to stages toward compact realization, increased high-power handling capability, and improving utility interface. In this dissertation, several new converter topologies are proposed in conjunction with developed control schemes based on the modern ac/ac converters which enhance performance and solve the drawbacks of conventional converters. Three phase AC –AC converter using modified SPWM is proposed to improve the PF. This scheme has some advantages like including low cost in installation, ease to maintain and reliable which make this scheme popular option in industry as many of the industrial loads are inductive. It has a wide range of applications like induction heating, light control, reactive power control and starting as well as speed control of AC motors.

#### 4.2 BLOCK DIAGRAM

For high power loads, three phase regulators are used. Fig. 4.1 shows the block diagram of three phase PWM chopper in which RL load is star connected. The switches can be used are gate commutated switches like MOSFET, IGBT etc. In case of ac choppers that a single pulse can be modulated to control the output or the load voltage. If  $V_s$  the rms value of the input voltage per phase, and assuming the voltage,  $V_{an}$  the reference, the instantaneous input voltages per phase are.

The instantaneous input phase voltages are

$$v_{AN} = \sqrt{2} v_s \sin \omega t \quad (4.1)$$

$$v_{BN} = \sqrt{2} v_s \sin (\omega t - 2\pi/3) \quad (4.2)$$

$$v_{CN} = \sqrt{2} v_s \sin (\omega t - 4\pi/3) \quad (4.3)$$

The instantaneous input line voltages are

$$v_{AB} = \sqrt{6} v_s \sin (\omega t + \pi/6) \quad (4.4)$$

$$v_{BC} = \sqrt{6} v_s \sin (\omega t - \pi/2) \quad (4.5)$$

$$v_{CA} = \sqrt{6} v_s \sin (\omega t - 7\pi/6) \quad (4.6)$$

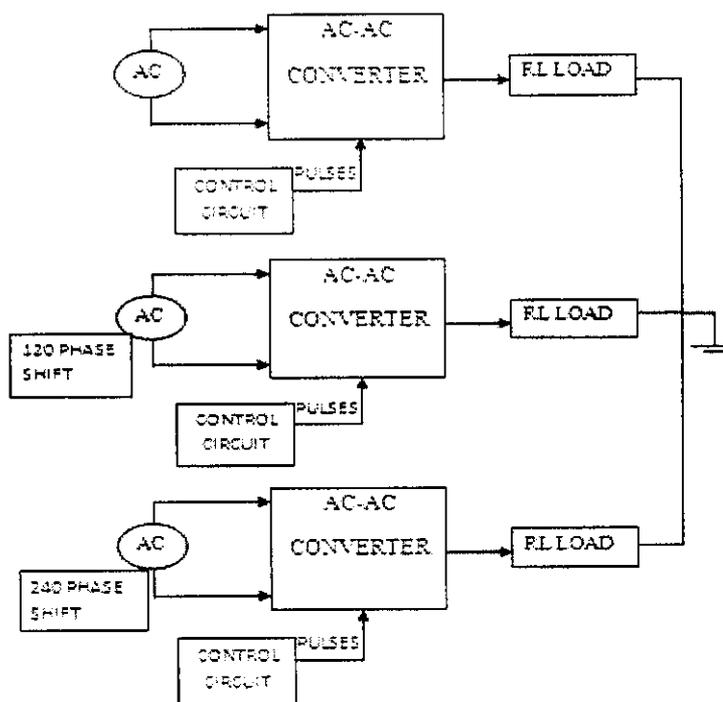


Fig. 4.1 Block Diagram of Three Phase AC-AC Converter

### 4.3 CIRCUIT DIAGRAM OF THE PROPOSED CONVERTER

The proposed converter is shown in Fig. 4.2. It has three single phase converters of which second and the third phases are shifted by  $120^\circ$  and  $240^\circ$  respectively. The RL load is star connected with neutral point grounded. It employs the IGBT switches and the gate pulses to it are generated by modified SPWM technique ( $\alpha$ - SPWM).

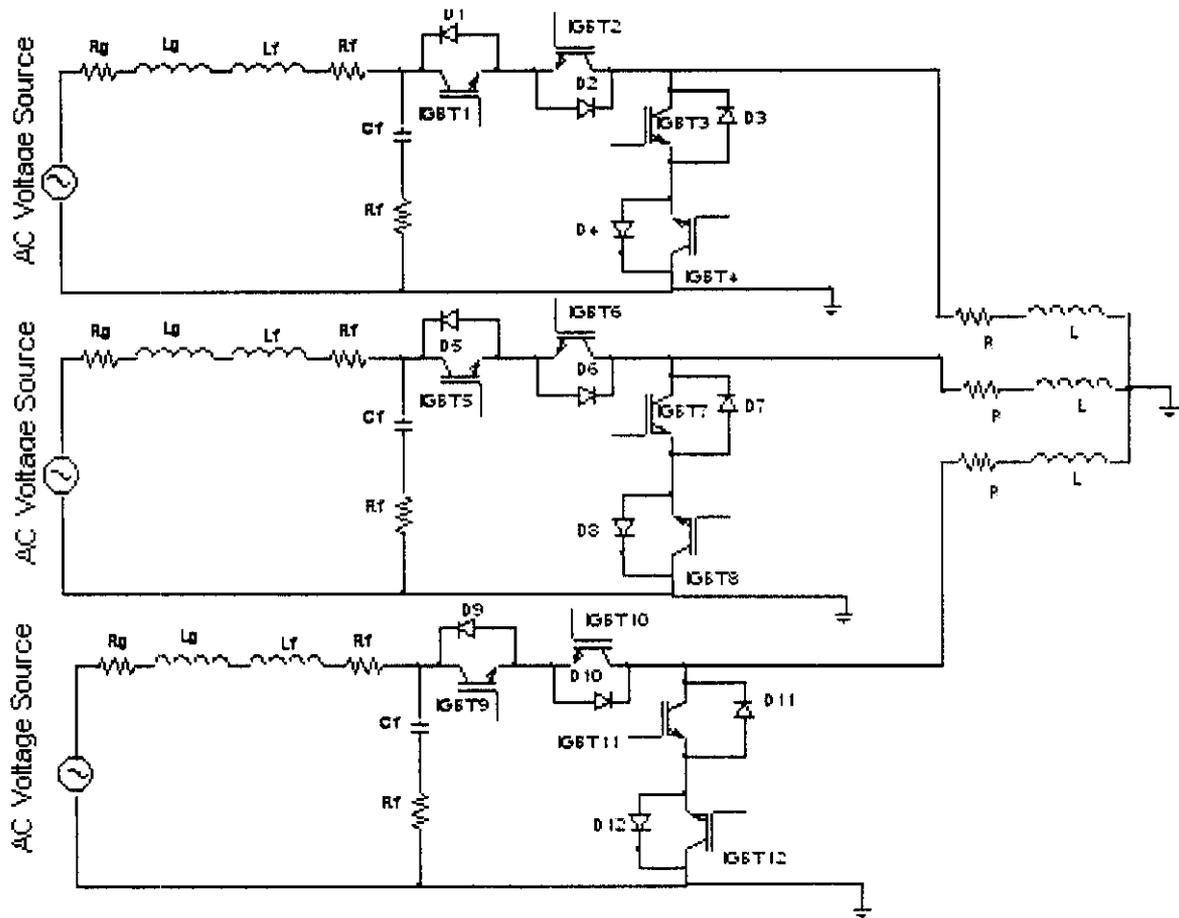


Fig. 4.2 Circuit Diagram of Three Phase AC voltage regulator

#### 4.4 PRINCIPLE OF OPERATION

In the three phase ac PWM chopper only one phase is considered and its operation is explained in this section. The two main modes of operation are active and freewheeling modes. A diode connected in anti-parallel with each parallel switch is used to complete the freewheeling current path. It also prevents reverse voltages from appearing across the switches. The switching sequences of the devices are given below in Table 4.1.

Table 4.1 Switching Sequence

	IGBT 1	IGBT2	IGBT3	IGBT4
$V_s > 0$	PWM	OFF	OFF	PWM
$V_s < 0$	OFF	PWM	PWM	OFF

#### 4.4.1 ACTIVE MODES

This mode of operation occurs during both the positive and negative half cycle of the ac supply. During the active mode of the positive half cycle, the switching power electronic element IGBT1 operates with high switching frequency. The current flows from source to load through IGBT 1, diode D2 and the inductor get charged as shown in Fig. 4.3

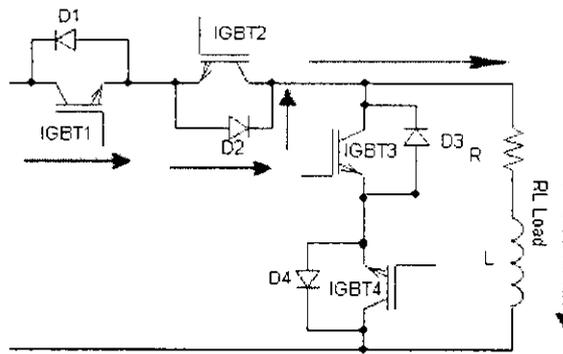


Fig. 4.3 Active mode of Positive Half cycle

In the negative half cycle active mode occurs when switching element IGBT2 is turned ON. The current flows via the load, IGBT 2, D1 as shown in Fig. 4.4

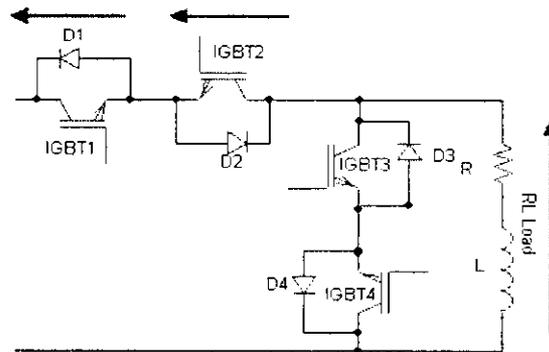


Fig. 4.4 Active mode of Negative Half cycle

#### 4.4.2 FREEWHEELING MODES

Both during the positive and negative half cycle of the ac supply, freewheeling mode occurs. In the positive half cycle freewheeling occurs, when IGBT1 is off, the stored energy in the inductor freewheels from load to source through IGBT4 and the diode D3 as shown in Fig. 4.5

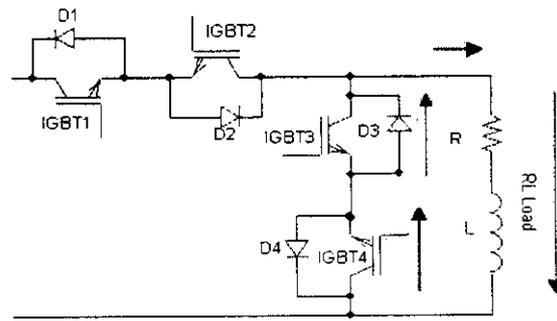


Fig. 4.5 Freewheeling mode of Positive Half cycle

Similarly during the negative half cycle, when IGBT2 is off, a free-wheeling path occurs through IGBT3, the diode D4 and the load is created as shown in Fig. 4.6. By controlling the duration of the conduction time (duty cycle) of IGBT1 and IGBT2, the load voltage  $V_L$  and load power can be controlled.

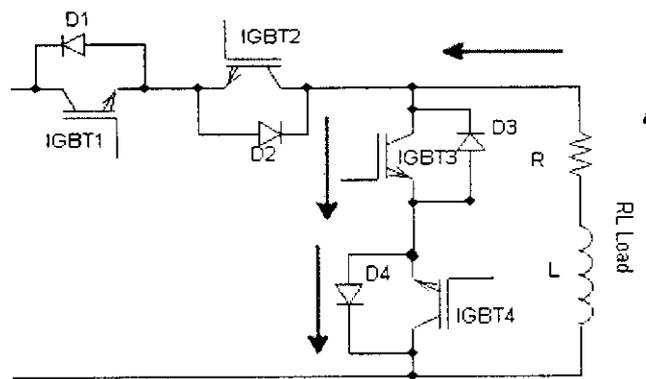


Fig. 4.6 Freewheeling mode of Negative Half cycle

The other two phases are displaced by  $120^\circ$  and  $240^\circ$  respectively. These two phases also conduct similarly to the single phase described above in a three phase ac-ac converter circuit. The gate pulses are generated through the  $\alpha$ -SPWM switching technique. Using that technique the lag of the current to the voltage caused by the resistive-inductive load can be eliminated in order to improve the PF which is verified by simulation results.

## 4.5 SIMULATION RESULTS AND DISCUSSIONS

To investigate the validity of the proposed system, the proposed converter is simulated using MATLAB/SIMULINK. The three phase ac-ac converter is simulated with the three single phase's converter in which the input voltages of the second and third phases are displaced by  $120^\circ$  and  $240^\circ$  respectively. Each single phase has the following simulation parameters  $R_g = 0.0262 \Omega$  and inductance  $L_g = 30 \mu\text{H}$ , filter inductance  $L_f = 3.5 \text{ mH}$ , capacitor  $C_f = 4 \mu\text{F}$  and resistances  $R_L = R_C = 0.05 \text{ V}$  and the load values are  $R = 40 \Omega$  and  $L = 90 \text{ mH}$  ( $\phi_l \approx 35$ ).

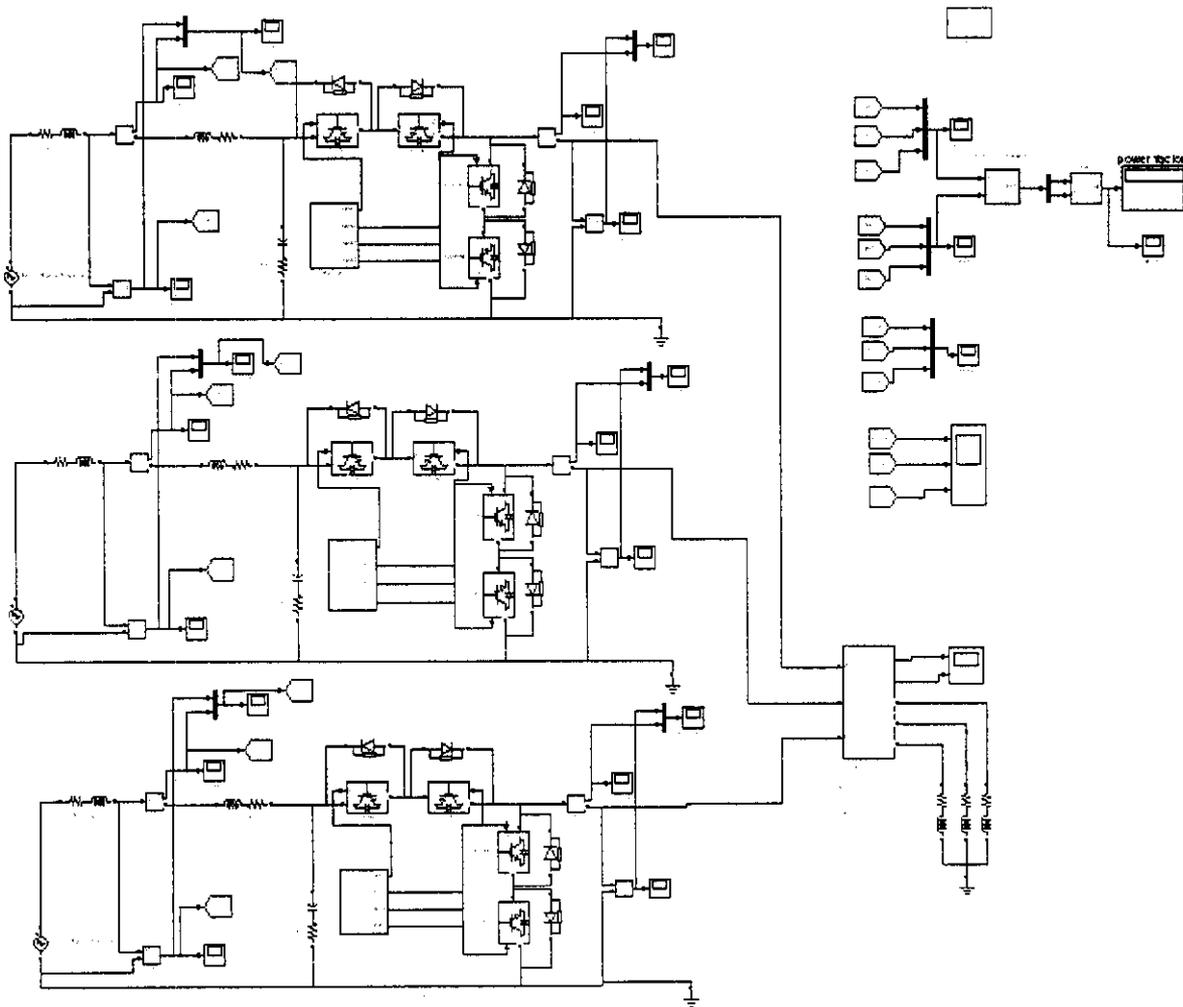


Fig. 4.7 Simulation Circuit of Three Phase ac-ac converter

The switching frequency is chosen as a parameter in the characteristic range  $4 \text{ kHz} < f_{sw} < 13 \text{ kHz}$  taking into account the chosen  $L_f - C_f$  values. The  $L_f - C_f$  filter plays a significant role

for the reactive power reduction caused by the high harmonics. The overall simulation circuit is shown in Fig. 4.7. The simulations presented in this paper study the comparison between the Input voltage & Input current characteristics, Output Voltage, Power factor.

#### 4.5.1 INPUT VOLTAGE AND INPUT CURRENT CHARACTERISTICS

By the application of the SPWM pulses to the three phase ac voltage regulator, from Fig. 4.8. It is inferred that there is a lag between the input voltage and current. Furthermore by using  $\alpha$ -SPWM technique a shifting of the fundamental current harmonic takes place in order to decrease the phase angle between this harmonic and the input voltage. It is obvious in this way that the reactive power of the fundamental harmonic is reduced and hence the lag between the input voltage and current is almost zero as in Fig. 4.9

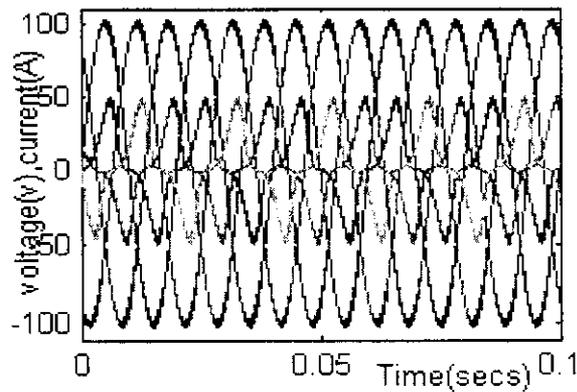


Fig. 4.8 Input Voltage and Current for conventional SPWM

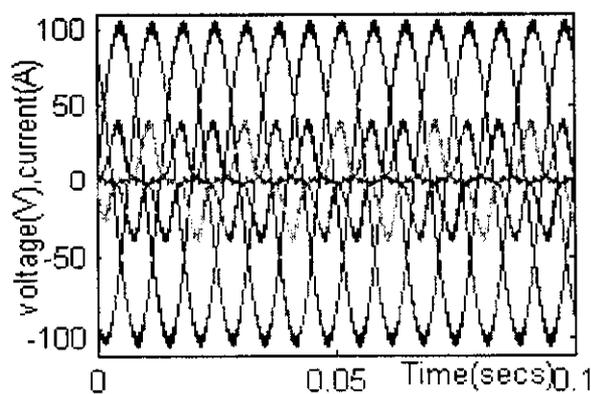


Fig. 4.9 Input Voltage and Current for  $\alpha$ -SPWM

### 4.5.2 OUTPUT VOLTAGE

In this case input supply voltage is chopped into segments and output voltage level is decided by the ratio between ON/OFF. The converter output voltage for the three phases are shown in Fig. 4.10

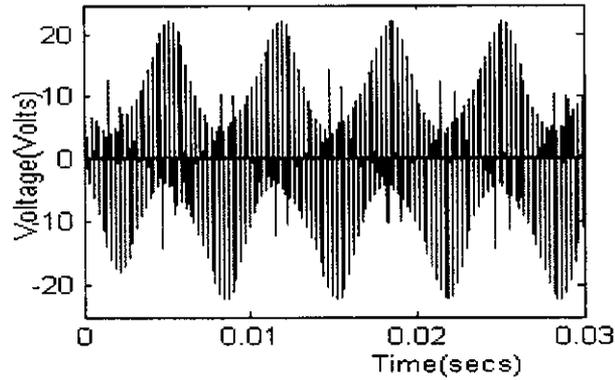


Fig. 4.10 Output voltage

### 4.5.3 POWER FACTOR

The power factor can be calculated by the formula

$$P.F = \frac{P}{\sqrt{P^2+Q^2}} \quad (4.7)$$

Where P is active power and Q is the apparent power

$$P = \sqrt{3}VI \cos\phi \quad (4.8)$$

$$Q = \sqrt{3}VI \sin\phi \quad (4.9)$$

The  $\alpha$ -SPWM technique in a three phase ac voltage regulators has a power factor of almost 0.99 as inferred from Fig. 4.11.

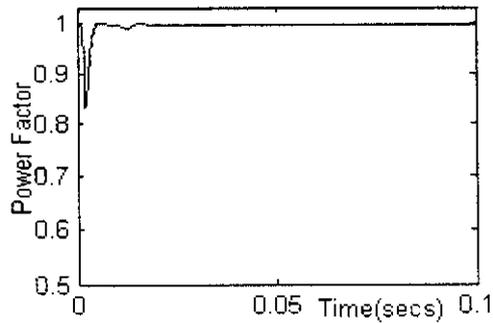


Fig. 4.11 Power Factor

---

---

## CHAPTER 5

---

---

## CHAPTER 5

### HARDWARE IMPLEMENTATION OF SINGLE PHASE AC CHOPPER IMPLEMENTING $\alpha$ -SPWM

#### 5.1 BLOCK DIAGRAM OF SINGLE PHASE AC PWM CHOPPER

This chapter explains the block diagram and components used for the hardware prototype of the proposed system. It includes the photographs of the fabricated model and output waveforms. The prototype is done only for single phase AC PWM choppers. The voltage of the system is reduced to 12V. The schematic is done in AutoCAD.

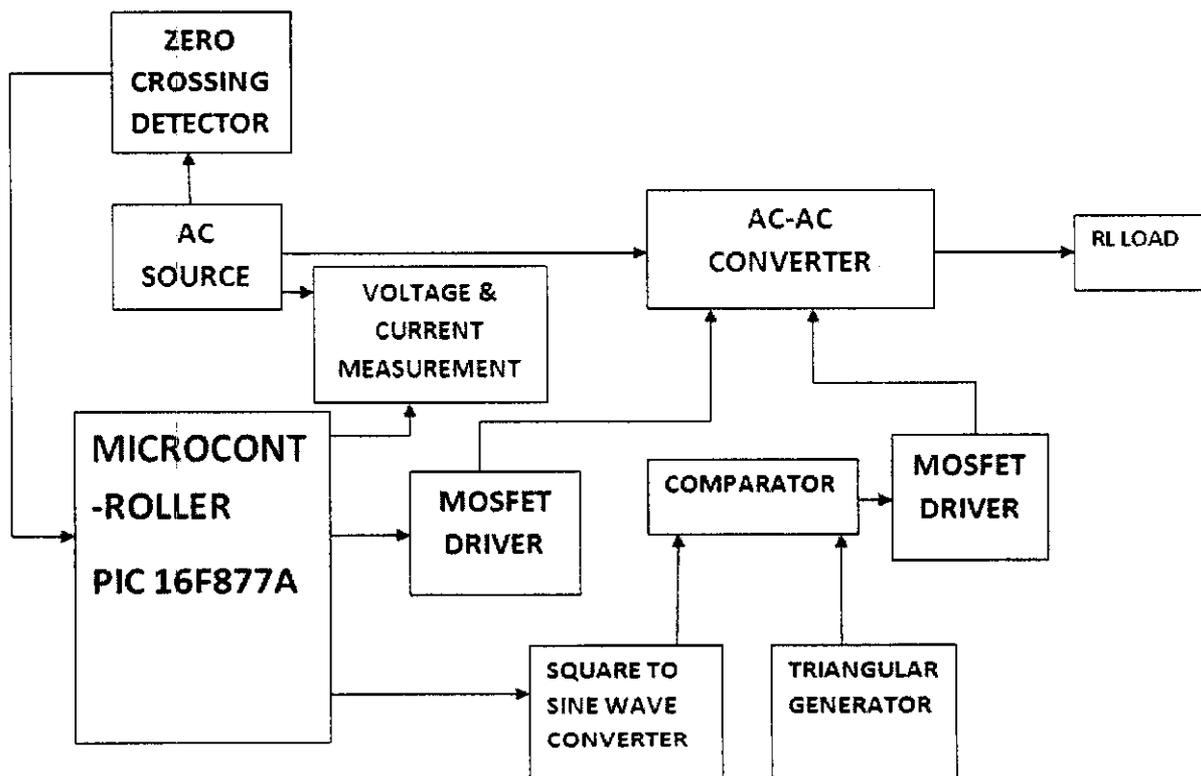


Fig 5.1 Hardware Block diagram

The prototype of the proposed system has single phase step down diode rectifier, single phase PWM ac chopperr, pulse generation module and micro controller (PIC16F877A) with 5V power supply. These parts are explained with schematic diagram in following sections.

### 5.1.1 POWER SUPPLY

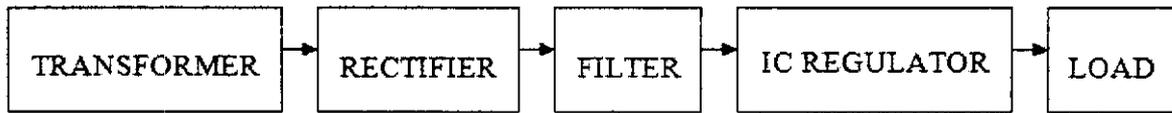


Fig. 5.2 Block diagram of power supply

The block diagram of power supply is shown in Fig.5.2. The AC voltage, typically 220V rms, is connected to a transformer, which steps that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation.

A regulator circuit removes the ripples and also remains the same dc value even if the input dc voltage varies, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of the popular voltage regulator IC units. The power circuit diagram is shown in Fig.5.3

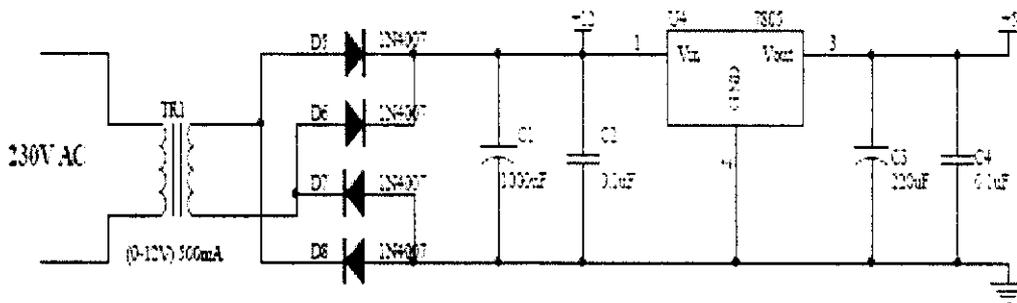


Fig 5.3 Schematic of rectifier

### 5.1.2 MODIFIED SPWM PULSE GENERATION

The triangular generator is used to generate triangular wave of certain carrier frequency is then compared with shifted sine wave using OP-AMP LM358. The details of the LM358 is given in APPENDIX I

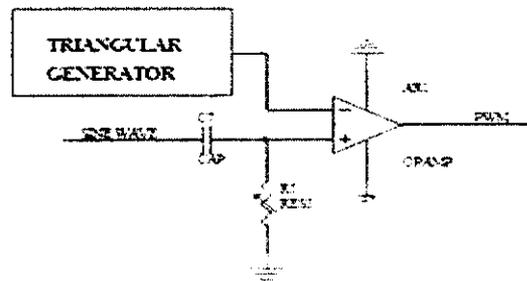


Fig 5.4 Schematic of PWM Generation

### 5.1.3 MOSFET IRFZ44

#### CHARACTERISTICS OF MOSFET

The practical MOSFET has the following switching and conduction Characteristics:

- Limited power handling capabilities, that is, limited conduction current when the switch is in the on-state and limited blocking voltage when the switch is in the Off-state.
- Limited switching speed caused by the finite turn-on and turn-off times. This limits the maximum operating frequency of the device.
- Finite on-state and off-state resistances, that is, forward voltage drop exists when in the on-state, and reverse current flow (leakage) exists when in the off state.
- Because of characteristics 2 and 3, the practical switch experiences power losses in the on- and off-states (known as conduction loss), and during switching transitions (known as switching loss).

### 5.1.4 MOSFET DRIVER IR2110

The IR2110/IR2113 are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500

or 600 volts. It can be used for voltage protection, shut down protection and stable operation. the pin diagram is shown in fig. 5.5 and the driver circuit is shown in Fig.5.6

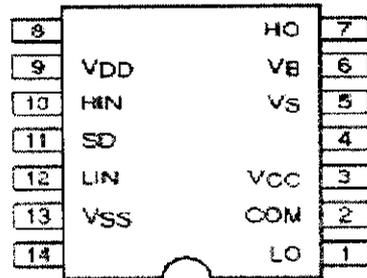


Fig.5.5 Pin diagram of IR2110

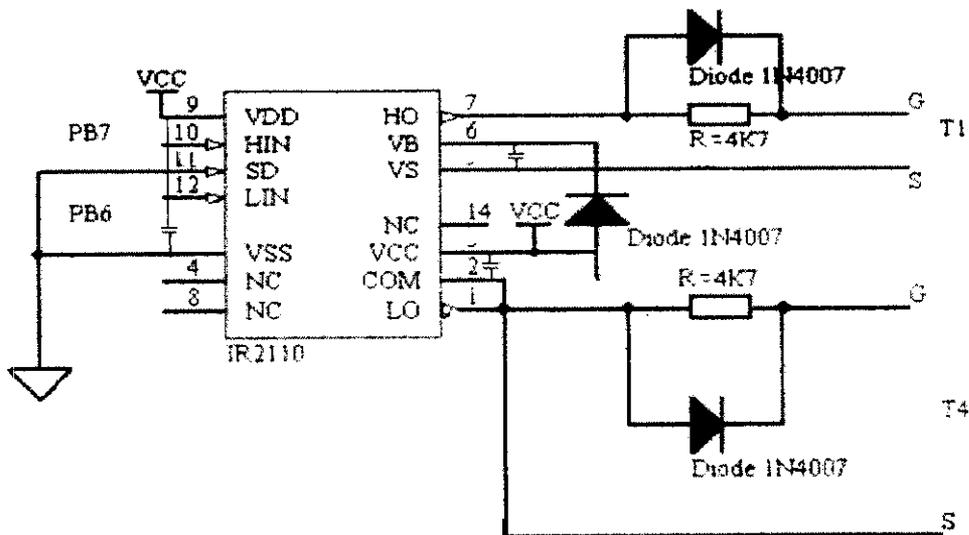


Fig. 5.6 Driver circuit of IR2110

### 5.1.5 SINGLE PHASE AC PWM CHOPPER

The single phase ac PWM chopper is used in this part. Here four MOSFETs are used in the bridge. These power switches are driven by the gate pulse generated by micro controller (PIC16F877A). This circuit bridge is isolated from the gating circuit by the opto-coupler. The resistive inductive load is connected across the load side of the inverter. The schematic of single phase PWM ac chopper is shown in the fig.5.7.

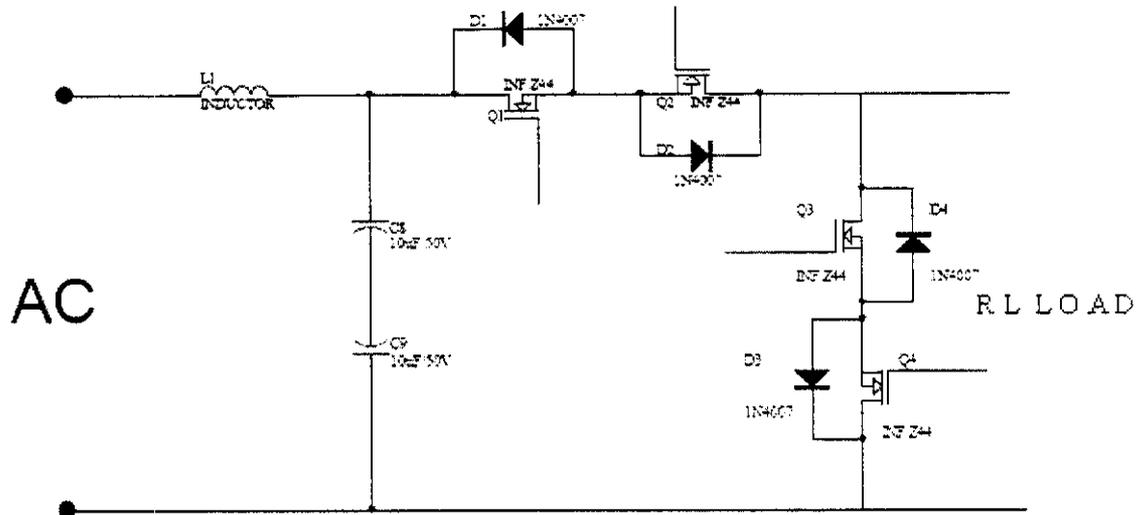


Fig 5.7 Schematic of Single phase PWM ac chopper

#### ADVANTAGES OF MOSFET

- MOSFETs provide much better system reliability.
- MOSFET are fast switching devices permit much higher switching frequencies and there by the efficiency is increased.
- MOSFETs have better temperature stability.
- Overload and peak current handling capacity is high.
- MOSFETS have low leakage current.
- MOSFETs are able to operate in hazardous radiation environments.

Here 8A, 500V, 0.850 Ohm, N-Channel Power MOSFETs are used with the common emitter configuration.

#### 5.1.6 MICROCONTROLLER FOR SINGLE PHASE AC PWM CHOPPER

The gate pulse for the inverter switches and the switches in soft-switching module is generated by PIC16F877A controller. This micro controller circuit works in 5V power supply. So separate step down rectifier unit is made for the controller. The detail about PIC16F877A is given in APPENDIX II. This controller is isolated from the main circuits by means of opto-coupler. The schematic of micro controller circuit is shown in Fig.5.8.



- Base Lead Provided for Conventional Transistor Biasing
- High-Voltage Electrical Isolation
- 1.5-kV, or 3.55-kV Rating
- Plastic Dual-In-Line Package
- High-Speed Switching

## 5.2 HARDWARE PROTOTYPE AND RESULTS

The fabricated hardware model is as shown in fig.5.10. The output waveforms of the input voltage, input current and the output voltages are shown in the fig. 5.11, 5.12 and 5.13 respectively

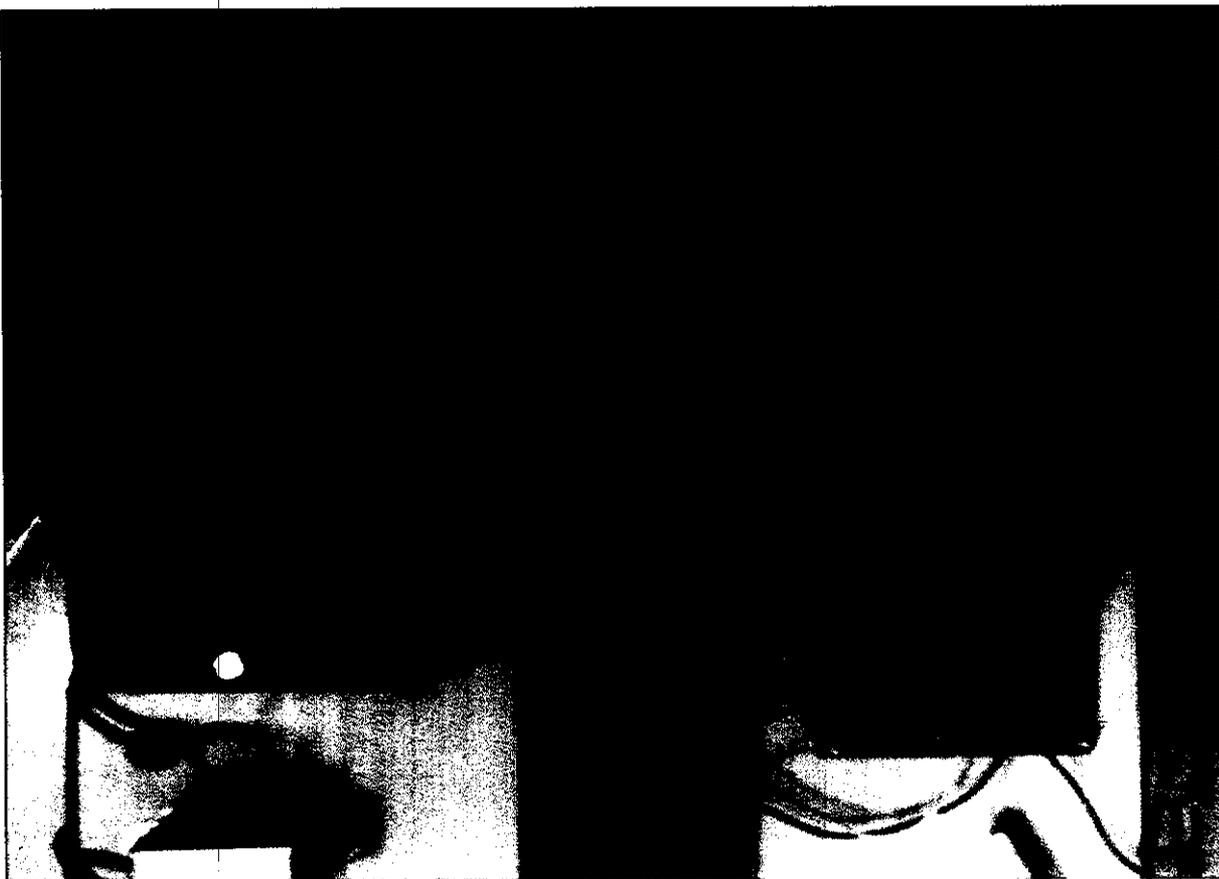


Fig 5.10 Prototype Photo

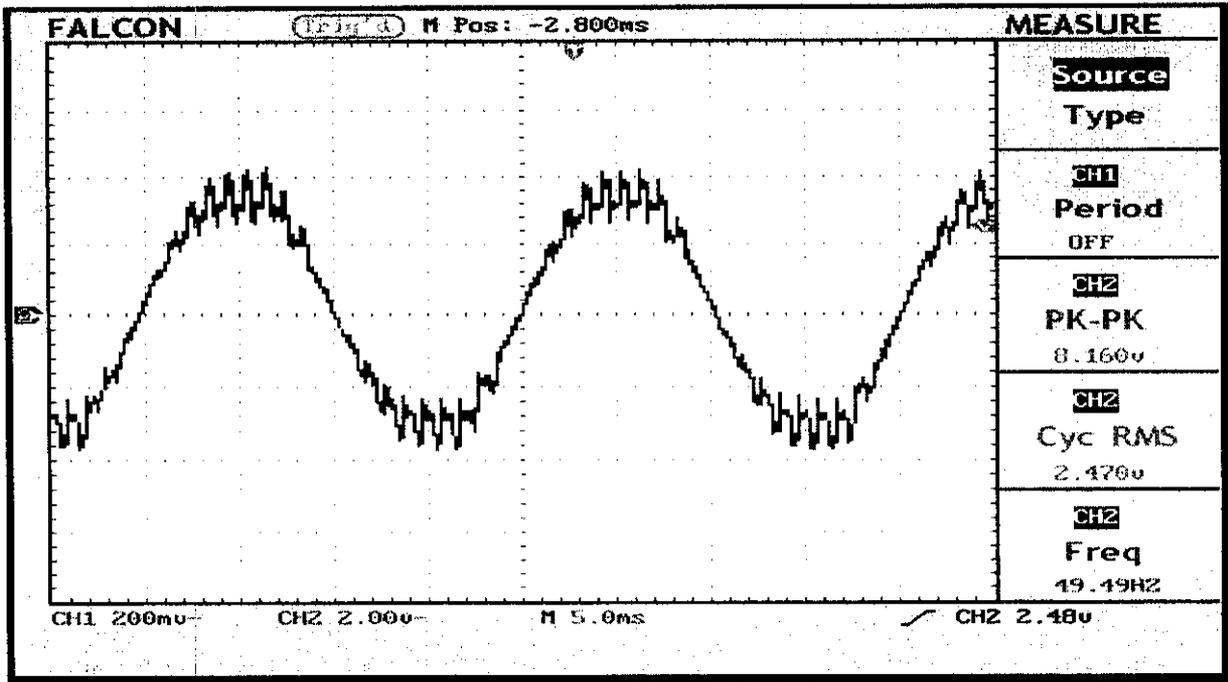


Fig. 5.11 Input Voltage

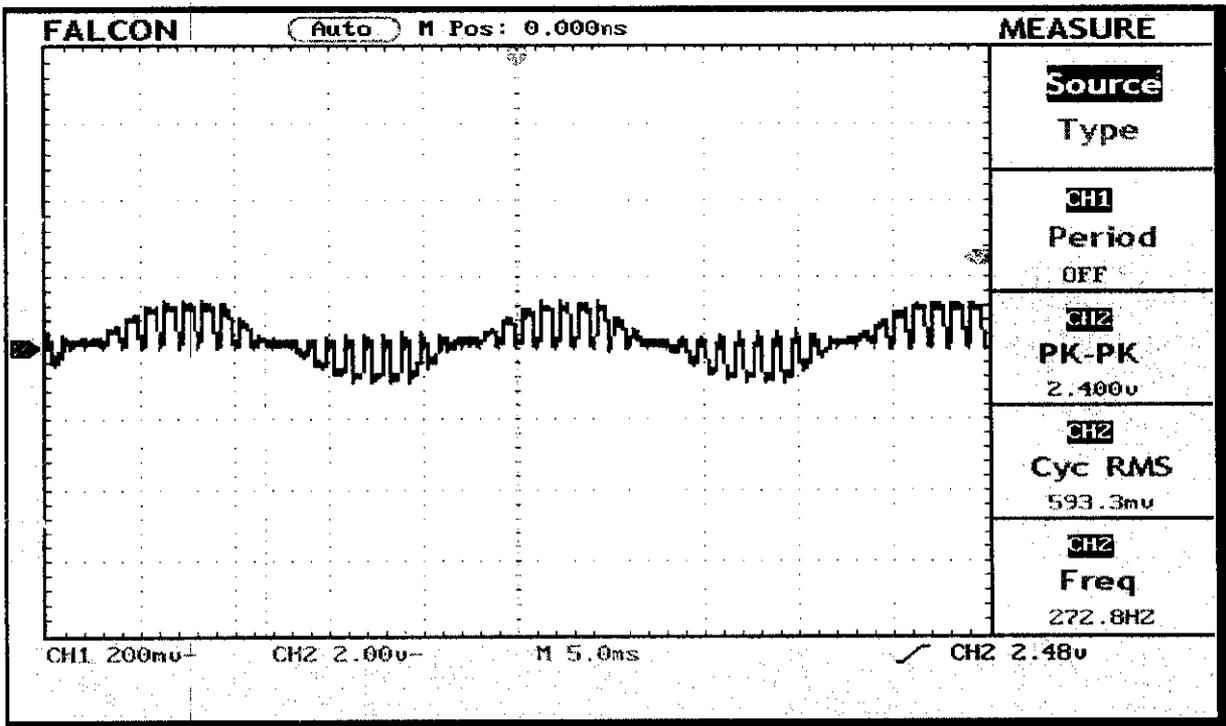


Fig. 5.12 Input Current

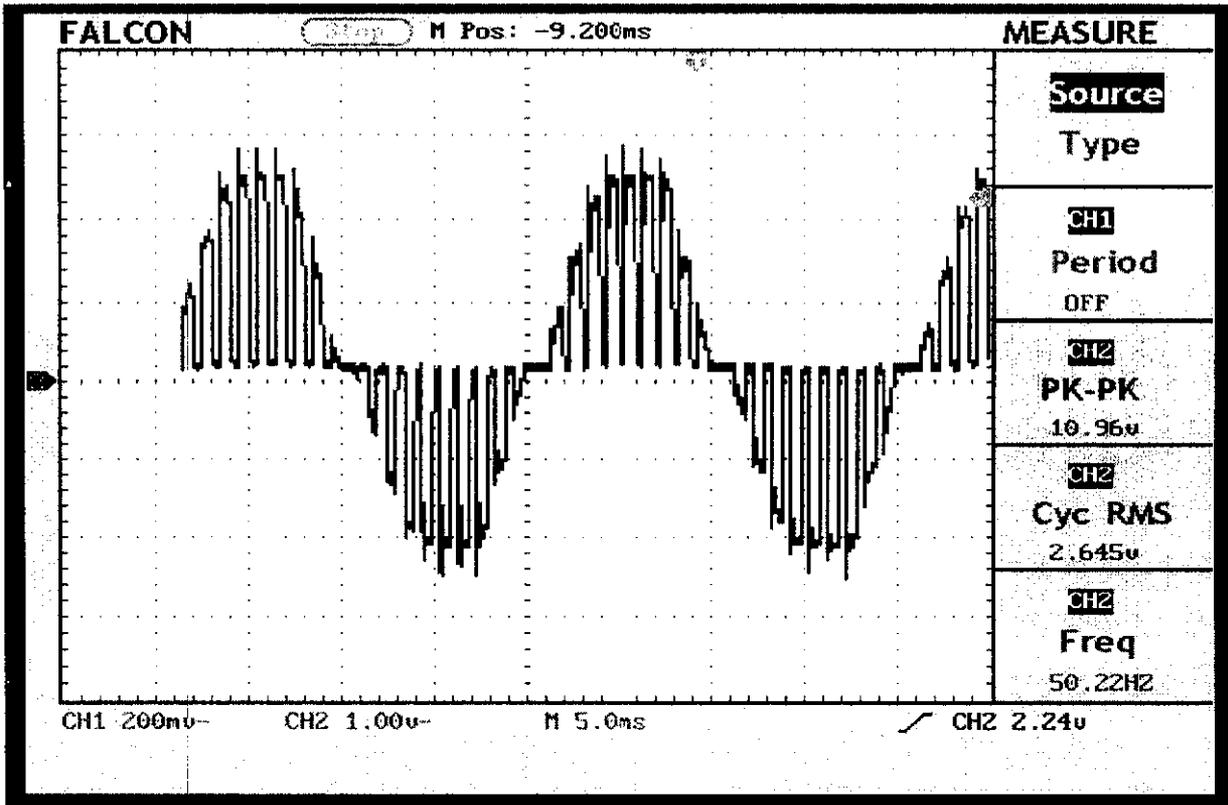


Fig. 5.13 Output Voltage

---

---

## CHAPTER 6

---

---

## **CHAPTER 6**

### **CONCLUSION AND FUTURE SCOPE**

#### **6.1 CONCLUSION**

In this project, the circuit for the three phase ac voltage regulator employing modified sinusoidal pulse width modulation technique is used and the results are obtained by simulation. Comparing the modified sine wave with a high-frequency triangular signal, switching pulses for the conduction of semiconductor power elements (IGBT) can be achieved. A shift of these switching pulses acts so that the current waveform is near to the voltage waveform, which is verified from simulation results. This critical value of the shifting angle depends on the resistive and inductive load components as well as on the active output power. The operation of this ac voltage regulator gives the following advantages: Improved load power factor due to high frequency switching, Control range is wide in terms of firing angles regardless of load power factor. The investigation leads to the conclusion that there is a value of the shifting angle for which the PF can be improved.

#### **6.2 FUTURE SCOPE**

In the future scope of the work, the concept of modified SPWM can be implemented for three phase ac-ac PWM chopper with closed loop variable speed drive applications.

## REFERENCES

- [1] M. H. Rashid, "Power Electronics: Circuits, Devices and Applications", 2nd ed. Upper Saddle River, NJ:Prentice Hall, 1993.
- [2] B. W. Williams, "Asymmetrically modulated AC choppers," *IEEE Trans. Ind. Electron.*, vol. IE-29, pp. 181–185, Aug. 1982.
- [3] S. A. Bhat and J. Vithayathil, "A simple multiple pulse width modulated AC chopper," *IEEE Trans Ind. Electron.* vol. IE-29, pp. 185–189, Aug. 1982.
- [4] G. H. Choe, A. K. Wallace, and M. H. Park, "An improved PWM technique for AC choppers," *IEEE Trans. power Electron.*, vol. 4, pp. 496–505, Oct. 1989.
- [5] D. A. Deib and H. W. Hill, "Optimal harmonic reduction in ac/ac chopper converters," in *Proc. IEEE PESC '93*, 1993, pp. 1055–1060.
- [6] M. Mazzuccheli, L. Puglisi, G. Sciutto, and P. Tenti, "Improving the performance of AC/AC static converters with high frequency AC chopper control," in *Proc. POWERCON 9*, 1982, vol. I-3, pp. 1–9.
- [7] D. H. Jang, J. S. Won, and G. H. Choe, "Asymmetrical PWM method of ac chopper with improved input power factor," in *Proc. IEEE PESC '91*, 1991, pp. 838–845.
- [8] P. D. Ziogas, D. Vincenti, and D. Joos, "A practical PWM ac chopper topology," in *Proc. IEEE IECON '91*, 1991, pp. 880–887.
- [9] N.A Ahmed, K. Anei, M.Saku, "A new configuration of single-phase symmetrical PWM AC chopper voltage controller", *IEEE Trans. Ind. Electron.*, 1999, 46, (5), pp. 942–952
- [10] J. Spangler, A. Behera, "A comparison between hysteretic and fixed frequency boost converters used for power factor correction". *Proc. IEEE Applied Power Electronics Conf. Expo, 1993*, pp. 281–286
- [11] K. Georgakas, A. Safacas, "Power factor improvement of an AC–DC converter via appropriate sPWM Technique". *MED07. Athens, Greece, 27–29 June 2007*, paper T26–024
- [12] Dalapati S., Chakraborty C.: 'A direct PWM technique for a single-phase full-bridge inverter through controlled capacitor charging', *IEEE Trans. Ind. Electron.*, 2008, 55, (8), pp. 2912–2922

- [13] Georgakas K., Safacas A. 'Efficiency and power factor investigation of characteristic converter topologies via simulation'. ICEMS Conf., Nanjing, China, 27–29 September 2005, pp. 1422–1427
- [14] Saracoglu B., Kale M., Ozdemir E.: 'A novel technique for optimal efficiency control of induction motor fed by PWM IGBT AC chopper'. 35th Annual IEEE Power Electronics Specialists Conf., Aachen, Germany, 2004, pp. 3353–3358
- [15] Georgakas K., Safacas A.: "Modified sinusoidal pulse-width modulation operation technique of an AC–AC single-phase converter to optimise the power factor" Power electronics, IET, volume: 3, issue: 3, publication year: 2010 , pp: 454-464

## APPENDIX I



www.fairchildsemi.com

# LM2904, LM358/LM358A, LM258/ LM258A

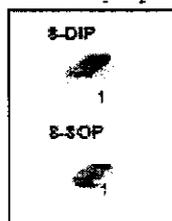
## Dual Operational Amplifier

### Features

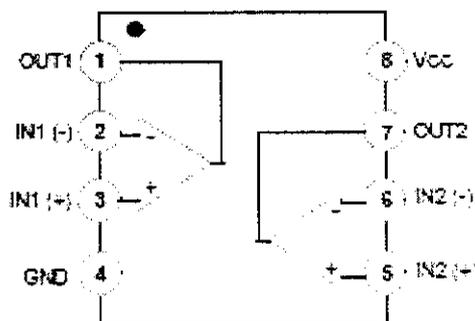
- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:  
LM258/LM258A, LM358/LM358A: 3V-33V (or ±1.5V ~ 16V)  
LM2904: 3V-36V (or ±1.5V ~ 18V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V DC to Vcc -1.5V DC
- Power Drain Suitable for Battery Operation

### Description

The LM2904, LM358/LM358A, LM258/LM258A consist of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifier, DC gain blocks and all the conventional OP-AMP circuits which now can be easily implemented in single power supply systems.

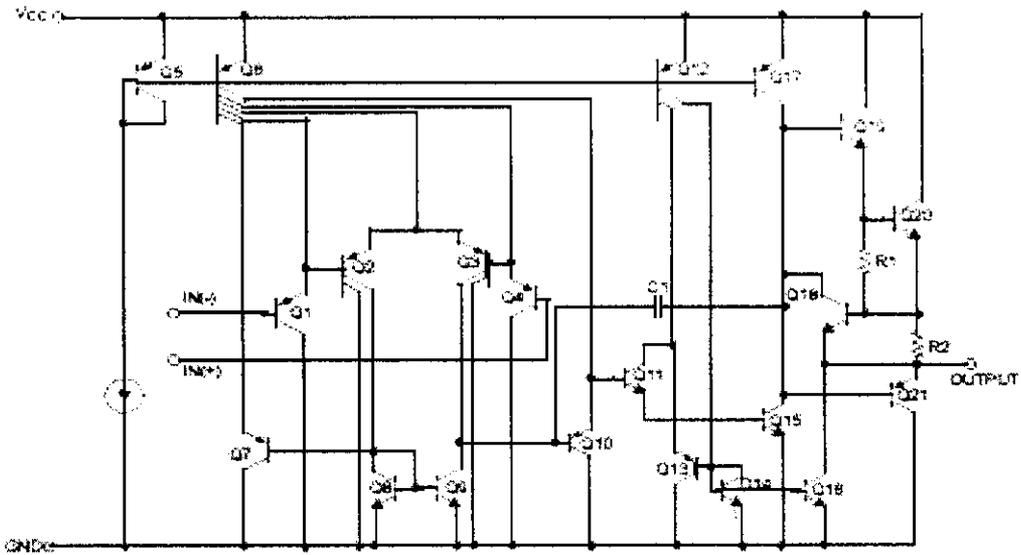


### Internal Block Diagram



### Schematic Diagram

(One section only)



### Absolute Maximum Ratings

Parameter	Symbol	LM258/LM258A	LM358/LM358A	LM2904	Unit
Supply Voltage	V <sub>CC</sub>	±16 or 32	±16 or 32	±13 or 26	V
Differential Input Voltage	V <sub>I(DIFF)</sub>	32	32	26	V
Input Voltage	V <sub>I</sub>	-0.3 to +32	-0.3 to +32	-0.3 to +26	V
Output Short Circuit to GND V <sub>CC</sub> ≤ 15V, T <sub>A</sub> = 25°C (One Amp)	-	Continuous	Continuous	Continuous	-
Operating Temperature Range	T <sub>OPR</sub>	-25 ~ +85	0 ~ +70	-40 ~ +85	°C
Storage Temperature Range	T <sub>STG</sub>	-65 ~ +150	-65 ~ +150	-65 ~ +150	°C

## Electrical Characteristics

( $V_{CC} = 5.0V$ ,  $V_{EE} = GND$ ,  $T_A = 25^\circ C$ , unless otherwise specified)

Parameter	Symbol	Conditions	LM258			LM358			LM2904			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	$V_{IO}$	$V_{CM} = 0V$ to $V_{CC}$ -1.5V $V_{OIP} = 1.4V$ , $R_S = 0\Omega$	-	2.9	5.0	-	2.9	7.0	-	2.9	7.0	mV
Input Offset Current	$I_{IO}$	-	-	3	30	-	5	50	-	5	50	nA
Input Bias Current	$I_{BIAS}$	-	-	45	150	-	45	250	-	45	250	nA
Input Voltage Range	$V_{VR}$	$V_{CC} = 30V$ (LM2904, $V_{CC} = 26V$ )	0	-	$V_{CC} - 1.5$	0	-	$V_{CC} - 1.5$	0	-	$V_{CC} - 1.5$	V
Supply Current	$I_{CC}$	$R_L = \infty$ , $V_{CC} = 30V$ (LM2904, $V_{CC} = 26V$ )	-	0.8	2.0	-	0.8	2.0	-	0.8	2.0	mA
		$R_L = \infty$ , $V_{CC} = 5V$	-	0.5	1.2	-	0.5	1.2	-	0.5	1.2	mA
Large Signal Voltage Gain	$G_V$	$V_{CC} = 15V$ , $R_L = 2k\Omega$ $V_{OIP} = 1V$ to $11V$	50	100	-	25	100	-	25	100	-	V/mV
Output Voltage Swing	$V_{OH}$	$V_{CC} = 30V$ , $R_L = 2k\Omega$	26	-	-	26	-	-	22	-	-	V
		$V_{CC} = 26V$ for LM2904, $R_L = 10k\Omega$	27	28	-	27	28	-	23	24	-	V
	$V_{OL}$	$V_{CC} = 5V$ , $R_L = 10k\Omega$	-	5	20	-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-	70	85	-	65	80	-	50	80	-	dB
Power Supply Rejection Ratio	PSRR	-	65	100	-	65	100	-	50	100	-	dB
Channel Separation	CS	$f = 10kHz$ to $20kHz$ (Note 1)	-	120	-	-	120	-	-	120	-	dB
Short Circuit to GND	$I_{SC}$	-	-	40	60	-	40	60	-	40	60	mA
Output Current	$I_{SOURCE}$	$V_{I(+)} = 1V$ , $V_{I(-)} = 0V$ , $V_{CC} = 15V$ , $V_{OIP} = 2V$	20	30	-	20	30	-	20	30	-	mA
		$V_{I(+)} = 0V$ , $V_{I(-)} = 1V$ , $V_{CC} = 15V$ , $V_{OIP} = 2V$	10	15	-	10	15	-	10	15	-	mA
	$I_{SINK}$	$V_{I(+)} = 0V$ , $V_{I(-)} = 5V$ , $V_{CC} = 15V$ , $V_{OIP} = 200mV$	12	100	-	12	100	-	-	-	-	$\mu A$
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	$V_{CC}$	-	-	$V_{CC}$	-	-	$V_{CC}$	V

### Note:

1. This parameter, although guaranteed, is not 100% tested in production.

# MC78XX/LM78XX/MC78XXA

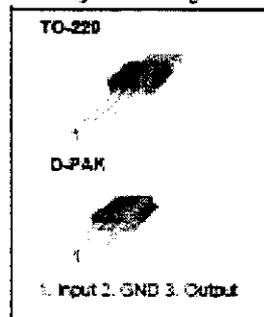
## 3-Terminal 1A Positive Voltage Regulator

### Features

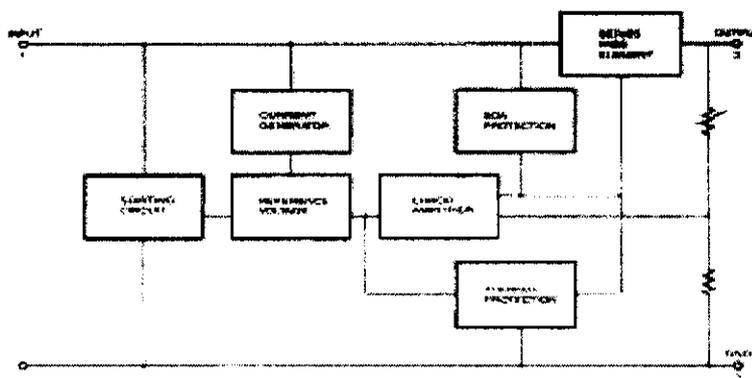
- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

### Description

The MC78XX/LM78XX/MC78XXA series of three terminal positive regulators are available in the TO-220 D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.



### Internal Block Diagram



### Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for $V_O = 5V$ to $18V$ ) (for $V_O = 24V$ )	$V_I$	35	V
	$V_{I1}$	40	V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	$^{\circ}C/W$
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	$^{\circ}C/W$
Operating Temperature Range	$T_{OPR}$	0 ~ +125	$^{\circ}C$
Storage Temperature Range	$T_{STG}$	-65 ~ +150	$^{\circ}C$

### Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit,  $0^{\circ}C < T_J < 125^{\circ}C$ ,  $I_O = 500mA$ ,  $V_I = 10V$ ,  $C_I = 0.33\mu F$ ,  $C_O = 0.1\mu F$ , unless otherwise specified)

Parameter	Symbol	Conditions	MC7805/LM7805			Unit	
			Min.	Typ.	Max.		
Output Voltage	$V_O$	$T_J = +25^{\circ}C$	4.8	5.0	5.2	V	
		$5.0mA < I_O < 1.0A$ , $P_D < 15W$ $V_I = 7V$ to $20V$	4.75	5.0	5.25		
Line Regulation (Note 1)	Regline	$T_J = +25^{\circ}C$	$V_O = 7V$ to $25V$	-	4.0	100	mV
			$V_I = 8V$ to $12V$	-	1.6	50	
Load Regulation (Note 1)	Regload	$T_J = +25^{\circ}C$	$I_O = 5.0mA$ to $1.5A$	-	9	100	mV
			$I_O = 250mA$ to $750mA$	-	4	50	
Quiescent Current	$I_Q$	$T_J = +25^{\circ}C$	-	5.0	8.0	mA	
Quiescent Current Change	$\Delta I_Q$	$I_O = 5mA$ to $1.0A$	-	0.03	0.5	mA	
		$V_I = 7V$ to $25V$	-	0.3	1.3		
Output Voltage Drift	$\Delta V_O / \Delta T$	$I_O = 5mA$	-	-0.8	-	mV/ $^{\circ}C$	
Output Noise Voltage	$V_N$	$f = 10Hz$ to $100kHz$ , $T_A = +25^{\circ}C$	-	42	-	$\mu V/V_O$	
Ripple Rejection	RR	$f = 120Hz$ $V_O = 8V$ to $18V$	62	73	-	dB	
Dropout Voltage	$V_{Drop}$	$I_O = 1A$ , $T_J = +25^{\circ}C$	-	2	-	V	
Output Resistance	$r_O$	$f = 1kHz$	-	15	-	m $\Omega$	
Short Circuit Current	$I_{SC}$	$V_I = 35V$ , $T_A = +25^{\circ}C$	-	230	-	mA	
Peak Current	$I_{PK}$	$T_J = +25^{\circ}C$	-	2.2	-	A	

**Note:**

1. Load and line regulation are specified at constant junction temperature. Changes in  $V_O$  due to heating effects must be taken into account separately. Pulse testing with low duty is used.

# 1N4001 - 1N4007

## Features

- Low forward voltage drop.
- High surge current capability.



DO-41

COLOR BAND DENOTES CATHODE

## General Purpose Rectifiers (Glass Passivated)

### Absolute Maximum Ratings\*

$T_A = 25^\circ\text{C}$  unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
$V_{RRM}$	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{(AV)}$	Average Rectified Forward Current, 0.375" lead length @ $T_A = 75^\circ\text{C}$	1.0							A
$I_{FSM}$	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
$T_{stg}$	Storage Temperature Range	-55 to +175							$^\circ\text{C}$
$T_J$	Operating Junction Temperature	-55 to +175							$^\circ\text{C}$

\*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

### Thermal Characteristics

Symbol	Parameter	Value	Units
$P_D$	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	$^\circ\text{C}/\text{W}$

### Electrical Characteristics

$T_A = 25^\circ\text{C}$  unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
$V_F$	Forward Voltage @ 1.0 A	1.1							V
$I_{rr}$	Maximum Full Load Reverse Current, Full Cycle $T_A = 75^\circ\text{C}$	30							$\mu\text{A}$
$I_s$	Reverse Current @ rated $V_R$ $T_A = 25^\circ\text{C}$ $T_A = 100^\circ\text{C}$	50 500							$\mu\text{A}$ $\mu\text{A}$
C-	Total Capacitance $V_R = 4.0\text{ V}$ , $f = 1.0\text{ MHz}$	15							pF

**N-channel enhancement mode  
TrenchMOS™ transistor**

**IRFZ44N**

**GENERAL DESCRIPTION**

N-channel enhancement mode standard level field-effect power transistor in a plastic envelope using 'trench' technology. The device features very low on-state resistance and has integral zener diodes giving ESD protection up to 2kV. It is intended for use in switched mode power supplies and general purpose switching applications.

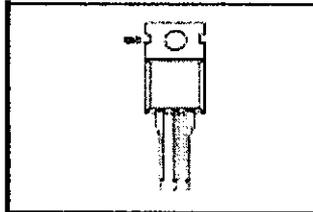
**QUICK REFERENCE DATA**

SYMBOL	PARAMETER	MAX.	UNIT
$V_{DS}$	Drain-source voltage	55	V
$I_D$	Drain current (DC)	49	A
$P_{tot}$	Total power dissipation	110	W
$T_j$	Junction temperature	175	°C
$R_{DS(on)}$	Drain-source on-state resistance $V_{GS} = 10\text{ V}$	22	mΩ

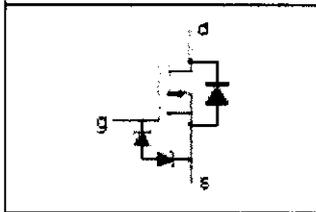
**PINNING - TO220AB**

PIN	DESCRIPTION
1	gate
2	drain
3	source
tab	drain

**PIN CONFIGURATION**



**SYMBOL**



**LIMITING VALUES**

Limiting values in accordance with the Absolute Maximum System (IEC 134)

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
$V_{DS}$	Drain-source voltage	-	-	55	V
$V_{GS}$	Drain-gate voltage	$R_{DS(on)} = 20\text{ k}\Omega$	-	55	V
$\Delta V_{GS}$	Gate-source voltage	-	-	20	V
$I_D$	Drain current (DC)	$T_{amb} = 25\text{ }^\circ\text{C}$	-	49	A
$I_{DM}$	Drain current (DC)	$T_{amb} = 100\text{ }^\circ\text{C}$	-	35	A
$I_{DM}$	Drain current (pulse peak value)	$T_{amb} = 25\text{ }^\circ\text{C}$	-	150	A
$P_{tot}$	Total power dissipation	$T_{amb} = 25\text{ }^\circ\text{C}$	-	110	W
$T_{stg}$ , $T_j$	Storage & operating temperature	-	-55	175	°C

**ESD LIMITING VALUE**

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
$V_C$	Electrostatic discharge capacitor voltage, all pins	Human body model (100 pF, 1.5 kΩ)	-	2	kV

**THERMAL RESISTANCES**

SYMBOL	PARAMETER	CONDITIONS	TYP.	MAX.	UNIT
$R_{th(jc)}$	Thermal resistance junction to mounting base	-	-	1.4	K/W
$R_{th(ja)}$	Thermal resistance junction to ambient	in free air	60	-	K/W

N-channel enhancement mode  
TrenchMOS™ transistor

IRFZ44N

STATIC CHARACTERISTICS

T = 25°C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$V_{(BR)DSS}$	Drain-source breakdown voltage	$V_{GS} = 0\text{ V}; I_D = 0.25\text{ mA}; T_J = -55^\circ\text{C}$	55	-	-	V
$V_{GS(th)}$	Gate threshold voltage	$V_{GS} = V_{DS}; I_D = 1\text{ mA}; T_J = -55^\circ\text{C}$	2.0	3.0	4.0	V
		$T_J = 175^\circ\text{C}$	1.0	-	-	V
		$T_J = -55^\circ\text{C}$	-	-	4.4	V
$I_{DSS}$	Zero gate voltage drain current	$V_{GS} = 55\text{ V}; V_{DS} = 0\text{ V}; T_J = 175^\circ\text{C}$	-	0.05	10	µA
$I_{GSS}$	Gate source leakage current	$V_{GS} = \pm 10\text{ V}; V_{DS} = 0\text{ V}; T_J = 175^\circ\text{C}$	-	0.04	1	µA
$\pm V_{GS(BR)}$	Gate source breakdown voltage	$I_D = \pm 1\text{ mA}; T_J = 175^\circ\text{C}$	16	-	-	V
$R_{DS(on)}$	Drain-source on-state resistance	$V_{GS} = 10\text{ V}; I_D = 25\text{ A}; T_J = 175^\circ\text{C}$	-	15	22	mΩ
			-	-	42	mΩ

DYNAMIC CHARACTERISTICS

T<sub>amb</sub> = 25°C unless otherwise specified

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$g_m$	Forward transconductance	$V_{GS} = 25\text{ V}; I_D = 25\text{ A}$	6	-	-	S
$C_{iss}$	Input capacitance	$V_{GS} = 0\text{ V}; V_{DS} = 25\text{ V}; f = 1\text{ MHz}$	-	1350	1800	pF
$C_{oss}$	Output capacitance		-	330	400	pF
$C_{fsw}$	Feedback capacitance		-	155	215	pF
$Q_g$	Total gate charge	$V_{DS} = 44\text{ V}; I_D = 50\text{ A}; V_{GS} = 10\text{ V}$	-	-	62	nC
$Q_{gs}$	Gate-source charge		-	-	15	nC
$Q_{gd}$	Gate-drain (Miller) charge		-	-	26	nC
$t_{on}$	Turn-on delay time	$V_{GS} = 30\text{ V}; I_D = 25\text{ A}; V_{DS} = 10\text{ V}; R_{\theta j-c} = 10\ \Omega$	-	18	26	ns
$t_{r}$	Turn-on rise time		-	50	75	ns
$t_{off}$	Turn-off delay time		-	40	50	ns
$t_{f}$	Turn-off fall time		-	30	40	ns
$L_D$	Internal drain inductance	Measured from contact screw on tab to centre of die	-	3.5	-	nH
$L_L$	Internal drain inductance	Measured from drain lead 6 mm from package to centre of die	-	4.5	-	nH
$L_S$	Internal source inductance	Measured from source lead 6 mm from package to source bond pad	-	7.5	-	nH

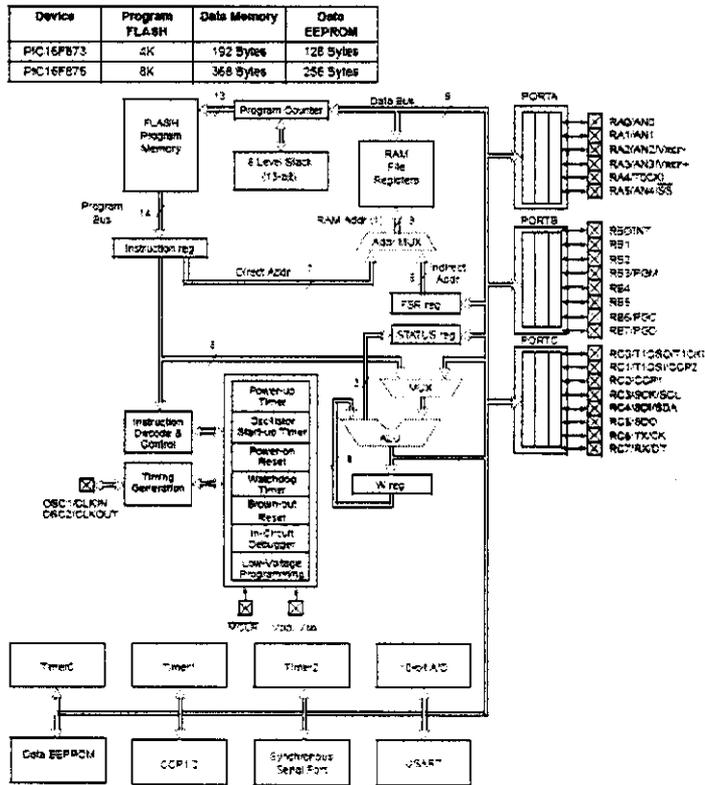
REVERSE DIODE LIMITING VALUES AND CHARACTERISTICS

T = 25°C unless otherwise specified

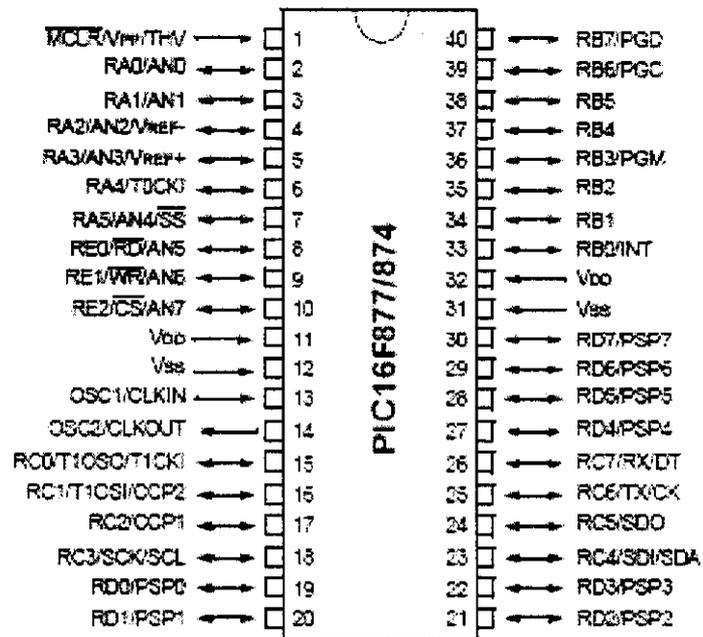
SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$I_{SRM}$	Continuous reverse drain current		-	-	49	A
$I_{SM}$	Pulsed reverse drain current		-	-	160	A
$V_{SD}$	Diode forward voltage	$I_S = 25\text{ A}; V_{GS} = 0\text{ V}$	-	0.95	1.2	V
		$I_S = 40\text{ A}; V_{GS} = 0\text{ V}$	-	1.0	-	V
$t_{rr}$	Reverse recovery time	$I_D = 40\text{ A}; -dI_D/dt = 100\text{ A}/\mu\text{s}; V_{GS} = -10\text{ V}; V_L = 30\text{ V}$	-	47	-	ns
$Q_{rr}$	Reverse recovery charge		-	0.15	-	µC

## APPENDIX II

### ARCHITECTURE OF PIC16F877A



### Pin Configuration of PIC16F877A



### TIMER 0 CONTROL REGISTER:

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
RBP0	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0
bit 7							bit 0

bit 7: **RBP0**

bit 6: **INTEDG**

bit 5: **T0CS**: TMR0 Clock Source Select bit

- 1 = Transition on T0CKI pin
- 0 = Internal instruction cycle clock (CLKOUT)

bit 4: **T0SE**: TMR0 Source Edge Select bit

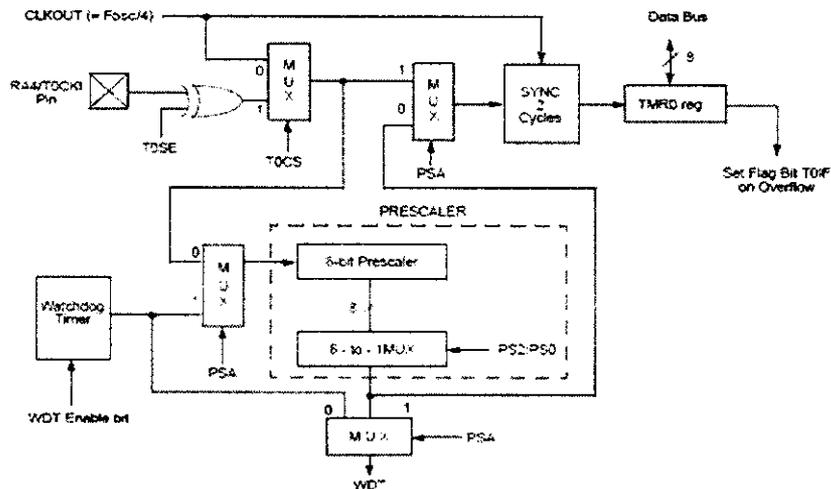
- 1 = Increment on high-to-low transition on T0CKI pin
- 0 = Increment on low-to-high transition on T0CKI pin

bit 3: **PSA**: Prescaler Assignment bit

- 1 = Prescaler is assigned to the WDT
- 0 = Prescaler is assigned to the Timer0 module

bit 2-0: **PS2 PS1 PS0**: Prescaler Rate Select bits

### TIMER 0 BLOCK DIAGRAM:



### TIMER 1 CONTROL REGISTER:

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
---	---	T1CKPS1	T1CKPS0	T1OSCEN	T1SYNC	TMR1CS	TMR1ON
bit 7							bit 0

bit 7-6: **Unimplemented**: Read as '0'

bit 5-4: **T1CKPS1:T1CKPS0**: Timer1 Input Clock Prescale Select bits

- 11 = 1:8 Prescale value
- 10 = 1:4 Prescale value
- 01 = 1:2 Prescale value
- 00 = 1:1 Prescale value

bit 3: **T1OSCEN**: Timer1 Oscillator Enable Control bit

1 = Oscillator is enabled

0 = Oscillator is shut off (The oscillator inverter is turned off to eliminate power drain)

bit 2: **T1SYNC**: Timer1 External Clock Input Synchronization Control bit

TMR1CS = 1

1 = Do not synchronize external clock input

0 = Synchronize external clock input

TMR1CS = 0

This bit is ignored. Timer1 uses the internal clock when TMR1CS = 0.

bit 1: **TMR1CS**: Timer1 Clock Source Select bit

1 = External clock from pin RC0/T1OSO/T1CKI (on the rising edge)

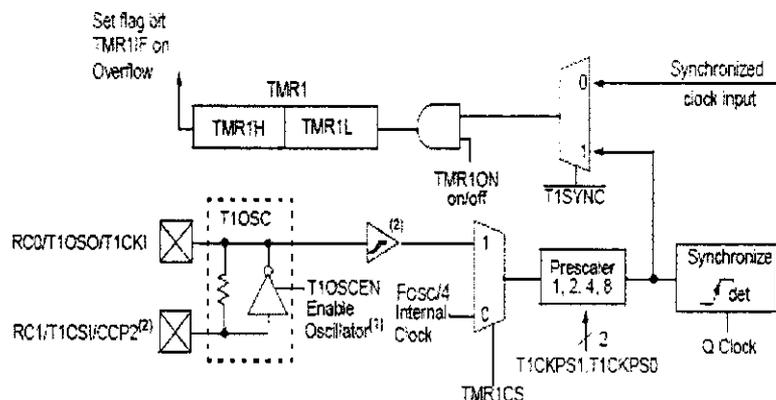
0 = Internal clock (FOSC/4)

bit 0: **TMR1ON**: Timer1 On bit

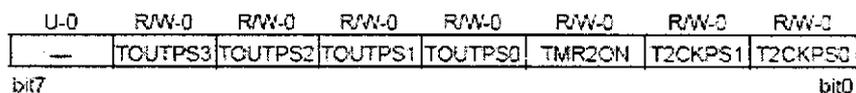
1 = Enables Timer1

0 = Stops Timer1

### TIMER 1 BLOCK DIAGRAM:



### TIMER 2 CONTROL REGISTER:



bit 7: **Unimplemented**: Read as '0'

bit 6-3: **TOUTPS3:TOUTPS0**: Timer2 Output Postscale Select bits

0000 = 1:1 Postscale

0001 = 1:2 Postscale

0010 = 1:3 Postscale  
 1111 = 1:16 Postscale

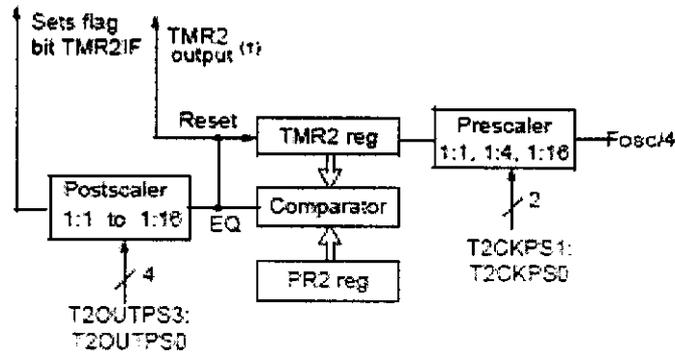
bit 2: **TMR2ON**: Timer2 On bit

1 = Timer2 is on  
 0 = Timer2 is off

bit 1-0: **T2CKPS1:T2CKPS0**: Timer2 Clock Prescale Select bits

00 = Prescaler is 1  
 01 = Prescaler is 4  
 1x = Prescaler is 16

**TIMER2 BLOCK DIAGRAM:**



**CCP1CON REGISTER/CCP2CON REGISTER:**

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	CCPxX	CCPxY	CCPxM3	CCPxM2	CCPxM1	CCPxM0
bit7							bit0

bit 7-6: **Unimplemented**: Read as '0'

bit 5-4: **CCPxX :CCPxY**: PWM Least Significant bits

Capture Mode: Unused

Compare Mode: Unused

PWM Mode: These bits are the two LSB s of the PWM duty cycle. The eight MSB s are found in CCPRxL.

bit 3-0: **CCPxM3:CCPxM0**: CCPx Mode Select bits

0000 = Capture/Compare/PWM off (resets CCPx module)

0100 = Capture mode, every falling edge

0101 = Capture mode, every rising edge

0110 = Capture mode, every 4th rising edge

0111 = Capture mode, every 16th rising edge

1000 = Compare mode, set output on match (CCPxIF bit is set)

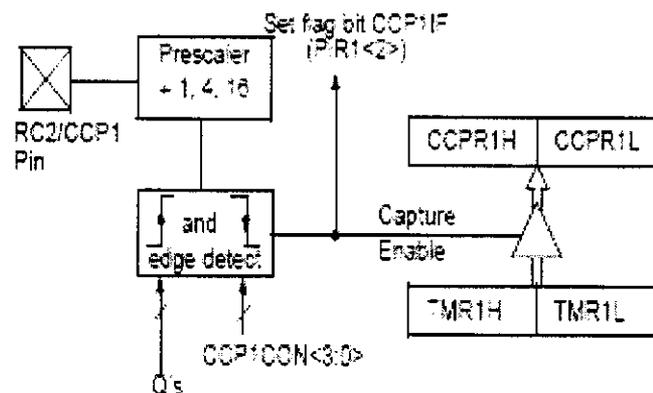
1001 = Compare mode, clear output on match (CCPxIF bit is set)

1010 = Compare mode, generate software interrupt on match (CCPxIF bit is set, CCPx pin is unaffected)

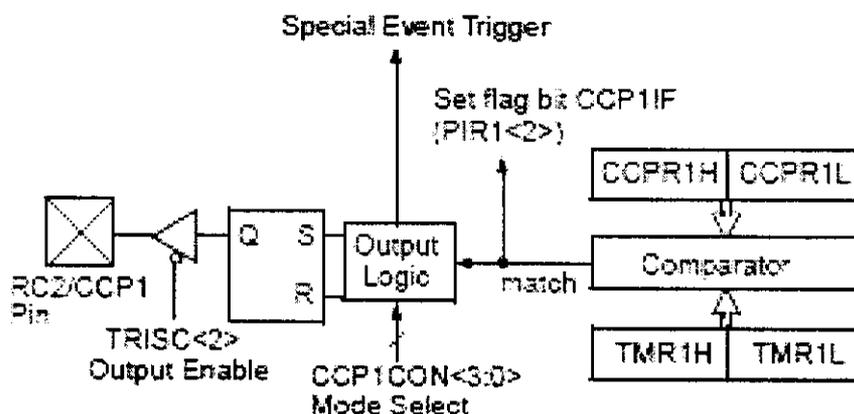
1011 = Compare mode, trigger special event (CCPxIF bit is set, CCPx pin is unaffected); CCP1 resets TMR1; CCP2 resets TMR1 and starts an A/D conversion (if A/D module is enabled)

11xx = PWM mode

### CAPTURE MODE OPERATION BLOCK DIAGRAM:



### COMPARE MODE OPERATION BLOCK DIAGRAM:



## APPENDIX III

### PIC PROGRAMMING

```
#include<pic.h>
__CONFIG(0X20A4);
__CONFIG(0X3FFF);
void main()
{
    TRISA=0XFF;
    ANSEL=0;
    ANSELH=0;

    TRISC=0;
    PORTC=0;

    TRISB=0;
    PORTB=0;

    PR2=249;
    T2CON=0X05;
    CCP1CON=0X0C;
    CCPR1L=125;

    while(1)
    {
        if(RA4==1)
        {
            PORTB=0XC0;
            delay();
            PORTB=0X31;
        }
    }
}
```

```
        }  
    else  
    {  
        PORTB=0X30;  
        delay();  
        PORTB=0XC1;  
    }  
  
    }  
  
}  
  
delay()  
{  
    unsigned int i;  
    for(i=0;i<500;i++);  
}
```