A Boost Rectifier Using Matrix Converter Topology Incorporating Active Pulse Width Modulation Technique

A Project Report

Submitted By

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ABSTRACT

The System presents the application of single-phase matrix converter (SPMC) as a boost rectifier that could synthesize a greater DC output voltage from a given AC supply voltage. For boost rectifier operation, PWM technique was used to calculate the switch duty ratio to synthesize the output. This is then extended to produce an active pulse width modulation (APWM) in order to maintain input current waveform to become continuous, sinusoidal and in phase with the supply voltage and hence near unity power factor when a Capacitor filtered load is used. Classical rectifier with DC capacitor filter has a setback in that it draws discontinuous supply current waveform with high harmonics content, As a result it contributes to high total harmonic distortion (THD) level and low total effective supply power factor affecting the quality of the power supply system. To solve this problem, Matrix converter acting as a single phase rectifier with an active pulse width modulation Technique (APWM) was proposed to suppress the harmonic current drawn by rectifier with a capacitor-filtered load. Control electronics was used to generate active pulse width modulation (APWM) using boost technique that is piloted by a current control loop (CCL). The SPMC with APWM is verified by simulating the models using MATLAB/SIMULINK. Results of simulations are presented to verify that the proposed technique is feasible. The prototype model is also designed, fabricated and tested.

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ABBREVIATIONS

SPMC	Single Phase Matrix Converter
THD	Total Harmonic Distortion
PWM	Pulse Width Modulation
APWM	Active Pulse Width Modulation
AC	Alternating Current
RMS	Root Mean Square
DC	Direct Current
UPS	Uninterrupted Power Supply
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PIC	Peripheral Interface Controller
APF	Active Power Filter
PI	Proportional Integral
IGBT	Insulated Gate Bipolar Transistor

CHAPTER 1

1. INTRODUCTION

Development of semiconductor devices and microprocessor technology during the last thirty years has changed rapidly power electronics technology and the number of applications has been on the increase.A typical power electronic system is normally used as an interface between a load and supply comprising a power converter, a load/source and a control unit. It can be generally classified in terms of basic functions, namely;

- AC-AC conversion
- AC-DC conversion (rectifier)
- DC-DC conversion
- DC-AC conversion (inverter)

Development of advanced power semiconductor devices, increased usage of power switching circuits and other power electronic applications are becoming a common place within modern commercial and industrial environment particularly in applications for AC-DC conversions. Among different types of energy conversion, the AC-DC (rectifier) is by far the widest in applications ranging from industrial drives to low-powered portable equipments. It is used in adjustable-speed drives (ASDs), switch-mode power supplies (SMPSs), uninterrupted power supplies (UPS) and utility interface with non-conventional energy source such as photovoltaic (PV) and battery energy storage systems (BESSs) etc. They have also found applications in process technology such as electroplating, welding units and battery charging for electric vehicles. Other applications also includes but not limited to various power supply technologies for communication systems, measurement and test equipments .

Conventionally, the rectifier topologies are developed using diodes and thyristors to provide uncontrolled and controlled dc power with unidirectional and bidirectional power flow. However, they have demerits of poor power quality due to injected current harmonics, causing current distortions and poor power factor at input ac mains and slow varying rippled dc output at load end with low efficiency; requiring large size ac and dc filters. In light of strict requirement of power quality at input ac mains several standards such as IEEE 519 have been developed to limit problems. Because of severity of power quality problems some other options such as passive filters and active filters (AFs) have been extensively developed to solve this problem. In this work, studies are carried out on the use of implementation of Single-Phase Matrix Converter Operating as AC-DC Converter with Active Power Filter (APF) function.

Matrix Converter (MC) has been described to offer an "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional rectifier –inverter based system and hence an attractive alternative converter. Its topology was first described in 1976 Gyugyi. The single phase variant denoted as SPMC was first realized by Zuckerberger It has a distinct advantage of affording bi-directional power flow with any desired number of input and output phase. The key element in a matrix converter is the fully controlled four quadrant bidirectional switch, which allows high frequency operation. The matrix converter has many advantages over traditional topologies. It is inherently bi-directional so can regenerate energy back to the supply It draws sinusoidal input currents and, depending on the modulation technique, it can be arranged that unity displacement factor is seen at the supply side irrespective of the type of load. The size of the power circuit has the potential to be greatly reduced in comparison to conventional technologies since there are no large capacitors or inductors to store energy.

Harmonic power and reactive power, which is drawn by the proliferation of nonlinear loads such as high power diode/thyristor, rectifiers, cyclo converters, and arc furnaces in industrial, commercial, and residential applications, has become a research topic.Power electronics application is dependent on the use of power switching devices that inadvertently, results with a non-sinusoidal current being drawn from the supply, containing harmful harmonics components which are then feedback to supply system creating various problems such as voltage distortion, additional losses, failure of sensitive equipments, resonance, and interference and so on.

In this paper the basic SPMC topology will be reviewed based on controlled rectifier operation by suitable switching schemes. MOSFET s are used as the main power switching device. Simple resistive load will be initially used, followed by inclusion of simple capacitor filter to remove ripples at the load. An active pulse width modulation (APWM) are then produced in order to maintain input current waveform to become continuous, sinusoidal and in phase with the supply voltage and hence near unity power factor. The input side will be provided with an inductance that is used for boost rectifier operation.

An experimental test-rig was then constructed to verify the operation of the proposed system, including its control electronics, gate drives and power circuits. Control implementation in practical realizations is proposed using peripheral interface controller (PIC). In this work implementation of peripheral interface controller (PIC) 16F877 micro controller.to generate pulse width modulation (PWM) signal to control the synthesize output waveform of single-phase matrix converter is described. An active pulse width modulation (APWM) are then produced in order to maintain input current waveform to become continuous, sinusoidal and in phase with the supply voltage and hence near unity power factor by analogue method. Prior to the practical realization, a computer model using MATLAB/Simulink was developed for comparisons to accelerate investigations.

1.1 MATRIX CONVERTER

The market of power electronics shows a clear tendency towards the following objectives improving the interaction between power electronic converters and the grid, bidirectional power flow, high efficiency and high switching frequency, reduced size and high integration of complex solutions in a single power module. The Matrix Converter (MC) presents an architecture with many of the before mentioned characteristics. The MC is an AC/AC converter, formed by n x m bidirectional switches (n input phases and m output phases), where any of the inputs can be connected to any of the output phases. In this way, it is possible to implement a n x m poly phase converter. This architecture is an "all-silicon" solution, because no significant reactive element is necessary to store energy, although in practice, an input filter and a clamp circuit may be necessary for the safe operation of the converter. Reactive components are sensitive to temperature changes, expensive and their price is not expected to decrease with time.

The advantages of the MC are:

a) Four quadrant operation and, therefore, it is inherently bidirectional. Thanks to bidirectional switches, the MC can deliver or take power from the grid. with a direct and instantaneous conversion between input and output of the converter (conventional AC/AC converters use two conversion steps with an intermediate DC link).

b) Although the MC uses a high number of switches, there is a tendency in the market towards a price reduction of silicon components, and this problem will be minimized in a foreseeable future. The high number of switches means a higher distribution of the thermal stress in the switches.

c) The MC can operate in high and low pressure environments, and at high temperatures, such as space and submarine applications where the use of electrolytic capacitors is restricted. In this sense, the MC is a good candidate for the connection of tidal energy power stations.

d) The power losses of the MC may be considerable reduced using semi-soft commutation strategies. For this reason, high switching frequencies can be used, highly reducing the size of filters and auxiliary equipment. High operating frequencies mean high order harmonics, which are less harmful for the grid. All this makes the MC more efficient than a "rectifier-inverter" approach.

e) Using appropriate modulation strategies, it is possible to achieve sinusoidal currents at the grid and sinusoidal voltages at the load, with an unity power factor with any type of load.

The MC is a very promising technology that may contribute to the development of power electronics, but nowadays, several technological barriers must be superseded in order to extend its use in real commercial applications. Some of the challenges are:

a) Protection of the converter is a complex task, because there is no way to store energy.

b) The MC is very sensitive to voltage dips and distortions in the grid, because the power conversion has no intermediate steps. There are some strategies to reduce this effect, such as load stored energy recovery or improved modulation strategies, anyway this is an open research field.

c) The high number of power switches in a MC means a higher connection complexity, control, thermal management, etc. Thus, the development of Intelligent Power Modules (IPM) or Power Electronics Building Blocks (PEBB), integrating the power switches with the gate control circuits, increases the reliability and the efficiency of the converter, and makes the design task easier. The development of new silicon switches, such as RB-IGBT, will further improve these aspects.

It requires the use of bidirectional switches capable of blocking voltage and conducting current in both directions. Unfortunately there is no discrete semiconductor device currently that could fulfil the needs and hence the use of common emitter anti-parallel IGBT, diode pair as shown in Figure.1.1. The IGBT were used due to its popularity amongst researchers that could lead to high-power applications with reasonably fast switching frequency for fine control.

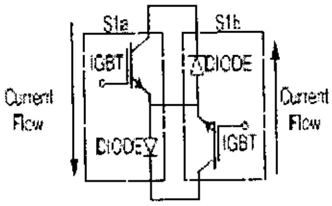


Figure .1.1 Bidirectional Switch

TABLE 1. COMPARISON OF DIFFERENT POWER CONVERTERS

	'Inverter-Rectifier' Converter	Multilevel converter	Matrix converter
Capacitors	Large sized capacitors, reduced lifetime	Small capacitors but in large numbers	No high capacitors
Temperature	Very sensitive	High influence in behaviour	Less influence in behaviour
Switching loss	High	High	Low
Control	Simple	Very complex	Complex
Power quality	Poor	Acceptable	Good

1. 2. SINGLE-PHASE MATRIX CONVERTER

The single-phase matrix converter (SPMC) similar tools three-phase version has been described to offer "all silicon" solution for AC-AC conversion, removing or minimizing the need for reactive energy storage component used in conventional rectifier-inverter based system. It has a distinct advantage of affording bidirectional power flow with any desired number of input and output phases. By proper modulation it may be possible to generate various output irrespective of the load from various types of input.The single-phase matrix converter (SPMC) as shown in Figure. 1.2 consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections. Each of the individual switch is capable of conducting current in both directions, whilst at the same time capable of blocking voltage.

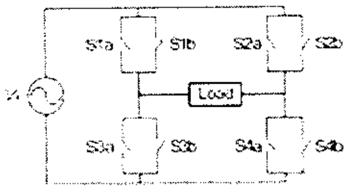


Figure 1.2 Single phase matrix converter topology

1.3. THE SPMC AS A CONTROLLED RECTIFIER

Classical rectifier normally uses bridge-diode without affording any control function, thus are major contributor to power factor and current distortion problems resulting in poor overall power factor, heating effects, device malfunction and destruction of other equipments. Therefore the demand for high quality power supply has shown an increase in the provision of unity power factor supply . Implementation of SPMC as a controlled rectifier has been presented in which uses only 4 switches as illustrated in Figure.1.3 and 1.4, making other 4 switches as redundant. However, these redundant switches could be used to add features to the controlled rectifier operation that may include, amongst others; safe-commutation when used in RL load and power factor correction operation particularly when RC load are used.

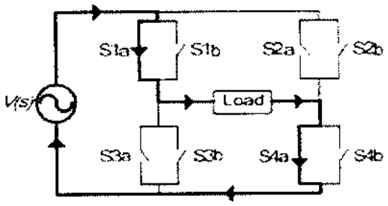


Figure.1.3 Controlled Rectifier Using SPMC (Positive State)

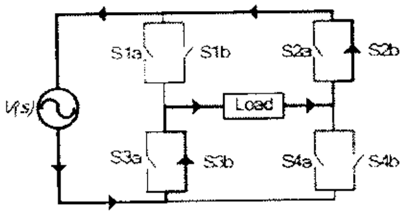


Figure.1.4 Controlled Rectifier Using SPMC (Negative State)

One of the major issues to be considered with the matrix converter is the commutation problem. Since there are no freewheel paths, it is difficult to reliably commutate current from one switch to another. Various methods have been proposed to avoid this difficulty and ensure successful commutation in three-phase systems; summarized as follows:

- Kwon proposed the dead time to avoid current spikes of switches and at the same time establishes a current path for the inductive load to avoid voltage spikes.
- Wei developed the zero current turn-on and turn-off of the line side converter to prevent the commutation problems.
- P. Wheeler created semi-soft current commutation that allows the current to commutate from one switch cell to another without causing a line-to-line short circuit or a load open circuit.

1.4. OBJECTIVE OF THE PROJECT

The purpose of this project is to develop a Matrix Converter as a Boost Rectifier with resistive load and capacitor filtered load .

The main objective of the project is mentioned below:

- Boosted Output Voltage.
- Minimization harmonics in source current
- Improving the input supply power factor.
- To compensate the reactive power.
- Reducing the THD.

1.5 LITERATURE SURVEY

The matrix converter (MC) offers possible "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional converter system. Its topology was first described in 1976 by Gyugyi in his paper "Static Power Chargers, Theory, Performance and Application". Previous published studies dealt with three-phase circuit topologies. MC in the three-phase variant is widely researched whilst the Single-Phase Matrix Converter (SPMC) has very little attention whilst offering very wide application.

The Single-phase matrix converter (SPMC) was first realised by Zuckerberger in his paper "Single-phase Matrix Converter". All previous works have focussed attention to direct AC-AC single phase converter and DC chopper but none on rectifier operation.

Investigations on the implementation of the Single phase Matrix Converter as an AC-DC converter was done by Baharom R.,A.S.A. Hasim, M.K.Hamzah and A.F Omar; in their paper "A New Single-Phase Controlled Rectifier Using Single-Phase Matrix Converter Topology".

Investigations on the implementation of the Single phase Matrix Converter as an AC-DC converter subjected to different load conditions was done by Baharom, R.; Hamzah, M.K.; Saparon, A.; Ibrahim, I.R,in their paper "Studies on control electronics implementation of Single-phase Matrix converter operating as AC-DC Converter with active power filter function" Excellent results like unity power factor and reduced THD has been achieved by the system.

Implementation of a new AC-DC matrix converter and its control system are described by H. Arifin, R. Baharom, M. K. Hamzah & N.R Hamzah in their paper "Peripheral Interface Controller as Signal Generator in the Single-Phase Matrix Converter as AC-DC Converter ". This paper describes implementation of peripheral interface controller (PIC) to generate pulse width modulation (PWM) signal to control the synthesize output waveform of single-phase matrix converter.

1.6 ORGANISATION OF THE THESIS:

This report presents a Matrix Converter as a boost Rectifier and with active power filter function .Chapter 1 gives an overview of Single Phase Matrix Converter as a Rectifier and their operation. It also explains the advantages of Matrix Converters over other types of converters. Chapter 2 details the Single Phase Matrix Converter as a Boost Rectifier with its MATLAB Simulation model. Chapter 3 describes the proposed system along with the control strategies of APWM pulses for the Matrix Converter switches. The MATLAB Simulation model of the proposed system is also obtained and compared with the base paper model in Chapter 4 .Chapter 5 deals with the hardware modelling of the proposed system ,results of hardware testing and the process coding of the PIC controller. In Chapter 6 the conclusion and future scope of the project is discussed.

CHAPTER 2

2. BOOST RECTIFIER USING SPMC TOPOLOGY

Boost converters are widely used for electronic power supplies, in which the desired output voltage is high compared to a typical ac input voltage level; i.e $V_{out} \geq V_{in}$. Generally, a single-inductor, single-switch boost converter topology and its variations exhibits satisfactory performance in the majority of applications. This Conventional topology could not be used in bidirectional and regenerative operation. Thus the redundant switches of SPMC ,when it works as a rectifier is used for boost operation.

2.1 CIRCUIT DIAGRAM OF THE BOOST RECTIFIER

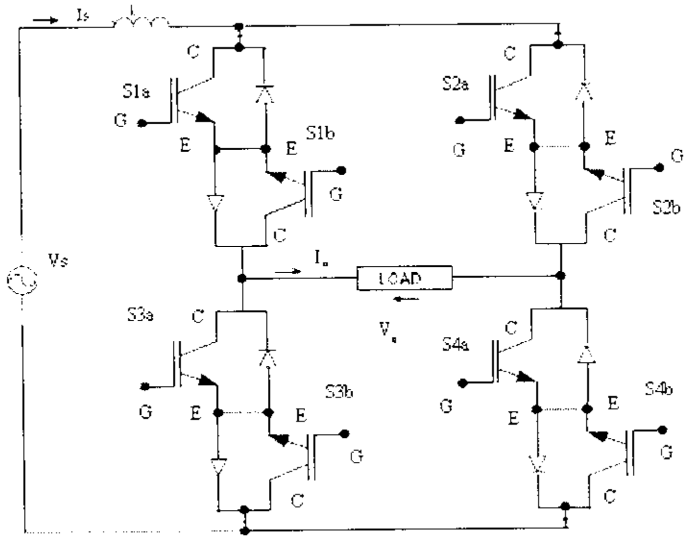


Figure.2.1 Boost Rectifier Using SPMC Topology

A Boost rectifier using single-phase matrix converter topology is presented that could synthesize a greater DC output voltage from a given AC supply voltage. The basic SPMC topology will be reviewed based on controlled rectifier operation by suitable switching schemes. IGBTs are used as the main power switching device. Simple resistive load will initially be used, followed by inclusion of simple capacitor filter to remove ripples at the load. Subsequently the input side will be provided with an inductance that is used for boost rectifier operation .

The Single-phase matrix converter(SPMC) shown in Figure. 2.1 consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections. Each of the individual switch is capable of conducting current in both directions, whilst at the same time capable of blocking voltage .A single-phase controlled rectifier using SPMC which is derived from the PWM switching as shown in Figure 2.3 according to the switching algorithm as shown in Figure.2.2.

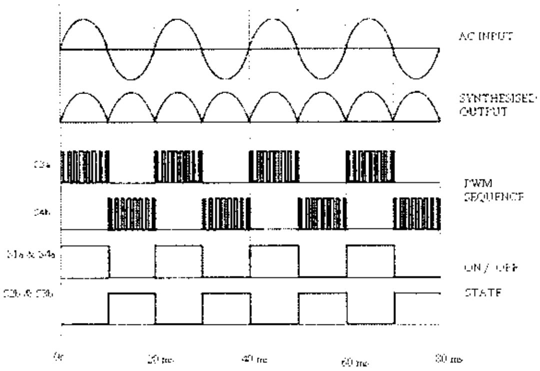


Figure. 2.2: Switching Algorithm For Boost Rectifier

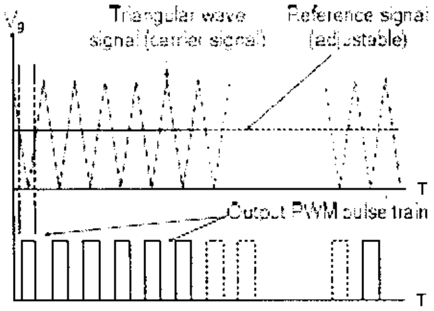


Figure.2.3: PWM Waveform

In the most straightforward implementation, generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high-frequency triangular ..carrier" wave .Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies of an close to the carrier frequency. Notice that the root mean square value of the ac voltage waveform is still equal to the dc bus voltage, and hence the total harmonic distortion is not affected by the PWM process. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system.

For boost rectifier operation; the pair of switches S1a & S4a are turn into 'on' state whilst switch S3a implements 'PWM' control for inductor charging/discharging for positive cycle operation. For negative cycle operation, the pair of switches S3b & S2b are turn into 'on' state, whilst switch S4b provides control using PWM. The boost inductor *L* is connected in the ac side . For this work, the switching frequency of 1 kHz is used to generate the PWM signal to control the switches S3aand S4b for boost operation which is shown in Figure 2.4 & 2.5

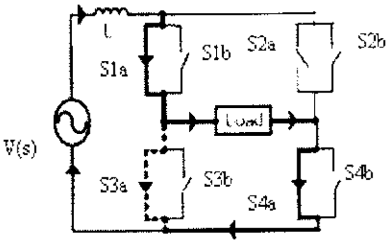


Figure.2.4: Positive State

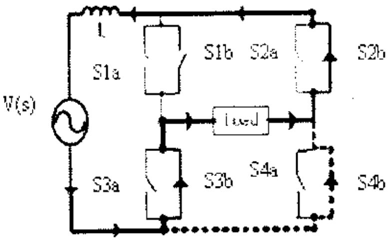


Figure. 2.5: Negative State

Figure 2.6,2.7,2.8 & 2.9 illustrate the different modes of operation of boost rectifier following the switching scheme as tabulated in Table 2.

Mode	ON'	PWM
positive cycle	S1a & S4a	S3a
negative cycle	S3b & S2b	S4b

Table 2 Switching State For Boost Rectifier Operation

The Mode 1 begins when S1a and S3a is turn ON. At t=0 the charging operation is carried out. The input current, which rises, flows through the inductor L. Thus the energy will be stored in inductor L. If the pulse width of the gate pulse to the switch S3a is increased by increasing the modulation index the inductor will charge for more time .

The Mode 2 begins when switch S1a and S4a is turn into 'on' at t = t1 whilst S3a is turn into 'off' (discharging operation). The current that was flowing through the switches S3a would now flow through the load. The inductor current falls until switch S3a is turned on again in the next state. The energy stored in inductor L is transferred to the load.

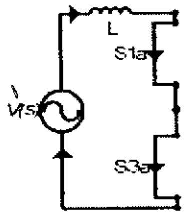


Figure 2.6 Mode 1

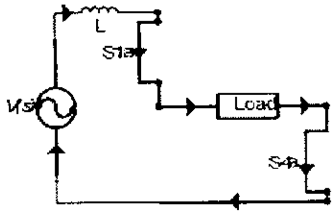


Figure 2.7 Mode 2

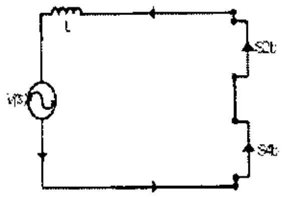


Figure 2.8 Mode 3

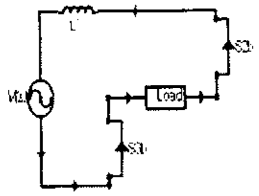


Figure 2.9 Mode 4

2.2. ANALYSIS OF THE PROPOSED BOOST RECTIFIER

In a boost regulator the output voltage is greater than the input voltage . The proposed operation can be divided into two modes. Mode 1 begins when S1a and S3a is turn into 'on' at t=0 (charging operation). The input current, which rises, flows through the inductor L. Mode 2 begins when switch S1a and S4a is turn into 'on' at t = t1 whilst S3a is turn into 'off' (discharging operation). The current that was flowing through the switches S3a would now flow through the load. The inductor current falls until switch S3a is turned on again in the next state. The energy stored in inductor L is transferred to the load. Mode 3 and 4 shows similar operation during negative cycle. The equivalent circuits for the modes of operation are shown in Figure.2.6 & 2.7 for positive cycle operation and Figure 2.8 & 2.9 for negative cycle. For the continuous load current, assumptions are made that the current rises or falls linearly. Hence, when the inductor current rises from I1 to I2 in time t1,

For the continuous load current, assumptions are made that the current rises or falls linearly. Hence, when the inductor current rises from I1 to I2 in time t1,

$$Vs = L\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1} \quad or \quad t_1 = \frac{\Delta IL}{V_s} \tag{1}$$

And inductor current falls linearly from I2 to I1 in time t2,

$$\mathrm{Vs} - V_{out} = -L\frac{\Delta I}{t_2} \quad \mathrm{or} \quad t_2 = \frac{\Delta IL}{V_s - V_{out}} \tag{2}$$

Where $\Delta I = I_2 - I_1$ the peak-to-peak is ripple current of inductor L. From equations (1) and (2)

$$\Delta I = \frac{V_s t_1}{L} = \frac{(V_{out} - V_s)t_2}{L} \tag{3}$$

Substituting t1 = kT and t2 = (1-k)T yields the average output voltage.

$$\mathrm{V_{out}} = \mathrm{V_s}\frac{T}{t_2} = \frac{Vs}{1-K} \tag{4}$$

Which give $$(1\text{-}K) = \frac{V_s}{V_{out}} \tag{5}$$

Substituting k = t1/T = t1f into equation (5) yields

$$t_1 \frac{V_{out} - V_s}{V_{out} f} \tag{6}$$

Assuming a lossless circuit $V_s I_s = V_{out} I_{out} = \frac{V_s I_{out}}{(1-K)}$ and the average input current is

$$\mathrm{I_s} = \frac{I_{out}}{1-K} \tag{7}$$

The switching period T can be found from

$$\mathrm{T} = \frac{1}{f} = \mathrm{t_1} + \mathrm{t_2} = \frac{\Delta IL}{V_s} + \frac{\Delta IL}{V_{out} - V_s} = \frac{\Delta IL V_{out}}{V_s(V_{out} - V_s)}$$

And this gives the peak-to-peak ripple current:

$$\Delta I = \frac{V_s (V_{out} - V_s)}{f L V_{out}} \qquad (8)$$

$$\Delta I = \frac{V_s K}{f L} \qquad (9)$$

2.3 SIMULATION OF THE BOOST RECTIFIER USING MATLAB 7.0.4

2.3.1 METHODOLOGY

The proposed control concept is verified through simulation using MATLAB/Simulink as shown in Figure.2.10. For simulation implementation, Sim power system in MATLAB (MLS) is used to model and simulate the circuit. The supply voltage of 30 Vp-p and boost inductor value of 1mH was used in the simulation.

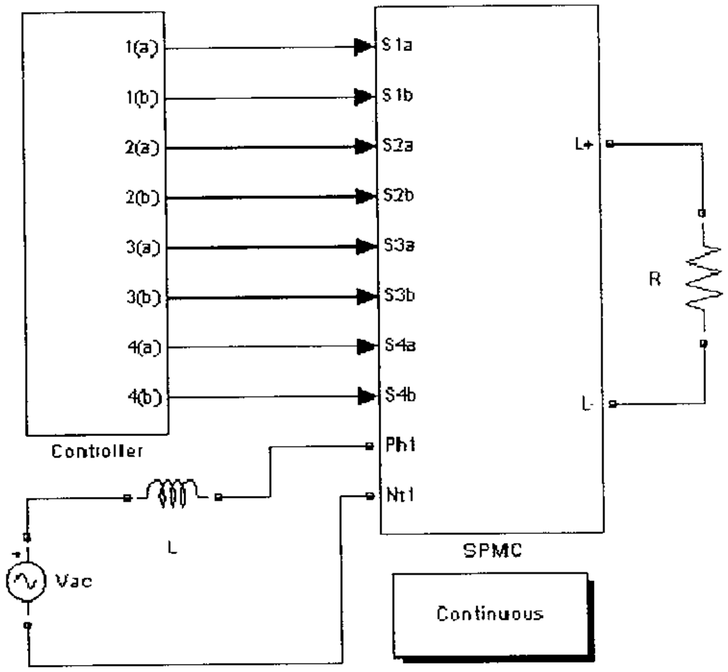


Figure.2.10 The MATLAB/SIMULINK Model Of The BOOST RECTIFIER

2.3.2 THE CONTROLLER CIRCUIT

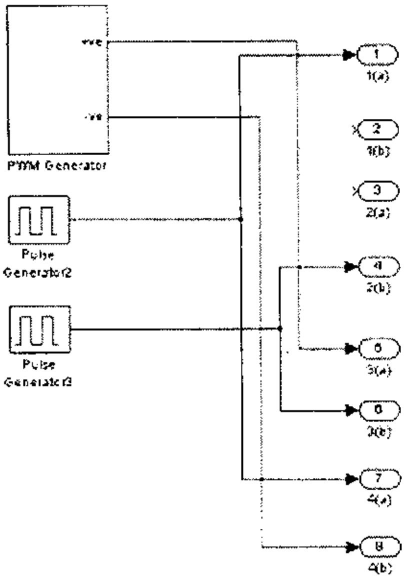


Figure.2.11 Boost Controller

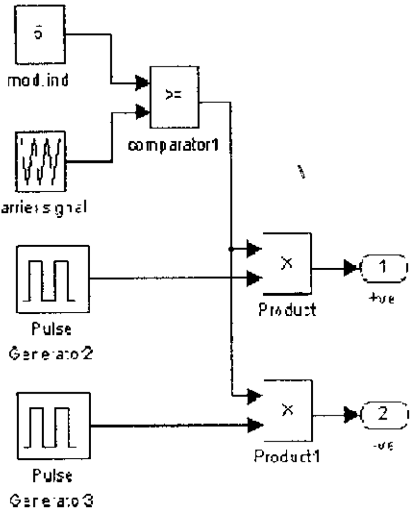


Figure.2.12 PWM Generator

The normal rectification operation of SPMC is carried out with switches S1a and S4b for positive cycle and switches S3b and S2b for negative cycle. The Figure 2.11 shows the control circuit. For rectification operation. Pulse generators provide gate pulses for both cycles. The Figure 2.12 shows the pwm pulse generation circuit for the redundant switches S3a and S4b.

When the modulating signal of amplitude Am, and the amplitude of the triangular carrier is Ac, the ratio m=Am/Ac is known as the modulation index. Note that controlling the modulation index therefore controls the amplitude of the applied output voltage. With a sufficiently high carrier frequency, the high frequency components do not propagate significantly in the ac network (or load) due the presence of the inductive elements. However, a higher carrier frequency does result in a larger number of switching per cycle and hence in an increased power loss. Typically switching frequencies in the 2-15 kHz range are considered adequate for power systems applications. Also in three-phase systems it is advisable to use so that all three waveforms are symmetric.

The pulse width is controlled and by these pwm pulses the boost operation of the SPMC is carried out. Here the modulation index is compared with carrier signal of 1 kHz in a comparator. The output of comparator and pulse generator 2 with time period 0.2 sec is given to the block product . The output of the product block is given to the gate of redundant switch S3a.

The output of comparator and pulse generator 3 with time period 0.2 sec and phase delay 0.01 is given to the block product. This output is given to the gate of redundant switch S4b.As the modulation index is increased the width of the pulses will be increased. As the width of pulses increases the conduction time increases. So the boost inductor will store charge for more time and hence the charge given to load will be also increased. Thus the modulation index increases the output voltage also gets increased.Modulation Index (M) is the ratio of amplitude of reference sine wave to the triangular carrier wave. RMS value of output voltage can be improved by varying M.

The switching frequency of 10 kHz was used to investigate the characteristics of boost converter changing the modulation index for 0.3, 0.5 and 0.8. The Load of Resistive value 300Ω is connected to the circuit.

2.4 SIMULATION RESULTS

The operation of the base paper system is evaluated by computer simulation using MATLAB/SIMULINK. The base paper system is simulated with various values of modulation indices. The variation of Output Voltage with Modulation index are noted. The output waveform are shown in figures 2.14 to 2.16.

The Matrix converter is connected across the supply mains. When the supply is ON the switches S1 and S4 are turned ON to work the circuit in the rectifier mode alternate sequence. This boost-charging strategy involves fast switching action of the switching devices which are piloted by Pulse Width Modulation (PWM) technique. All of these switching actions are carried out in the current control loop (CCL). Since instantaneous switching actions is required of the SPMC to make the supply current follows the sinusoidal reference current closely, the current control loop time response has to be fast. In the simulation works an operating switching frequency of 10 KHz is used.

The supply Voltage of 30 V p-p is given to SPMC as shown in Figure 2.13.The pulses are generated by varying modulation index and the results are investigated. By varying the modulation index the output voltage is also varied. As the modulation index is increased the output voltage is also increased.

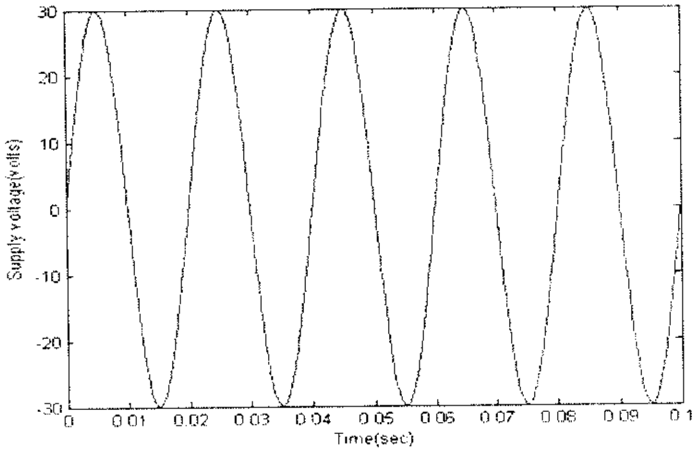


Figure.2.13 Supply Voltage

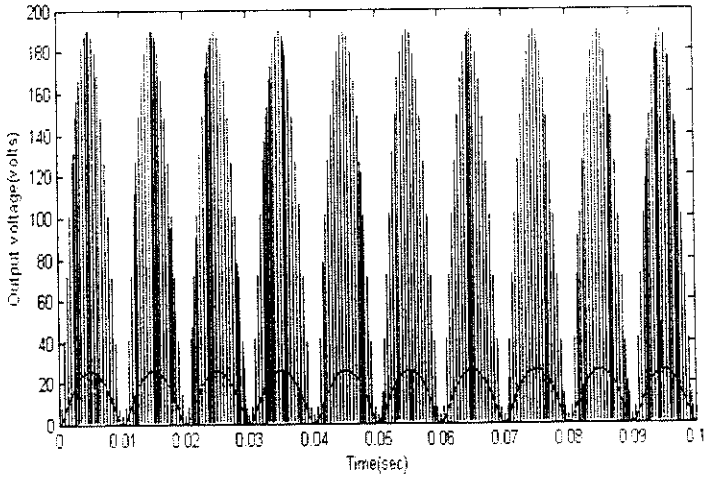


Figure.2.14 Output Voltage With Ma=0.5

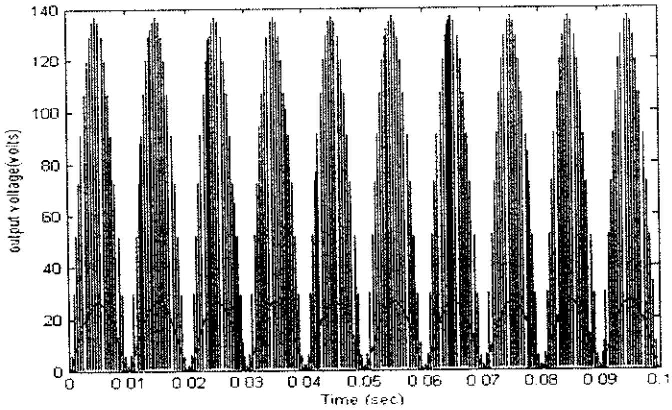


Figure.2.15 Output Voltage With Ma=0.3

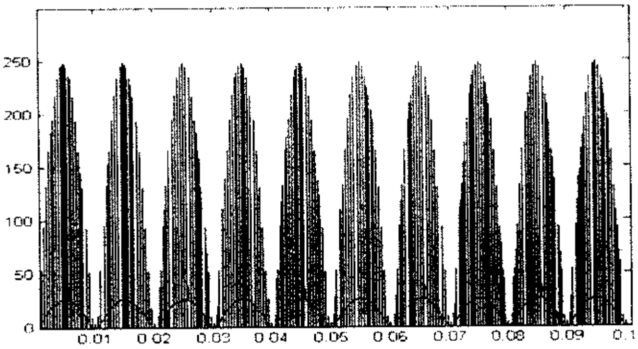


Figure.2.16 Output Voltage With Ma=0.8

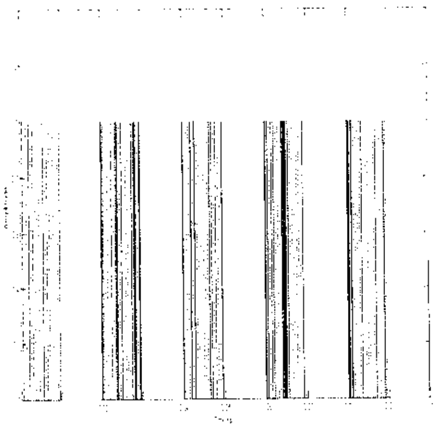


Figure.2.17 PWM2 PULSES (S3a)

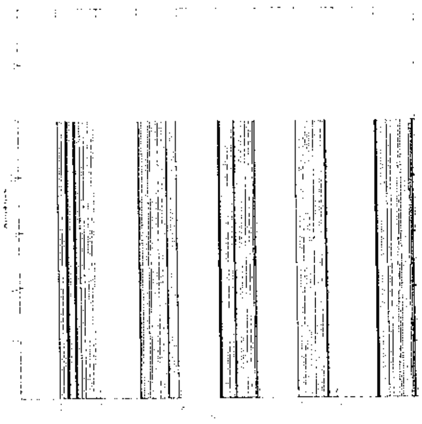


Figure.2.18: PWM1 PULSES (S4b)

2.5 CONCLUSION

The simulation is done for various values of modulation indices It is clearly shown that the high frequency will result in higher output voltage which means that the use of high modulation index will achieve maximum output voltage. At modulation index of 0.3, the output voltage achieve is up to 137 V p-p for 1 kHz switching frequency .At modulation index of 0.5, the output voltage achieve is up to 190 V p-p for 1 kHz switching frequency .At modulation index of 0.8, the output voltage achieve is up to 250 V p-p for 1 kHz switching frequency .The PWM pulses for the redundant switches are shown in Figure 2.16 and 2.17.

CHAPTER 3

3. SPMC INCORPORATING APF FUNCTION

Due to the intensive use of power converter and other non-linear load in industry and by consumers in general it can be observed an increasing deterioration of the power systems. Active filter is needed to eliminate all the unwanted harmonics. The Single Phase Matrix Converter topology that will operate with an active power filter function is presented. The APWM pulses are given to the two redundant switches in order to make input current sinusoidal.

3.1 ACTIVE POWER FILTER FUNCTION

Classical rectifier with DC capacitor filter has a setback in that it draws discontinuous supply current waveform with high harmonics content. As a result it contributes to high total harmonic distortion (THD) level and low total effective supply power factor affecting the quality of the power supply system. A series active power filter (SAPF) arrangement was proposed to suppress the harmonic current drawn by rectifier with a capacitor-filtered load (typical case: motor driver) .

A linear load is an electrical device that is characterized by a uniform rise and drop in current and voltage when connected in circuit. For example steady pattern can be observed when the device is operating in a circuit.

Examples of non-linear load are

- Resistance heating
- Incandescent lamp
- Unsaturated reactor

A non-linear load is a load whose impedance various within each cycle and draws current disproportional to the supply voltage. At each and every point of the waveform, the load impedance varies resulting into higher or lower current then it should be. This makes load current to be non sinusoidal, resulting in to harmonics creation or distortion

Examples of non-linear load are

- UPS
- Variable frequency drives
- Thyristor Rectifier

Modulation Index (M) is the ratio of amplitude of reference sine wave to the triangular carrier wave. RMS value of output voltage can be improved by varying M. The total harmonic distortion (THD) can be varied by varying the carrier frequency. The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Lesser THD allows the components in a loudspeaker, amplifier or microphone or other equipment to produce a more accurate reproduction by reducing harmonics added by electronics and audio media. A THD rating < 1% is considered to be in high-fidelity and inaudible to the human ear. When the input is a pure sine wave, the measurement is most commonly the ratio of the sum of the powers of all higher harmonic frequencies to the power at the first harmonic, or fundamental, frequency:

$$\mathrm{THD} = \frac{P_2 + P_3 + P_4 + \cdots + P_\infty}{P_1} = \frac{\sum_{n=2}^{\infty} P_n}{P_1}$$

Using SPMC it has been shown that it is possible to develop a control rectifier incorporated with active power filter function for maintaining a sinusoidal input current through proper control. This is done by injecting compensation current to the system, in order to improve the supply current waveform to a form that is continuous, sinusoidal and in phase with the supply voltage and hence to near unity power factor corrected input irrespective of the load behaviour. The block diagram of the APF function is as shown in Figure 3.1. This is achieved through implementation of boost inductance in series with suitable control algorithm.

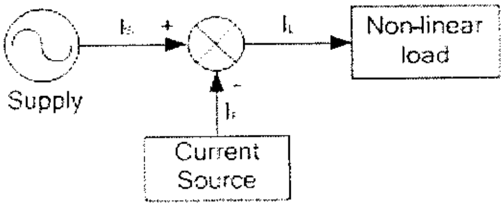


Figure 3.1. Block Diagram Of Active Power Filter Function

The following equations are represents of principle,

$$I_L = I_C + I_H \qquad (3.1)$$

$$I_F = -I_H \qquad (3.2)$$

$$I_S = I_L + I_F = (I_C + I_H) + (-I_H) = I_C \qquad (3.3)$$

Where,

I_S = Source Current

I_L = Load Current

Ic = Fundamental Current

I_H = Current Harmonics

I_F = Compensation Current

The equation (3.1) represents as the non-linear load current. It's the combination of fundamental and harmonic current so the non-linear load current obtains the distortion of the fundamental current. This distortion affects the source current. So we need to reduce the distortion of source current use the compensation current. (3.3) represent as obtain the fundamental current using the compensation current

3.2 CIRCUIT CONFIGURATIONS

The proposed controlled rectifier with active power filter function using SPMC is as shown in Figure 3.2. divided into three major components; a) SPMC circuit and b) boost inductor and c) control function. In this work, the non-linear load was represented by the use of a resistor and a shunt capacitor. Control electronics was used to generate active pulse width modulation (APWM) using boost technique that is piloted by a current control loop (CCL) as shown in Figure 3.9 to provide compensation algorithm.

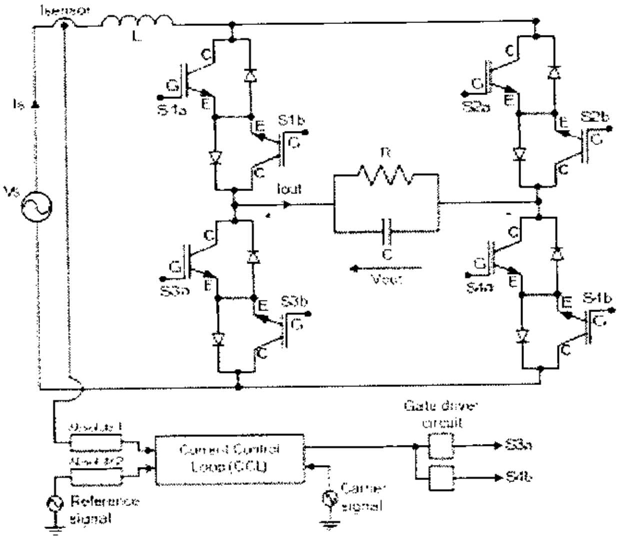


Figure3.2 SPMC With Current Control Loop

3.3 PRINCIPLES OF OPERATION

Implementation of active power filter function in this proposed work is to force the supply current to follow the reference current (desired signal). Based on the proposed APWM control scheme, the rectifier is controlled to have a sinusoidal line current with high power factor. A comparator is used to compare the carrier signal with the output of proportional integral (PI) signal (modulating signal) in the inner current control loop to track line current and improve the response due to load change. motor driver) . For current wave shaping operation, energy is initially stored by the inductor by turning "ON" switches S1a and S3a during positive cycle whilst S3b and S3b during negative cycle as shown in Figure 3.3 and 3.4 respectively. This is then followed by charging up the capacitor by turning "ON" the switches of S1 a and S4a during positive cycle whilst S3b and S2b for the negative cycle as shown in Figure 3.5 and 3.6. This boost-charging strategy involves fast switching action of the switching devices which are piloted by current control loop.

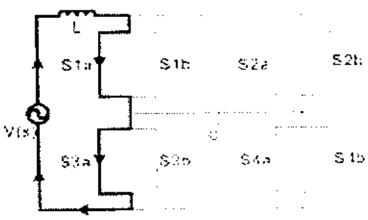


Figure 3.3 Positive Cycle (State1)

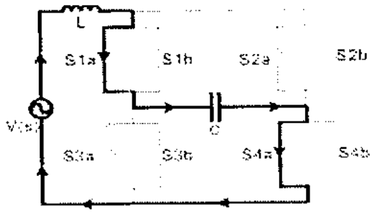


Figure 3.4 Positive Cycle (State 2)

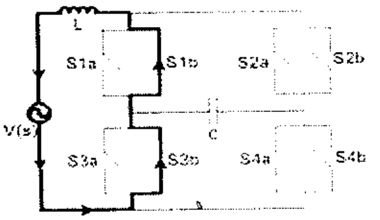


Figure 3.5 Negative Cycle (State 3)

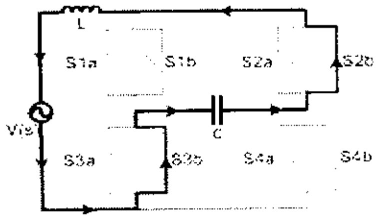


Figure 3.6 Negative Cycle(State 4)

The boost-charging strategy is shown in Figure 3.7 involves fast switching action of the switching devices which are piloted by pulse width modulation (PWM) Technique that are carried out in the current control loop (CCL). Since instantaneous switching action is required from the SPMC to make the supply current follow the sinusoidal reference current closely, the current control loop response time must be fast. By increasing the amplitude of supply current the average DC capacitor voltage can be increased to a higher value. Furthermore if the amplitude of the supply current is reduced average DC capacitor voltage will also be reduced. capacitor voltage will also be reduced. This shows that average DC capacitor voltage is directly proportional to the amplitude of the mains current. Therefore, correct amplitude of the mains current and average DC capacitor value can be manipulated so that the power delivered is equal to the power absorb by the load and switching losses whilst maintaining constant DC capacitor voltage.

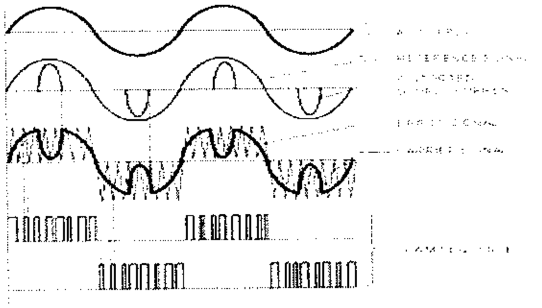


Figure 3.7 Switching Pattern

In this proposed method during the positive cycle operation, the current flows through switches S1a and S3a, the inductor stores enough energy in such a way that it increases the value of supply current above the value of the reference current; whilst during current flow through switches S1a and S4a pair, the capacitor C is connected to the line circuit in such a way that its voltage brings about a drop in the supply current below reference value; a capacitor charging operation as illustrated in Figure 3.8. During the negative cycle, the pair of switches S4b and S2b is used for charging the inductor whilst the pair of switches S3b and S2b for discharging operation.

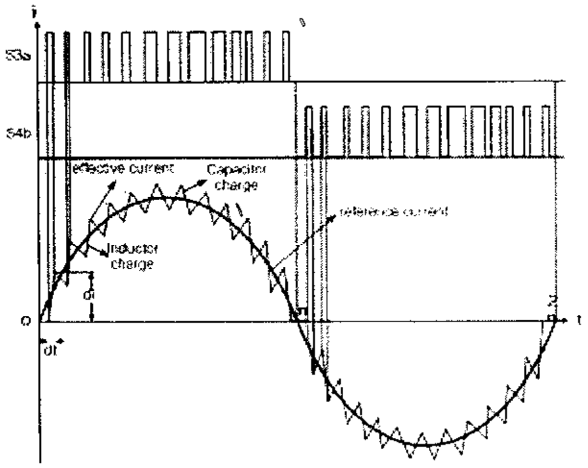


Figure 3.8. Filter Power Unit Function

3.4 THE CURRENT CONTROL LOOP (CCL)

The current control loop (CCL) is to provide control to the system by monitoring the supply current waveform and making corrections by current compensation techniques. It functions to detect the supply current waveform and subtract it from the reference current. The resultant error represents the modulation signal that is used to control the charging and discharging of the inductor as a current source for compensations. The CCL used in this work (Figure 3.9) is divided into three elements; a) Subtractor, b) Proportional Integral (PI) controller and c) PWM generator. A comparator is used to compare the carrier signal with the output of proportional integral (PI) signal (modulating signal) in the inner current control loop to track line current and improve the response due to load change.

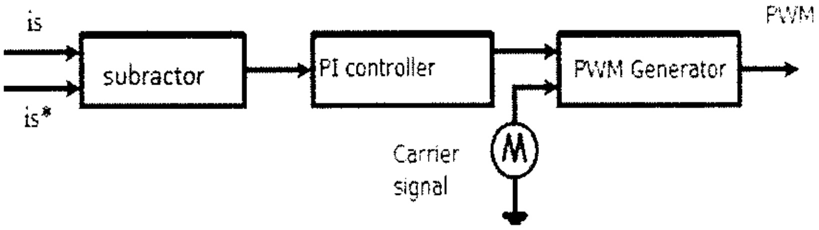


Figure 3.9 Block Diagram Of Current Control Loop (CCL)

CHAPTER 4

4. SIMULATION OF THE SPMC USING MATLAB 7.0.4

4.1 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 modelling and simulation of the proposed system is done using MATLAB(using simulink and power system block set tool boxes).

SIMULINK

Simulink is a software package for modelling, 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.

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 modelling 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

4.2 THE OVERALL SYSTEM STRUCTURE

The MATLAB/SIMULINK based simulation model of the proposed system is shown in figure 4.1. Single phase supply is given to the SPMC. An R load is connected with a capacitor filter across it. The measurements are taken from the measurement block. The MOSFET switches are controlled by the controller block.

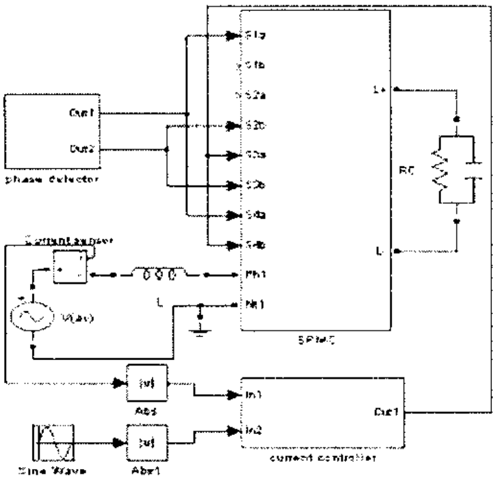


Figure.4.1 MATLAB/SIMULINK MODEL Of The SPMC

The investigations are carried out by the use of capacitor filtered load. Active power filter function is then incorporated to compensate the distorted supply current to become sinusoidal and in-phase with the supply voltage resulting with low total harmonics distortion (THD) affected from non-linear load. It is implemented using current controlled loop for active current wave shaping. The proposed rectifier was supplied by 30 V (pk-pk) voltage source; with a 300Ω pure resistive load and an output DC capacitor filter of 100 μF with switching frequency of up to 10 kHz as shown in figure 4.10.

4.3 CURRENT CONTROLLER

The modelling of current controller is shown in figure 4.2.The input current is sensed by a current sensor and is compared with a reference signal. The error signal is given to PI controller for stabilizing error signal. Then it is compared with the carrier signal and thus the APWM pulses are generated .These pulses are given to switches S3a and S4b.

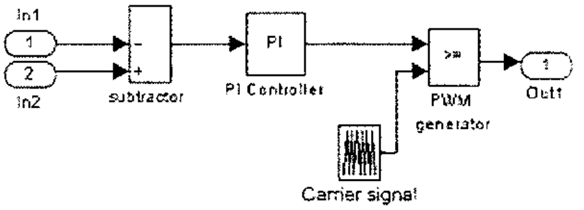


Figure. 4.2 Current Controller Model

The Matrix converter is connected across the supply mains. When the supply is ON the switches S1 and S4 are turned ON to work the circuit in the rectifier mode. This boost-charging strategy involves fast switching action of the switching devices which are piloted by Pulse Width Modulation (PWM) technique. All of these switching actions are carried out in the current control loop (CCL). Since instantaneous switching actions is required of the SPMC to make the supply current follows the sinusoidal reference current closely, the current control loop time response has to be fast. In the simulation works an operating switching frequency of 20 KHz is used.

4.4 SIMULATION RESULTS

Results of implementations of the proposed controlled rectifier with active power filter function are shown .The APWM pulses are given to make the input current sinusoidal and continuous. Here by simulating the SPMC with APWM a continuous ,sinusoidal and improved power factor is obtained. The output Voltage is boosted and is also with less ripples.

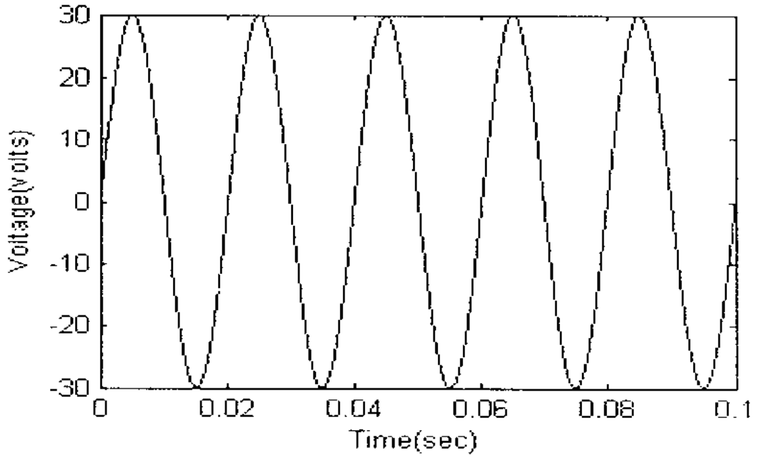


Figure 4.3 Supply Voltage

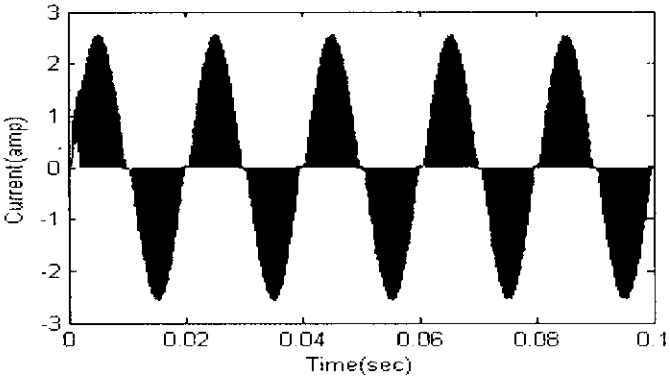


Figure.4.4 Supply Current With APWM

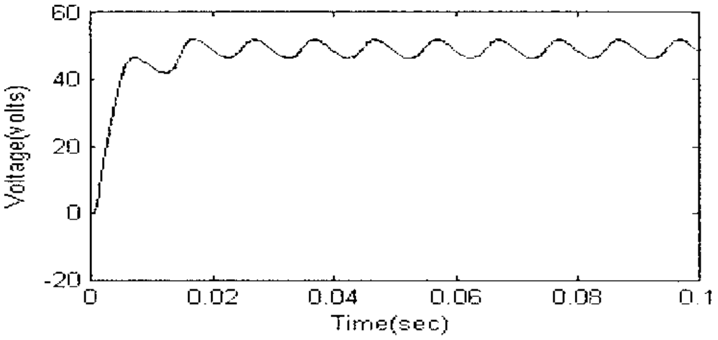


Figure.4.5 Output Voltage

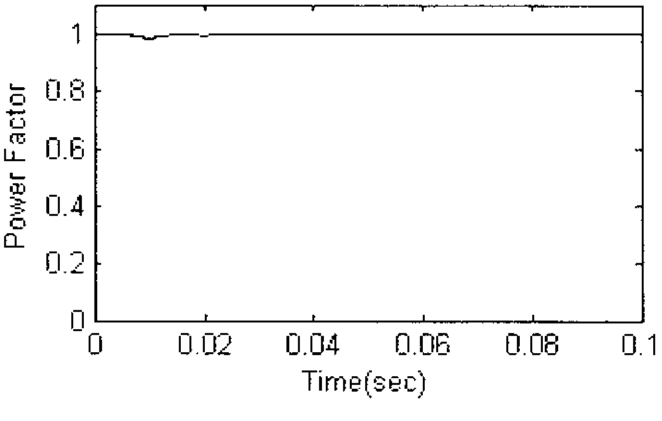


Figure.4.6 Power Factor With APWM

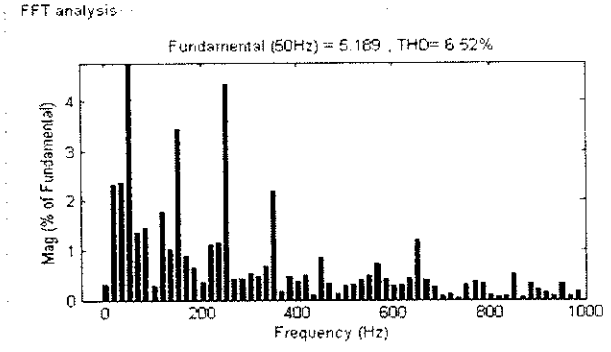
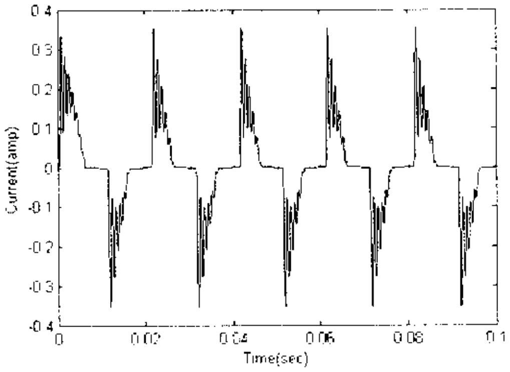


Figure.4.7 THD With APWM

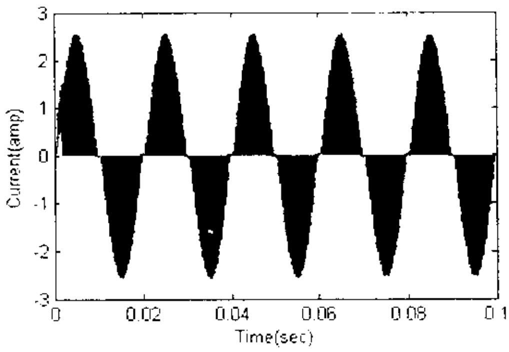
4.5 COMPARISON OF THE SIMULATION RESULTS

The comparison of results without APWM and with APWM are shown. The investigations on the output capacitor filter shows waveform of the supply current without compensation that is pulsating discontinuous and non-sinusoidal in nature . Implementation of compensation results in continuous and sinusoidal , where the supply current has shown significant improvements. The waveform is now continuous, sinusoidal and in-phase with the supply voltage The output voltage is boosted form 30V p-p to 50 V p-p and the ripples in the voltage has been reduced. In these studies it has been observed that the supply current has been improved from a THD of over 101% to a THD level of below 6.52% .APWM pulses improves with almost unity power factor compared to the input current without APWM.

4.5.1 COMPARISON OF SUPPLY CURRENT

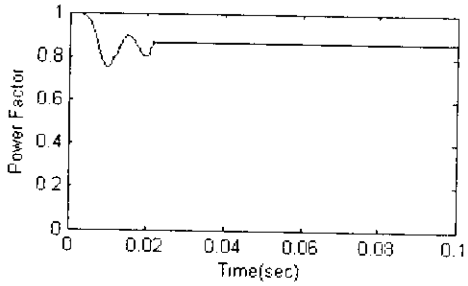


Supply Current Without APWM

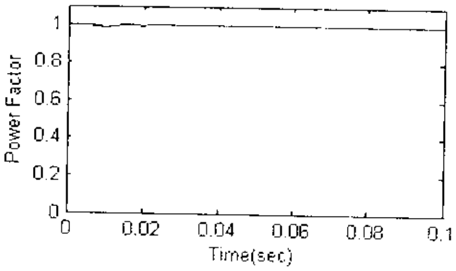


Supply Current With APWM

4.5.2 POWER FACTOR

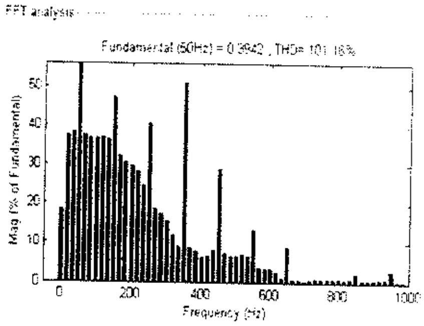


Power Factor Without APWM

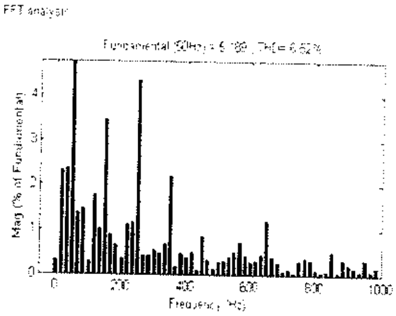


Power Factor With APWM

4.5.3 THD



THD Without APWM



THD With APWM

CHAPTER 5

5. HARDWARE MODEL OF SPMC WITH APF

5.1 HARDWARE BLOCK DIAGRAM

The block diagram of prototype model of SPMC with APF is shown in fig 5.1. It is designed to work in the rectifier mode when the supply is ON.

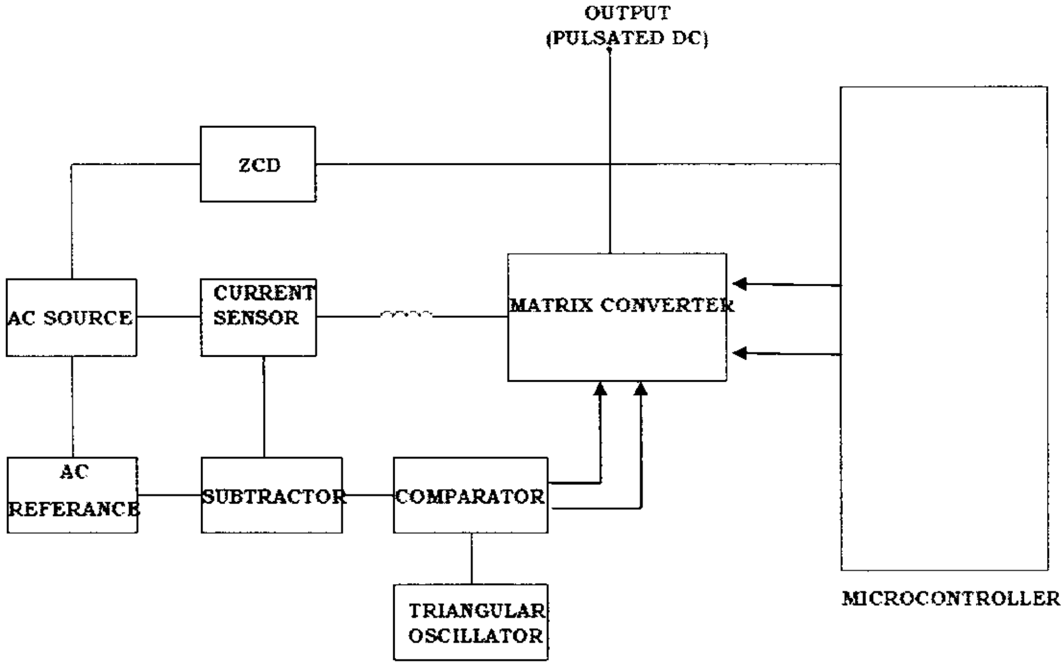


Figure.5.1 Hardware Block Diagram SPMC With APF

The entire system is divided into the following systems for the easiness of understanding.

- AC source
- Single Phase Matrix Converter.
- Zero Crossing Detector
- Current Sensor
- PIC 16f887
- Subtractor
- Comparator
- Triangular Oscillator

The Single phase supply is given to the Matrix converter. The load connected to the is matrix converter is capacitor filtered resistive load. Due to this capacitor filtered load the supply current drawn will be discontinuous. A current sensor is used to sense the input distorted current. The distorted input current is subtracted from a reference signal taken from the supply source. The error signal is then given to PI controller and is given to the comparator . The signal is compared with the carrier signal generated by Triangular oscillator. Thus the APWM pulses are generated. These pulses are given to S3a and S4b of matrix converter. The APWM pulses generated are controlled by analogue method. The pulses to the other switches are generated by PIC 16f887 with the detection of zero crossing of input supply by Zero crossing detector.

5.2 SCHEMATIC DIAGRAM

5.2.1 SCHEMATIC DIAGRAM OF SPMC

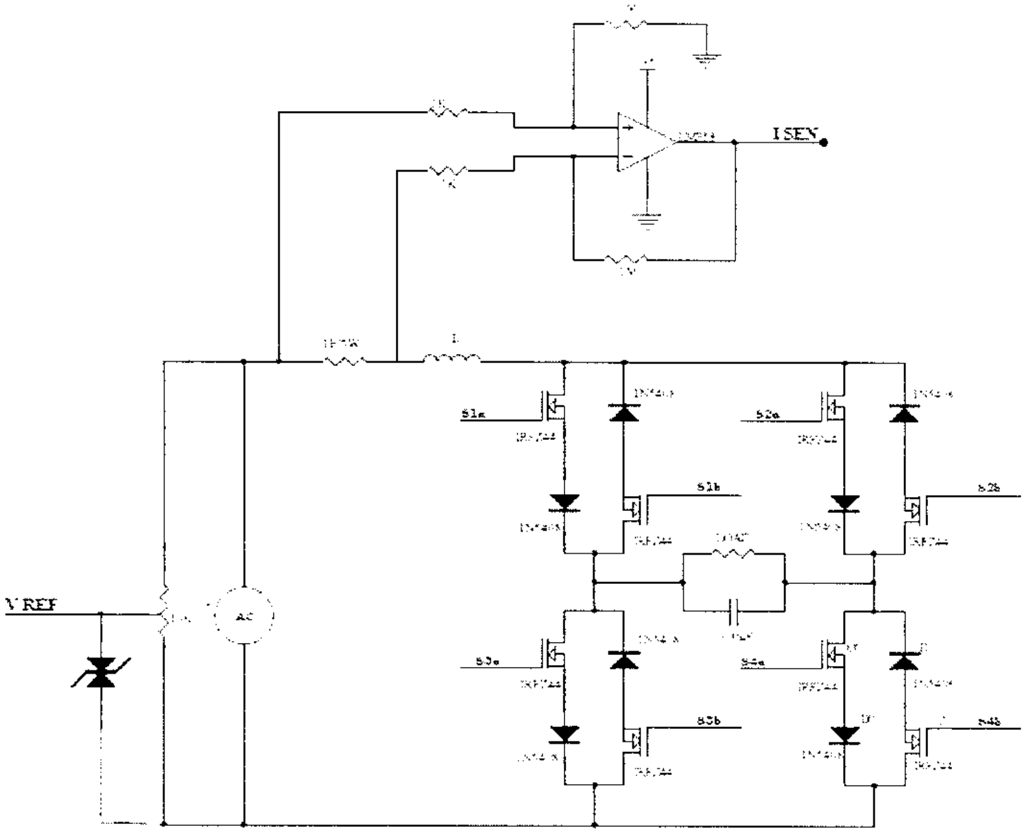


Figure.5.2 Schematic Diagram Of SPMC

The schematic diagram of SPMC is shown in Figure.5.2 with a capacitor filtered resistive load. The current is sensing from the supply by using the operational amplifier.

Then it is compared with the one reference signal which is in time phase with the supply voltage. The zener diode is connected across the supply to maintain the supply voltage as a constant value.

Advantages of MOSFET

- MOSFET provides much better system reliability.
- Driver circuitry is simpler and cheaper.
- MOSFET's fast switching speed permit much higher switching frequencies and thereby the efficiency are increased.
- Overload and peak current handling capacity is high
- MOSFETs have better temperature stability
- MOSFET's leakage current is low
- Drain-source conduction threshold voltage is absent which eliminates electrical noise.

5.2.2 SCHEMATIC DIAGRAM OF OPERATIONAL AMPLIFIRER

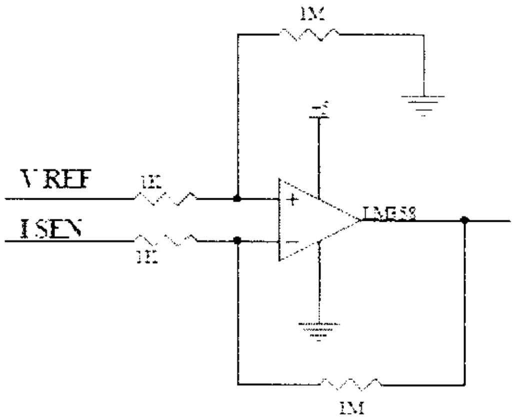


Figure.5.3 Schematic Diagram Of Operational Amplifier

Figur.5.3 shows the schematic diagram of operational amplifier. The sensed current from the supply is given to non-inverting terminal and the reference signal is given to inverting terminal. These two signals are compared with each other and we can generate the error signal .

5.2.3 SCHEMATIC DIAGRAM OF DUAL POWER SUPLLY UNIT

The rectifier block contains a step down transformer, which step downs the input voltage from 220V to 12V. In addition, the step downed voltage is rectified to DC. This is done by single phase matrix converter. The output of this block is 12V dc. Then this 12V dc is stepped down into 5V and is given to the PIC microcontroller.

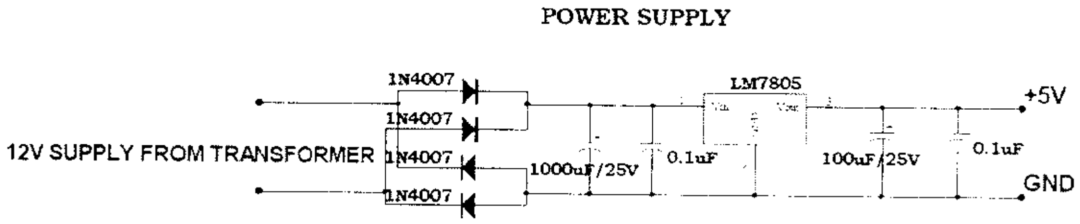


Figure.5.4 Schematic Of Dual Power Supply Unit

5.2.4 SHEMATIC OF CURRENT CONTROL LOOP

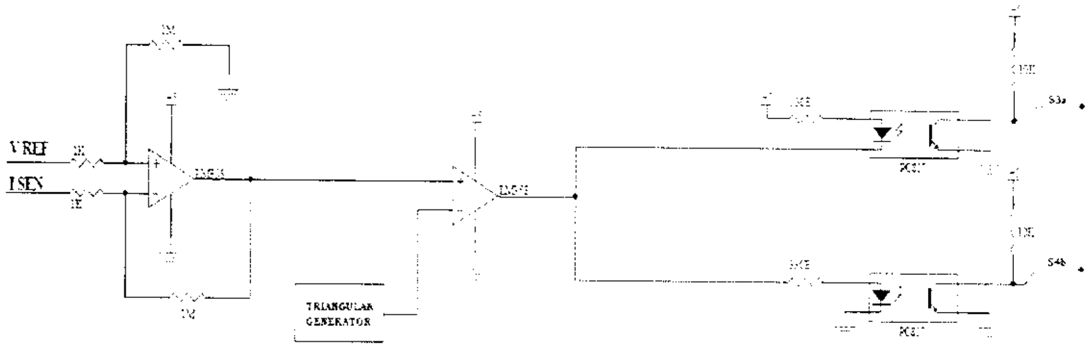


Figure.5.5 Schematic Of CCL

The schematic diagram of analogue controller is shown in figure.5.5.This controller is to generate APWM pulses. The APWM pulses are given to two switches S3a and S4b to make input current sinusoidal, continuous. A current sensor is used to sense the input distorted current. The distorted input current is subtracted from a reference signal taken from the supply source. The error signal is then given to PI controller and is given to the comparator . The signal is compared with the carrier signal generated by Triangular oscillator. Thus the APWM pulses are generated through analogue method.

5.2.5 SHEMATIC OF MICROCONTROLLER

The schematic diagram of PIC microcontroller is shown in figure.5.6. The gate pulse for the 6 switches of the matrix converter is generated by PIC16F887 controller. This micro controller circuit works in 5V power supply. So separate step down rectifier unit is made for the controller. The detail about PIC16F887 is given in APPENDIX I. This controller is isolated from the main circuits by means of opto-coupler.

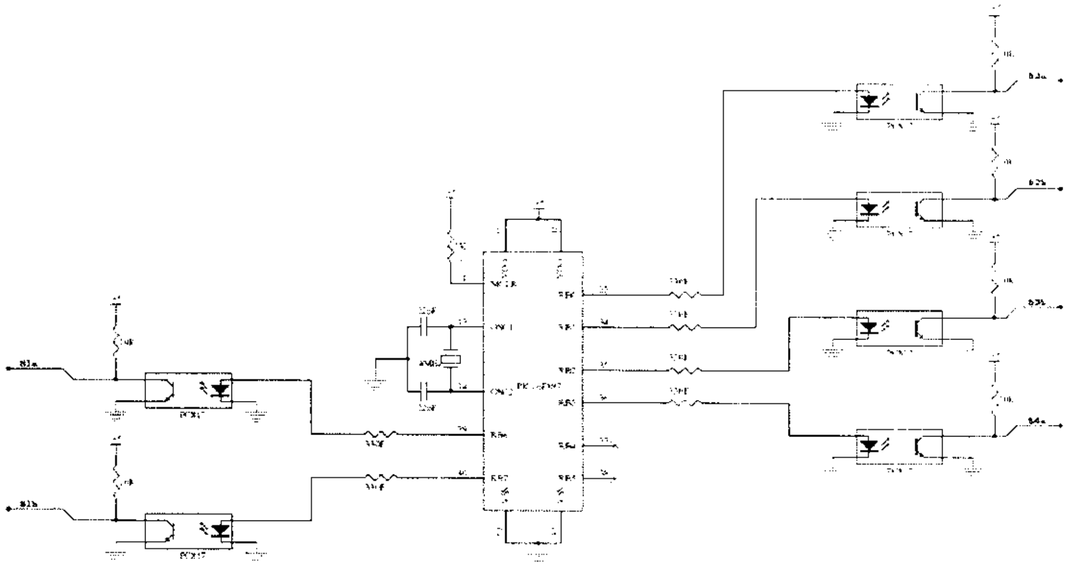


Figure.5.6 Schematic Diagram Of PIC 16F887

Features of PIC16F887

High-Performance RISC CPU

- Only 35 single word instructions to learn
- Operating speed: DC - 20MHz clock input.
- All single-cycle instructions except branches

Peripheral Features:

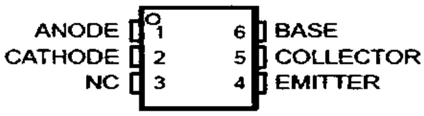
- 36 I/O pins
- High sink/source current 25 mA
- Interrupt-on-pin change option
- Two 8-bit timer/counter (TMR0, TMR2) with 8-bit programmable prescaler.
- Two Capture/Compare PWM (CCP) Module.

Special Micro controller Features

- Power-Saving Sleep mode
- Power-on Reset (POR)
- Selectable Brown-out Reset (BOR) voltage
- Extended Watchdog Timer (WDT) with its own on-chip RC oscillator for
    - reliable operation
- Master Synchronous Serial Port (MSSP)
- High-endurance Flash/EEPROM cell
- Self-reprogrammable under software control
- Programmable code protection.
- 10-bit 14 channel Analogue -to-Digital (A/D) Converter
- PWM output steering control.
- 368 bytes RAM memory
- 256 bytes EEPROM memory
- Analogue comparator module with
    - Two analogue comparators
    - Fixed voltage reference (0.6V)
    - Programmable on-chip voltage reference

Optocoupler:

Optocoupler is also termed as optoisolator. Optoisolator a device which contains a optical emitter, such as an LED, neon bulb, or incandescent bulb. and an optical receiving element, such as a resistor that changes resistance with variations in light intensity, or a transistor, diode, or other device that conducts differently when in the presence of light. These devices are used to isolate the control voltage from the **controlled** circuit.


MCT2 OR MCT2E . . . PACKAGE
(TOP VIEW)

NC – No internal connection

Figure.5.7 Optocoupler

- Gallium Arsenide Diode Infrared Source Optically Coupled to a Silicon npn Phototransistor
- High Direct-Current Transfer Ratio
- Base Lead Provided for Conventional Transistor Biasing
- High-Voltage Electrical Isolation . . .
- 1.5-kV, or 3.55-kV Rating
- Plastic Dual-In-Line Package

5.3 HARDWARE TESTING AND RESULT

The fabricated hardware model is as shown in fig.5.8. The input waveform of the matrix converter is shown in the figure 5.9. The control pulses for the Active filter operation is shown in figure 5.10 and thus the input current remain sinusoidal and continuous.

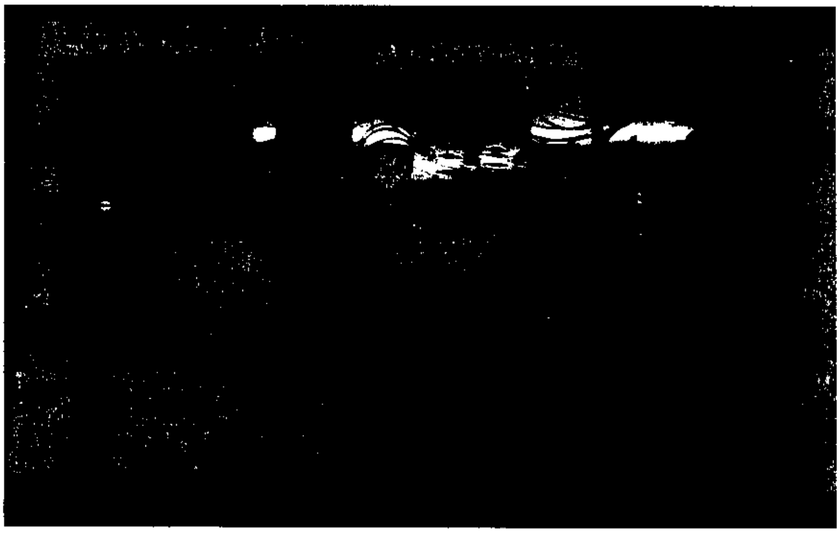


Figure.5.8 Prototype Photo

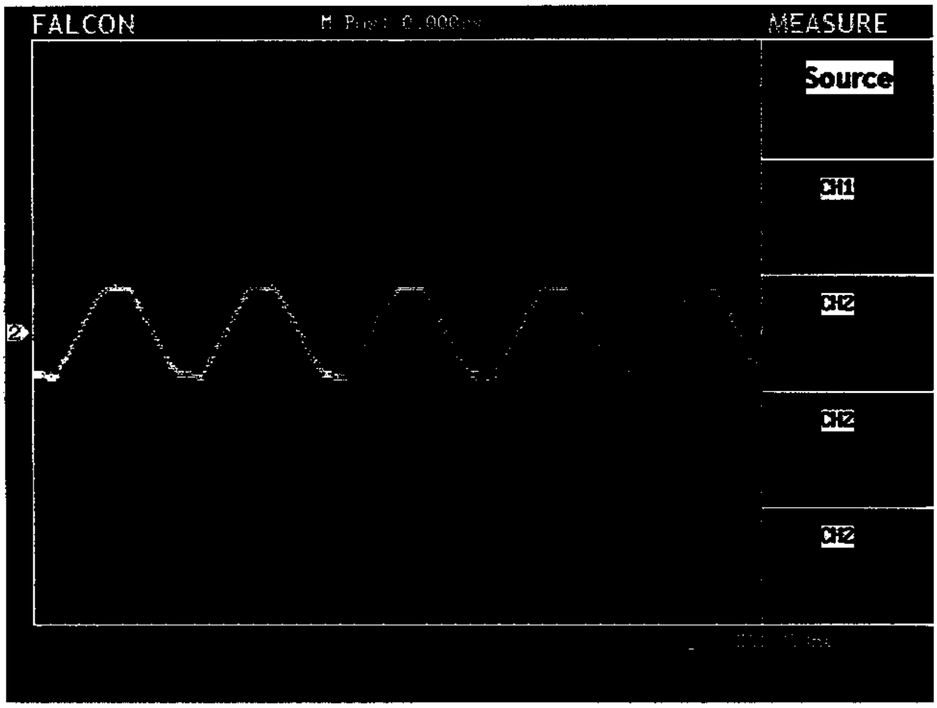


Figure.5.9 Supply Current Waveform

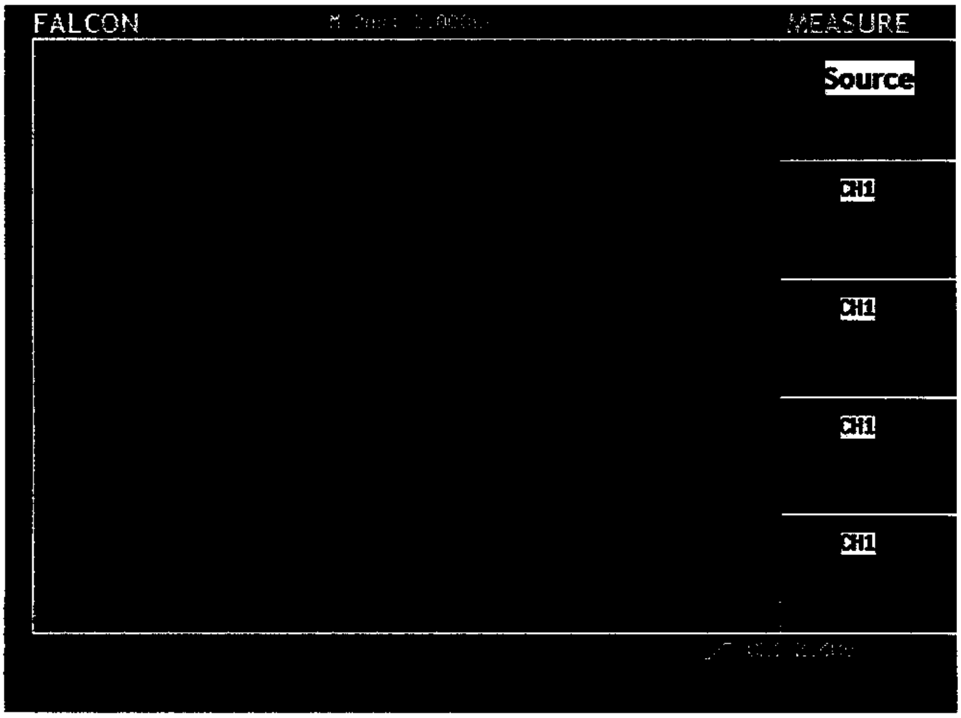


Figure.5.10 APWM Pulses

CHAPTER 6

6.CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

A single phase matrix converter topology as a boost rectifier has been studied and designed for non linear load condition. The supply current waveform for the RC load with active power filter function results with an almost sinusoidal and in-phase with the supply voltage. The APF function results in improved power factor and reduced THD level. The simulations results have been presented in the form of waveforms and tabulated data to verify the operation of the proposed rectifier. It is shown that the SPMC topology has inherent versatility extending beyond the direct AC-AC converter, DC chopper and rectifier operation. The behaviour and operation of the proposed structure was examined with the MATLAB/simulink. The same technique is implemented in hardware using PIC micro controller and the results are verified with the simulation results.

6.2 FUTURE SCOPE

Further advancement could be developed with switching control which has capabilities to eliminate spike that is commonly induced with the use of inductive load .

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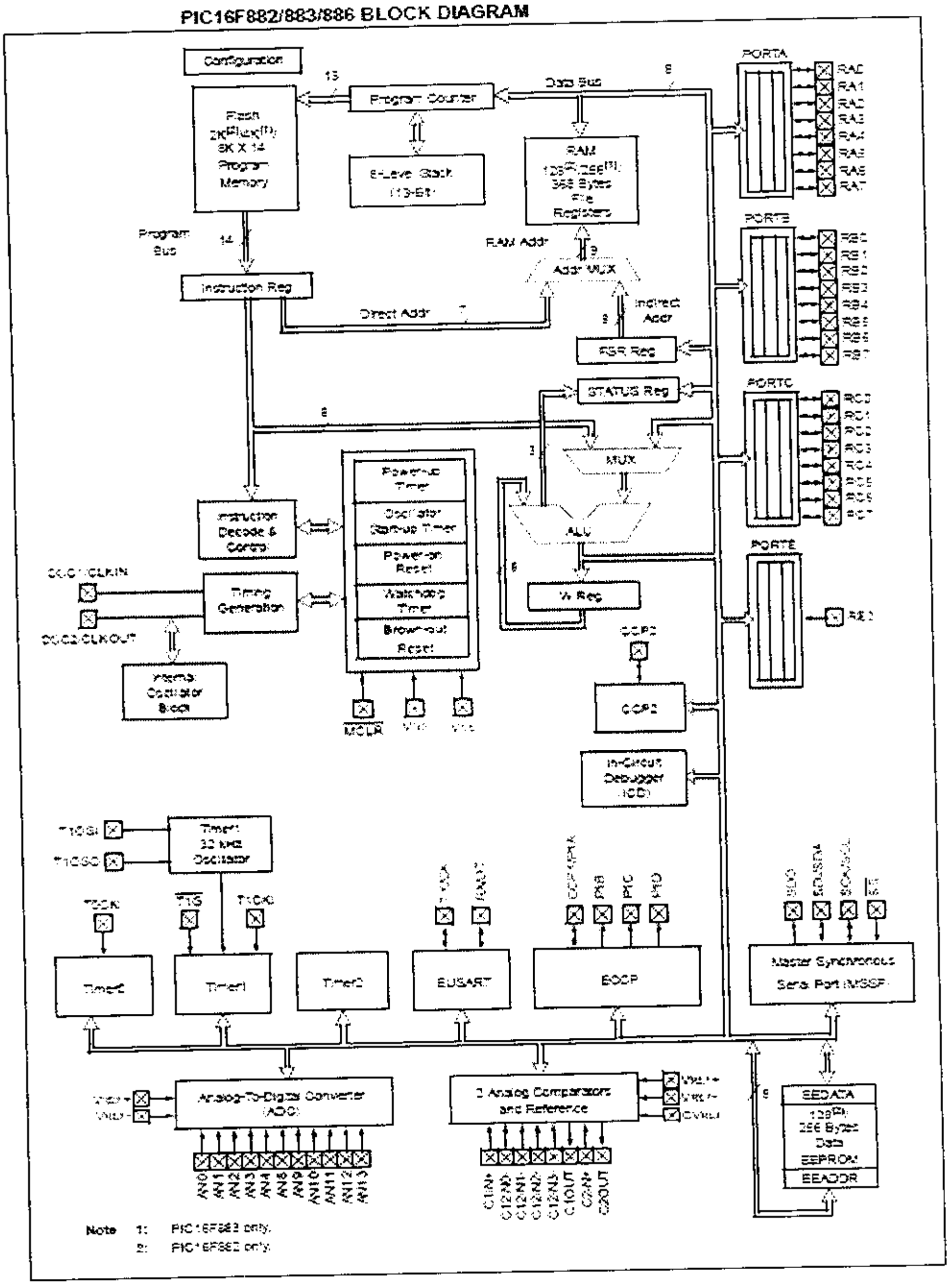
APPEDIX-I

ARCHITECTURE OF PIC 16F887

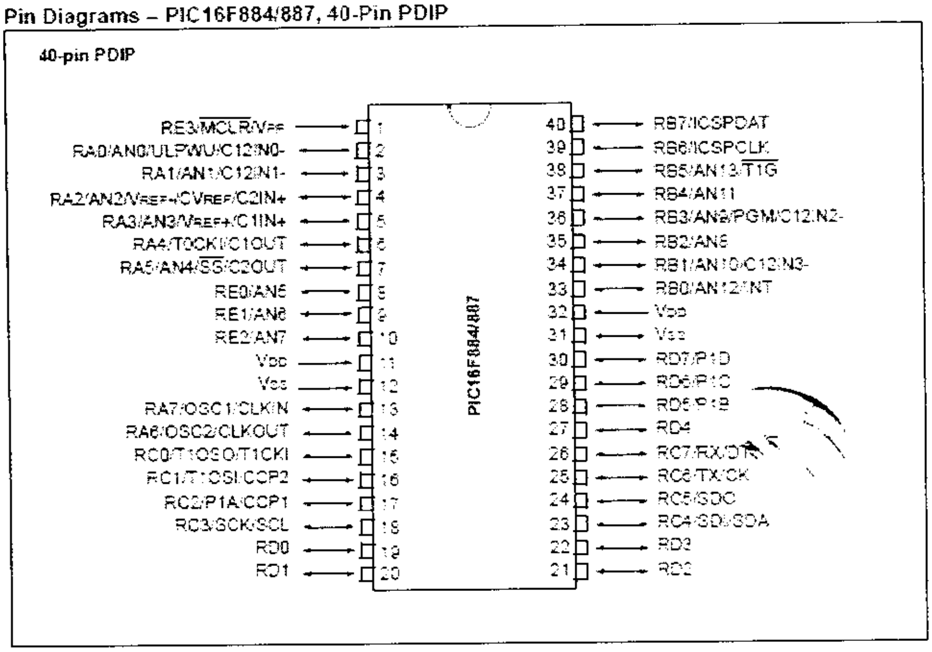
PIC16F882/883/886 BLOCK DIAGRAM



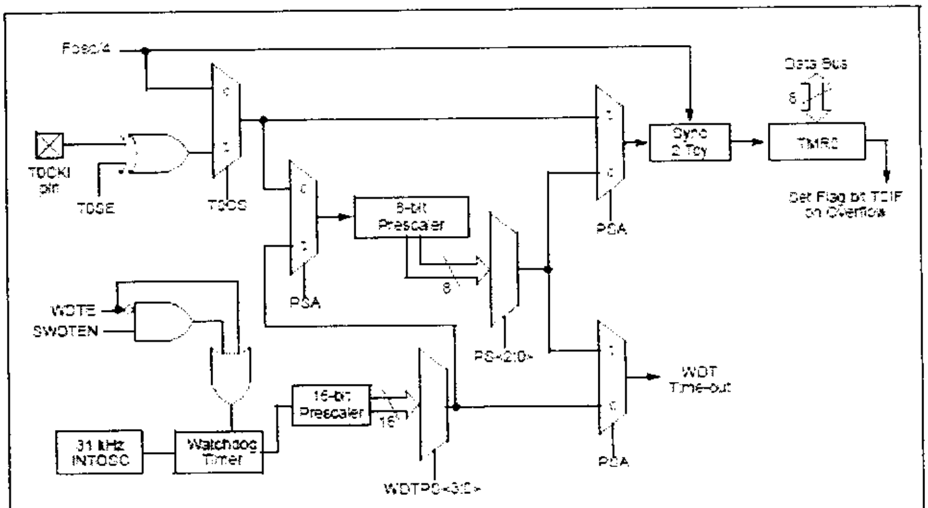
Note 1: PIC16F883 only.
2: PIC16F882 only.

Pin Configuration of PIC16F877A

Pin Diagrams – PIC16F884/887, 40-Pin PDIP



TIMERS 0 BLOCK DIAGRAM:

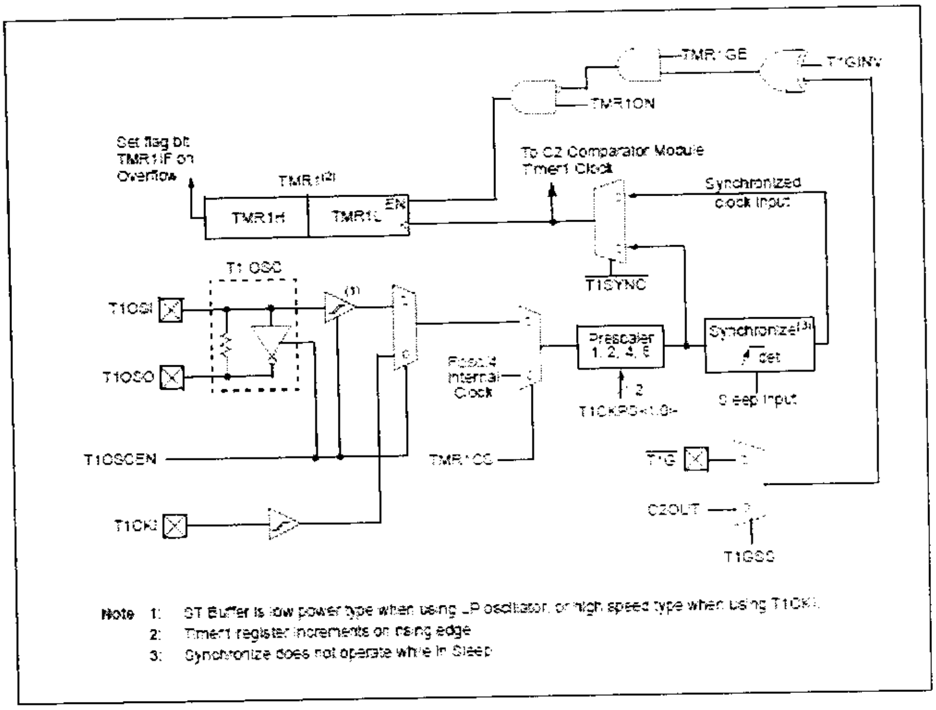


Note 1: T0SE, T0CS, PSA, PS<2:0> are bits in the OPTION register.

2: SWDTEN and WDTPS<3:0> are bits in the WDTCON register.

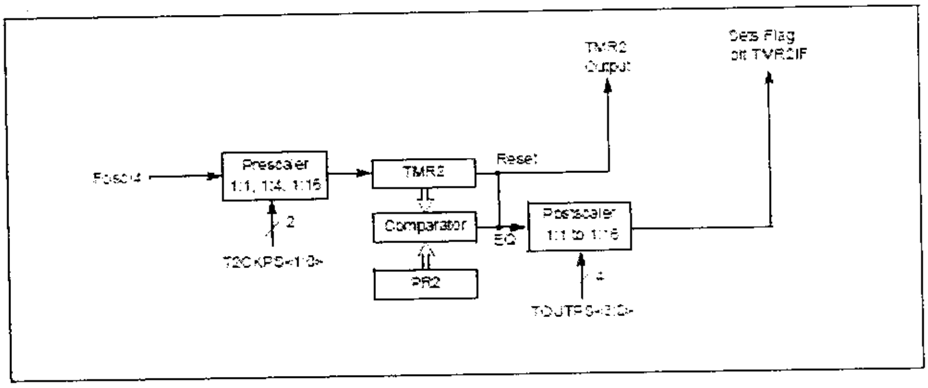
3: WDTE bit is in the Configuration Word Register1

TIMER 1 BLOCK DIAGRAM:

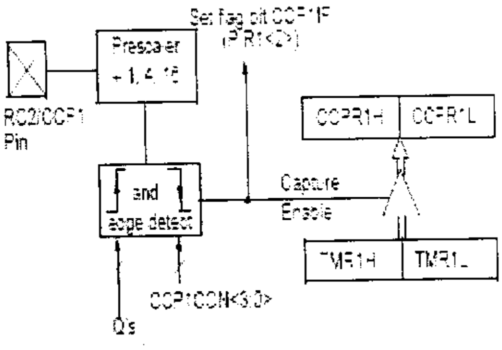


Note 1: ST Buffer is low power type when using LP oscillator, or high speed type when using T1CKI.
2: Timer1 register increments on rising edge.
3: Synchronize does not operate while in Sleep.

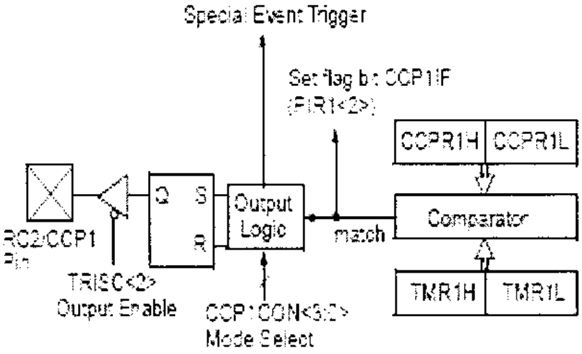
TIMER 1 BLOCK DIAGRAM:



CAPTURE MODE OPERATION BLOCK DIAGRAM:



COMPARE MODE OPERATION BLOCK DIAGRAM:



FEATURES OF PIC:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- Operating speed: DC - 20 MHz clock input
- Precision Internal Oscillator:
  - Factory calibrated to ±1%
  - Software selectable frequency range of
  - 8 MHz to 32 kHz
  - Software tuneable
  - Two-Speed Start-Up mode
  - Fail-safe clock monitoring for critical applications
  - Clock mode switching during operation for low-power operation

Power-Saving Sleep mode

- Power-on Reset (POR)
- Selectable Brown-out Reset (BOR) voltage
- Extended Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins
- High-endurance Flash/EEPROM cell:
  - 100,000 erase/write cycle enhanced Flash program memory, typical
  - 1,000,000 erase/write cycle data EEPROM memory, typical

  - Data EEPROM retention > 40 years

- Self-reprogrammable under software control
- Programmable code protection
- Peripheral Features:
- Timers:
  - TMR0: 8-bit timer/counter with 8-bit prescalar
  - TMR1 enhanced: 16-bit timer/counter with prescalar,
  - External Gate Input mode and dedicated low- power 32kHz oscillator
  - TMR2: 8-bit timer/counter with 8-bit period register, prescalar and postscalar
- Capture/Compare/PWM (CCP) module
- Enhanced Capture/Compare/PWM (ECCP) module with auto-shutdown and PWM steering
- Master Synchronous Serial Port (MSSP) module SPI™ mode. I2C™ mode with address mask capability
- Enhanced Universal Synchronous Asynchronous
  - Receiver Transmitter (EUSART) module:
  - Supports RS-485, RS-232 and LIN compatibility
  - Auto-Baud Detect
  - Auto-wake-up on Start bit
- Ultra Low-Power Wake-up (ULPWU)
- Analogue Features:
  - 10-bit 14 channel Analogue-to-Digital (A/D) Converter
- Analogue Comparator modules with:
  - Programmable on-chip Voltage Reference
  - (CVREF) module (% of VDD)
  - Fixed 0.6 V ref
  - Comparator inputs and outputs externally accessible
  - SR Latch mode

APPENDIX- 11

```
#include<pic.h>
__CONFIG(0X1F71);
unsigned int COUNT,ZC;
void main()
{
        TRISB=0;
        PORTB=0;

        ADCON1=0X06;
        TRISA=0X14;
        PORTA=0;

        ZC=1;

        T1CON=0;
        TMR1L=0X78;
        TMR1H=0XEC;

        PR2=99;
        CCPR1L=0X32;
        CCP1CON=0X0C;
```

```
T2CON=0X04;


GIE=PEIE=TMR1IE=1;


while(1)

{

        if(RA4==1)

        {

                if(ZC==1)

                {

                        T1CON=0X01;

                        PORTB=0XC0;

                        ZC=0;

                        COUNT=1;

                }

        }

        if(RA4==0)

        {

                if(ZC==1)

                {

                        PORTB=0X03;

                        T1CON=0X01;

                        ZC=0;
```

```
                                        COUNT=2;

                                        while(RA4==0);

                                }

                        }




                }

        }

        void interrupt isr()

        {

                if(TMR1IF==1)

                {

                        TMR1IF=0;
```

APPENDIX-III

Advanced Power MOSFET

IRFZ44

FEATURES

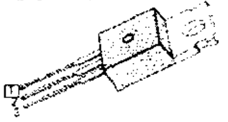
- Avalanche Rugged Technology
- Rugged Gate Oxide Technology
- Lower Input Capacitance
- Improved Gate Charge
- Extended Safe Operating Area
- 175°C Operating Temperature
- Lower Leakage Current: 10μA (Max.) @ V_{DS} = 60V
- Lower $R_{DS(ON)}$: 0.020Ω (Typ.)

BV_{DSS} = 60 V

$R_{DS(on)}$ = 0.024Ω

I_D = 50 A

TO-220



1.Gate 2. Drain 3. Source

Absolute Maximum Ratings

Symbol	Characteristic	Value	Units
V_{DSS}	Drain-to-Source Voltage	60	V
I_D	Continuous Drain Current (T_C=25°C)	50	A
	Continuous Drain Current (T_C=100°C)	35.4	
I_{DM}	Drain Current-Pulsed (1)	200	A
V_{GS}	Gate-to-Source Voltage	±20	V
E_{AS}	Single Pulsed Avalanche Energy (2)	857	mJ
I_{AR}	Avalanche Current (1)	50	A
E_{AR}	Repetitive Avalanche Energy (1)	12.6	mJ
dv/dt	Peak Diode Recovery dv/dt (3)	5.5	V/ns
P_D	Total Power Dissipation (T_C=25°C) Linear Derating Factor	126 0.84	W W/°C
T_J , T_{STG}	Operating Junction and Storage Temperature Range	- 55 to +175	°C
T_L	Maximum Lead Temp. for Soldering Purposes, 1/8. from case for 5-seconds	300	

Thermal Resistance

Symbol	Characteristic	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	--	1.19	°C/W
$R_{\theta CS}$	Case-to-Sink	0.5	--	
$R_{\theta JA}$	Junction-to-Ambient	--	62.5	

Electrical Characteristics (T_C=25°C unless otherwise specified)

Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Condition
BV_{DSS}	Drain-Source Breakdown Voltage	60	--	--	V	V_{GS}=0V, I_D=250μA
$\Delta BV/\Delta T_J$	Breakdown Voltage Temp. Coeff.	--	0.063	--	V/°C	I_D=250μA *See Fig 7*
$V_{GS(th)}$	Gate Threshold Voltage	2.0	--	4.0	V	V_{DS}=5V, I_D=250μA
I_{GSS}	Gate-Source Leakage , Forward	--	--	100	nA	V_{GS}=20V
	Gate-Source Leakage , Reverse	--	--	-100		V_{GS}=-20V
I_{DSS}	Drain-to-Source Leakage Current	--	--	10	μA	V_{DS}=60V
		--	--	100		V_{DS}=48V, T_C=150°C
$R_{DS(on)}$	Static Drain-Source On-State Resistance	--	--	0.024	Ω	V_{GS}=10V, I_D=25A (4)
g_{fs}	Forward Transconductance	--	32.6	--	$\mho$	V_{DS}=30V, I_D=25A (4)
C_{iss}	Input Capacitance	--	1770	2300	pF	V_{GS}=0V, V_{DS}=25V, f =1MHz *See Fig 5*
C_{oss}	Output Capacitance	--	590	680		
C_{rss}	Reverse Transfer Capacitance	--	220	255		
$t_{d(on)}$	Turn-On Delay Time	--	20	40	ns	V_{DD}=30V, I_D=50A, R_G=9.1Ω *See Fig 13* (4)(5)
t_r	Rise Time	--	16	40		
$t_{d(off)}$	Turn-Off Delay Time	--	68	140		
t_f	Fall Time	--	70	140		
Q_g	Total Gate Charge	--	64	83	nC	V_{DS}=48V, V_{GS}=10V, I_D=50A *See Fig 6 & Fig 12* (4)(5)
Q_{gs}	Gate-Source Charge	--	12.3	--		
Q_{gd}	Gate-Drain (Miller) Charge	--	23.6	--		

Source-Drain Diode Ratings and Characteristics

Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Condition
I_S	Continuous Source Current	--	--	50	A	Integral reverse pn-diode in the MOSFET
I_{SM}	Pulsed-Source Current (1)	--	--	200		
V_{SD}	Diode Forward Voltage (4)	--	--	1.8	V	T_J=25°C, I_S=50A, V_{GS}=0V
t_{rr}	Reverse Recovery Time	--	85	--	ns	T_J=25°C, I_F=50A
Q_{rr}	Reverse Recovery Charge	--	0.24	--	μC	di_F/dt=100A/μs (4)

Notes:

(1) Repetitive Rating: Pulse Width Limited by Maximum Junction Temperature
(2) L=0.4mH, I_{AS}=50A, V_{DD}=25V, R_G=27Ω, Starting T_J=25°C
(3) I_{SD} ≤ 50A, di/dt ≤ 350A/μs, V_{DD} ≤ BV_{DSS} , Starting T_J=25°C
(4) Pulse Test : Pulse Width = 250μs, Duty Cycle ≤ 2%
(5) Essentially Independent of Operating Temperature

MC78XX/LM78XX

3-terminal 1A positive voltage regulator

Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 11, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating area Protection

Description

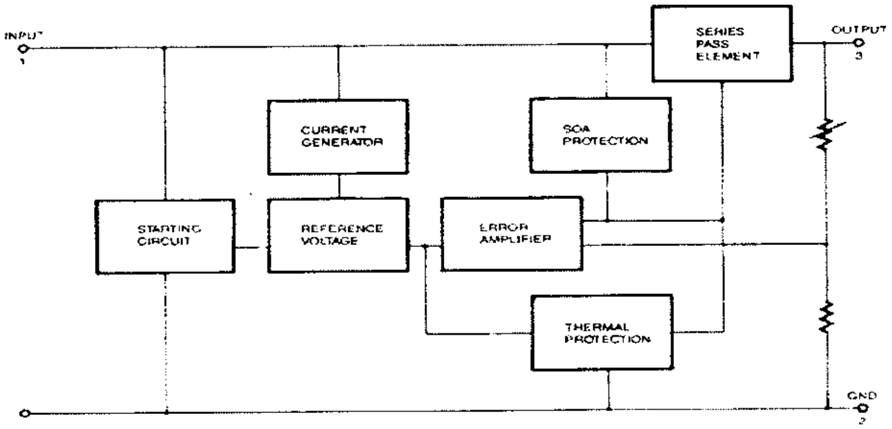
The MC78XX/LM78XX series of three-terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down and safe operating area protection, making 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.

TO-220

D-PAK

1. Input 2. GND 3. Output

Internal Block Digram



Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (MC78XXCT/LM78XXCT/MC78XXCDT)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I = 10V, C_I= 0.33μF, C_O= 0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		MC7805/LM7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA $\le$ Io $\le$ 1.0A, P_O $\le$ 15W V_I = 7V to 20V V_I = 8V to 20V		4.75	5.0	5.25	
Line Regulation	ΔV_O	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation	ΔV_O	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8	mA
Quiescent Current Change	ΔI_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/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	μV
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_O	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	R_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

- 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.

Electrical Characteristics (MC7806)

(Refer to test circuit ,$0^{\circ}C < T_J < +125^{\circ}C$, $I_O = 500mA$, $V_I = 11V$, $C_I = 0.33\mu F$, $C_O = 0.1\mu F$, unless otherwise specified)

Parameter	Symbol	Conditions		MC7806 Min.	MC7806 Typ.	MC7806 Max.	Unit
Output Voltage	V_O	$T_J = +25\ ^{\circ}C$		5.75	6.0	6.25	V
		$5.0mA \le I_O \le 1.0A$, $P_D \le 15W$ $V_I = 8.0V$ to $21V$ $V_I = 9.0V$ to $21V$		5.7	6.0	6.3	
Line Regulation	ΔV_O	$T_J = +25\ ^{\circ}C$	$V_I = 8V$ to $25V$	-	5	120	mV
			$V_I = 9V$ to $13V$	-	1.5	60	
Load Regulation	ΔV_O	$T_J = +25\ ^{\circ}C$	$I_O = 5mA$ to $1.5A$	-	9	120	mV
			$I_O = 250mA$ to$750A$	-	3	60	
Quiescent Current	I_Q	$T_J = +25\ ^{\circ}C$		-	5.0	8	mA
Quiescent Current Change	ΔI_Q	$I_O = 5mA$ to $1A$		-	-	0.5	mA
		$V_I = 8V$ to $25V$		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	$I_O = 5mA$		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, $T_A = +25\ ^{\circ}C$		-	45	-	μV
Ripple Rejection	RR	f = 120Hz $V_I = 9V$ to $19V$		59	75	-	dB
Dropout Voltage	V_O	$I_O = 1A$, $T_J = +25\ ^{\circ}C$		-	2	-	V
Output Resistance	R_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	$V_I = 35V$, $T_A = +25\ ^{\circ}C$		-	250	-	mA
Peak Current	I_{PK}	$T_J = +25\ ^{\circ}C$		-	2.2	-	A

- 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*

$T_A = 25°C$ 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
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ $T_A = 75°C$	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							°C
T_J	Operating Junction Temperature	-55 to +175							°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	°C/W

Electrical Characteristics

$T_A = 25°C$ 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 $T_A = 75°C$	30							μA
I_R	Reverse Current @ rated V_R $T_A = 25°C$ $T_A = 100°C$	5.0 500							μA μA
C_T	Total Capacitance $V_R = 4.0$ V, f = 1.0 MHz	15							pF

Typical Characteristics

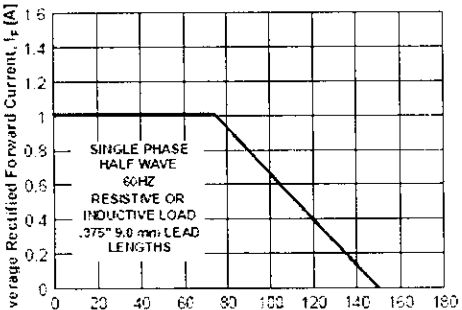


Figure 1. Forward Current Derating Curve

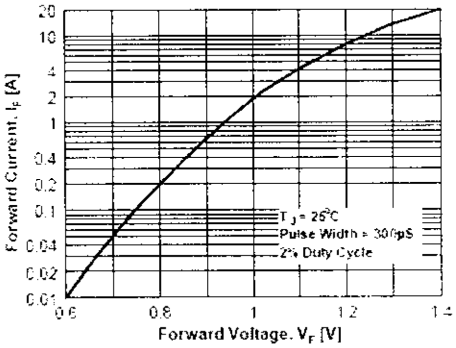


Figure 2. Forward Voltage Characteristics

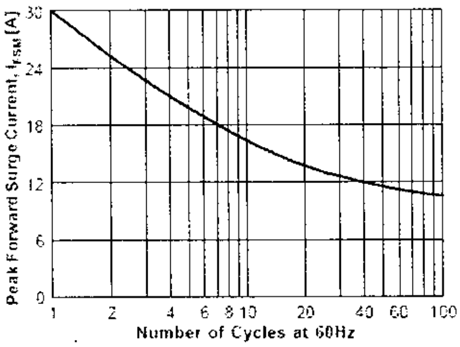


Figure 3. Non-Repetitive Surge Current

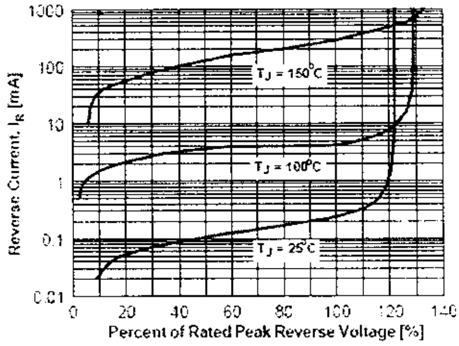


Figure 4. Reverse Current vs Reverse Voltage