MODELING, SIMULATION AND DEVELOPMENT OF FRONT END CONVERTER FOR POWER QUALITY IMPROVEMENT

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May 2014

MODELING, SIMULATION AND DEVELOPMENT OF FRONT END CONVERTER FOR POWER QUALITY IMPROVEMENT

Major Project Report

Submitted in Partial Fulfillment of the Requirements

For the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(POWER ELECTRONICS, MACHINES & DRIVES)

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May 2014

Undertaking for Originality of the Work

I Dhiren K Rathod, Roll No. 11MEEP51, give undertaking that the Major Project entitled Modeling, Simulation and Development of Front-End Converter for Power Quality Improvement " submitted by me, towards the partial fullfillment of the requirements for the degree of Master of Technology in Power Electronics Machines and Drives, Electrical Engineering, under Institute of Technology of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Dhiren K Rathod

Endosed By

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Certificate

This is to certify that the Major Project Report entitled **"Modeling, Simulation and Development of Front-End Converter for Power Quality Improvement "** submitted by **Mr. Dhiren K Rathod (Roll No.: 11MEEP51)** towards the partial fulfillment of the requirements for the award of degree of Master of Technology (Electrical Engineering) in the field of Power Electronics, Machines & Drives of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Acknowledgement

Successful accomplishment of any task is possible only with the cooperation of the people at various levels. It is impossible to express THANKS in words but a little and sincere effort is made here.

I am deeply grateful to my Project Guide Prof. M. T. Shah for allowing me to carry out the project under her guidance. I am indebted to her for giving his useful and valuable time and guidance at every level of the project. It is his inspiration, zeal, and constant encouragement that made this work to reach this level.

I express my sincere thanks to all faculty members of Electrical Engineering Department, Institute of Technology, Nirma University for their invaluable support during the project work.

I would also like to thank Dr. K. Kotecha, the Director of Institute of Technology, Nirma University and Dr. P. N. Tekwani, the Head of Electrical Engineering Department for providing the infrastructure to carry out the project work in-house at the institute.

I would also like to offer my thanks to Lab Assistants at Electrical Engineering Department for their kind support in all respect during the project work. I would like to thank the entire team of Institute of Technology, Nirma University for their guidance and active suggestions which are highly appreciated and acknowledged. I am indebted to my friends who were always there when needed the most. I am also thankful to all those who have helped me directly or indirectly during the project work.

At the last but not the least I would like to express thanks to GOD, my family and I would like to say that the cooperation made by everybody in the completion of this report would be remembered and cherished forever!

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Abstract

Harmonics are caused by the loads in which the current waveform does not have sinusoidal shape. These loads are called the nonlinear loads and are the source of harmonic current and voltage distortion. Current harmonics generated by these nonlinear loads are propagated throughout the power network. Voltage distortion is the result of these distorted currents passing through the series impedance of the system and results into power quality problems.

Thus various standards are set to limit the harmonics injected by nonlinear loads. IEEE standard 519 was first issued in 1991. It gave the first guidelines for system harmonics limitations and was revised in 1992 IEEE 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems provide the guidelines for determining what are the acceptable limits.

To improve power quality the front-end converter should be used that works at unity power factor at input side with low line current harmonics with nearly sinusoidal shape and maintains constant output voltage irrespective of the various load condition. The performance of the converter system largely depends on the quality of the applied current control strategy. Therefore, current control of PWM converters is very important in high dynamic performance applications. In the current controlled PWM converter, the hysteresis controllers are extensively used due to their simplicity and fast dynamic response.

The objective of this project is to design, simulate, and develop the control for the front-end converter using space vector modulation hysteresis current controller for improving the power quality.

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Chapter 1

Introduction

The power systems are designed to operate at frequencies of 50 or 60 Hz. However, certain types of loads produce harmonic currents in the power system. The power electronics converters are being widely used in domestic, commercial and industrial applications, ranging from few watts to MWs. However these converters suffer from the drawbacks of harmonic generation and reactive power flow from the source and offer highly non-linear characteristics. The generation of harmonics and reactive power flow in the power systems has given rise to the Electric Power Quality problems. One of the most harmful waveform events are the harmonic distortions. Harmonics are basically the additional frequency components present in the mains voltage or current which are integer multiples of the mains (fundamental) frequency. Harmonic distortion originates due to the nonlinear characteristics of devices and loads on the power system. Developments in digital electronics and power semiconducting devices have led to a rapid increase in the use of nonlinear devices. Power converters, most widely used in industrial, commercial and domestic applications are considered the primary source of undesired harmonics. In converter theory, the DC current is considered to be constant and the line currents at the AC side will consist of abrupt pulses instead of a smooth sinusoidal wave

At the DC side contains harmonics are present in the current and voltage. Since no energy storage can take place in the elements of a converter, the power balance of the input and output requires harmonics in the input power, and thus harmonic currents will flow in the supply lines. Energy balance considerations show and Fourier analysis of the square waves confirm that for a 6-pulse converter, each 6n harmonics in the DC voltage requires harmonic currents of frequencies 6n1 in the AC lines. Harmonics are the integral multiples of fundamental frequency superimposed on the fundamental frequency. These harmonics combine with the fundamental to form distorted wave shapes. Results show that the diode bridge rectifiers and phase-controlled converters create serious power quality problems in terms of distortion of the source current and deterioration of input power factor[10]

1.1 Problem Identification

Conventionally, AC to DC power conversion has been dominated by diode or phase-controlled rectifiers which act as non linear loads on the power systems and draw input currents which are rich in harmonics and have poor supply power factor, thus creating the power quality problem for the power distribution network and for other electrical systems in the vicinity of rectifier.

Various standards are set to limit the harmonics by nonlinear loads. IEEE standard 519 was first issued in 1991. It gave the first guidelines for system harmonics limitations and was revised in 1992 . IEEE 519-1992 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems provide the guidelines for determining what are the acceptable limits. The harmonic limits for current depend on the ratio of Short Circuit Current (SCC) at the Point of Common Coupling (PCC) to the average Load Current of maximum demand over one year, as illustrated in fugure 1[9]

1.2 Solution to the Problem

To solve the problem of input power factor and harmonics in line current a new breed of converters have been designed .This new breed of converters is specifically known as Power Factor Correction Converters (PFCs), Switched Mode Rectifiers (SMRs), PWM Converters, Improved Power Quality Converters (IPQCs), and High Power

Table 1. IEEE 519 Current Distortion Limits

SCR=I/I_1	<11	11<h<17	17<h<23	23<h<35	35<h	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Factor Converters (HPFCs). They are included as an inherent part of the AC-DC conversion system which produces excellent power quality at the line-side and load-side, higher efficiency, and reduced size. The power quality issues created by the use of conventional AC/DC converters are elegantly addressed by these converters. The output voltage is regulated even under the fluctuations of source voltage and sudden load changes. The PWM switching pattern controls the switchings of the power devices for input current wave shaping so that it becomes almost harmonic-pollution free and in phase with the source voltage, thus producing a nearly sinusoidal supply current at unity power factor without the need of any passive or active filter for harmonics and reactive power compensation. Remarkable progress in the capacity and switching speed of these devices has made it possible to develop the power quality front end converters for medium and large power applications. The parallel progress in the processors and high-speed DSPs has made it possible to implement the complex and computation-intensive control algorithms at very high speeds for the control of converters.[3]

1.3 Objectives of the work

The following objectives have been selected for this work:

- To model the three phase front end converter for line side power factor improvement,reducig harmonics in line current and DC link stabilization.
- To simulate the three phase front end converter using Space Vector Modulation Hysteresis Current Control strategy, analyze the results and compare it with

conventinal HCC technique

- Implementation of a front end converter for power quality improvement.
- To validate simulation results of the front end converter through experimental results.

Considering easy implementation, fast dynamic response, maximum current limit, and insensitivity to load parameter variation, the hysteresis current controller (HCC) is a rather popular technique. However, due to a lack of co-ordination among individual HCCs of the three phases, a high switching frequency may occur and the current error is not strictly limited.

On the other hand, the space vector modulation (SVM) technique has two excellent features .Its maximum output voltage is 15.5 greater and the number of switching is about 30 less at the same carrier frequency than with the sinusoidal PWM method. The SVM technique confines space vectors to be applied according to the region where the output voltage vector is located. To minimize the current error between the current command and line current, the SVM technique requires considerable calculations.

The HCC can be utilized to make the line current vector track the command vector with almost negligible response time and insensitivity to line voltage and parameter variation. However, the HCC generates other vectors than the space vectors required according to the region in the SVM technique, and increases the number of switchings. If the zero vectors is applied to reduce the magnitude of the line current vector, the line current is decreased with a slow slope and the number of switching is decreased. Thus, the utilization of nonzero vectors, instead of the zero vector, for decreasing the line current increases the number of switching. Therefore, a SVM-based HCC utilizing all the features of the HCC and SVM techniques needs to be developed.

A SVM-based HCC for the three-phase converter is used .This technique utilizes the advantages of the HCC and SVM technique. This configuration reduces significantly the number of switching and, at the same time, gives the same space vectors as those obtained from the SVM technique. The proposed current controller confines the space vectors from a region detector and applies a proper space vector, selected according to the HCC, for a better current shape. A set of space vectors, including the zero vector, is determined from the region detector made up of three comparators.

1.4 Literature Survey

- B. D. Min, J. H. Youm, B. H. Kwon

  In the paper titled SVM-Based hysteresis current controller for three-phase PWM rectifier"[1] the author gives a comparative study of conventional hysteresis current control and SVM based hysteresis current control. In case of conventional HCC due to lack of co-ordination among individual HCCs of the three phases, a high switching frequency may occur and the current error is not strictly limited. On the other hand, the space vector modulation has two excellent features: its maximum output voltage is 15.5 greater and the number of switching is about 30 less at the same carrier frequency than with the sinusoidal PWM method. So, hysteresis current control Techniques that apply the zero vectors to reduce the number of switching have been reported.

- Abdul Hamid Bhat, D. Amarnath Reddy and Pramod Agarwal

  In this paper titled Implementation of Space Vector Based Hysteresis Current Control for a Three-Phase High Power Factor Converter"[2], the author has combined the advantages of Space Vector Modulation (SVM) and Hysteresis Current Control (HCC) techniques. The controller used not only reduces the line current harmonics but also imoroves the power factor of input side.The controller determines a set of space vectors from a region detector and then applies a space vector selected according to HCC. A set of space vectors, including the zero space vector, is determined from the region detector made up of three comparators in order to reduce number of switching. A simple hardware implementation of the SVM based HCC has been presented. The simulation results show an improved performance of the converter and are validated by the experiment results.

- M. R. Baiju, K. K. Mohapatra, R. S. Kanchan, P. N. Tekwani and K. Gopakumar

  In the paper titled A space phasor based current hysteresis controller using adjacent inverter voltage vectors with smooth transition to six step operation for a three phase voltage source inverter"[3], authors proposed a space phasor based current hysteresis controller for a three- phase voltage source inverter. The controller uses only those inverter voltage vectors, which are adjacent to the machine voltage vector and does not require computation of machine voltage vector. The current errors are controlled along three axes jA, jB, jC which are perpendicular to the A, B, C phases respectively and the current error space phasor is held within a hexagonal boundary. The proposed controller uses a self adaptive region detection logic which ensures selection of a the unique inverter vector (among the adjacent vectors) for all regions of the boundary and a simple self adapting logic for sector changes.

- Bhim Singh, Brij N. Singh, Ambrish Chandra, and Dwarka P. Kothari

  In their paper titled A Review of Three-Phase Improved Power Quality ACDC Converters[4] they have given a review of Three-phase acdc that the converters have been developed to a matured level with improved power quality in terms of power-factor correction, reduced total harmonic distortion at input ac mains, and regulated dc output in buck, boost, buckboost, multilevel, and Multipulse modes with unidirectional and bidirectional power flow. Various topologies used for Front End Converter has been decribed in deails in the paper.This paper presents an exhaustive review of three-phase improved power quality acdc converters (IPQCs) configurations, control strategies, selection of components, comparative factors, recent trends, their suitability, and selection for specific applications. It is aimed at presenting a state of the art on the IPQC technology to researchers, designers, and application engineers dealing with three-phase acdc converters. A classified list of around 450 research articles on IPQCs is also appended for a quick reference.

- Yun liang Wang, Qi liang Guoi

  In this paper titled Hysteresis Current Control technique based on Space Vector Modulation for Active Power Filter[5] In this paper, the hysteresis current control (HCC) technique based on space vector modulation (SVM) for shunt active power filter (APF) is proposed. The switching control algorithms of the HCC based SVM manage to generate compensated current according to the reference current. Harmonics extraction is based on the instantaneous active and reactive power theorem in time domain by calculating the power compensation. A closed loop control system is carried out and the error current is the difference between the reference current which is obtained from the power compensation and the actual current needs to be injected back into the power grid. By implementing this control strategy, the APF manages to generate better compensated harmonics currents to the power grid.

Chapter 2

Front - End Converter for Power Quality Improvement

2.1 Introduction to Front- End Converters

An AC to DC power converter is an essential part of many power electronic systems such as uninterruptible power supplies (UPS), battery chargers, dc motor drives, front end converter in adjustable ac motor drive. The battery charger needs ac to dc conversion, while UPS and motor drives typically have an ac to dc conversion stage followed by dc to ac conversion[1].

In power electronic systems, especially, diode and thyristor rectifiers are commonly applied in the front end of dc-link power converters as an interface with the ac line power. The rectifiers act as non-linear loads on the power system and draws input currents, which are rich in harmonics and have poor supply power factor. Low input power factor and large amount of harmonic in supply current causes various undesirable effects such as harmonic distortion of line voltage, equipment overheating, malfunction and damage . Power pollution owing to the use of power converters results in serious power quality problems in transmission and distribution systems. In view of the above drawbacks, standards have been formulated to limit the amount of distortion in current drawn from and injected into the utility supply [2], [3].

For better power quality, high power factor converters are employed for ac-dc conversion system which draws almost sinusoidal current from the mains and maintains input current in phase with voltage. In this paper several three-phase power factor corrector front end converter topologies using advance semiconductor switches are described. Among various topologies discussed, PWM reversible rectifier is found to be the most suitable. This rectifier provides bidirectional power flow capability, draws near sinusoidal current from ac mains with less Total Harmonic Distortion (THD) and maintains unity power factor at the supply side. It also stabilizes the dc output voltage.[5]

In order to improve the performance of the system, current control techniques are more appropriate because of its gives fast dynamic response, maximum current capability and insensitivity to line parameter variation. Hysteresis current controller (HCC) uses three independent hysteresis comparators for three phases. Due to lack of coordination among individual comparators, it results in high switching frequency and the current error is not limited.

Space vector modulation (SVM) based hysteresis current controller can be used among various current control techniques. This current control technique offers advantage such as fast dynamic response, reducing switching frequency by using zero voltage vectors along with non-zero voltage vector. Harmonic pollution and low power factor in power system caused by power converters have been a great concern. To overcome these problems several converters and control schemes have been proposed in recent years.

2.2 Topologies for front end converters

Front End Converters for power quality improvement are classified into ten categories on the basis of converter circuit topologies such as buck, boost, buckboost, multilevel, and Multipulse, with unidirectional and bidirectional dc output voltage, current, and power flow [6].These converters are developed in such vastly varying configurations as to fulfill the very close and exact requirement in a variety of applications. Five most widely used topologies are showm in figure 2.1. Fig.(a) shows a simple boost converter.The main drawback of this topology is that, it gives low fre-

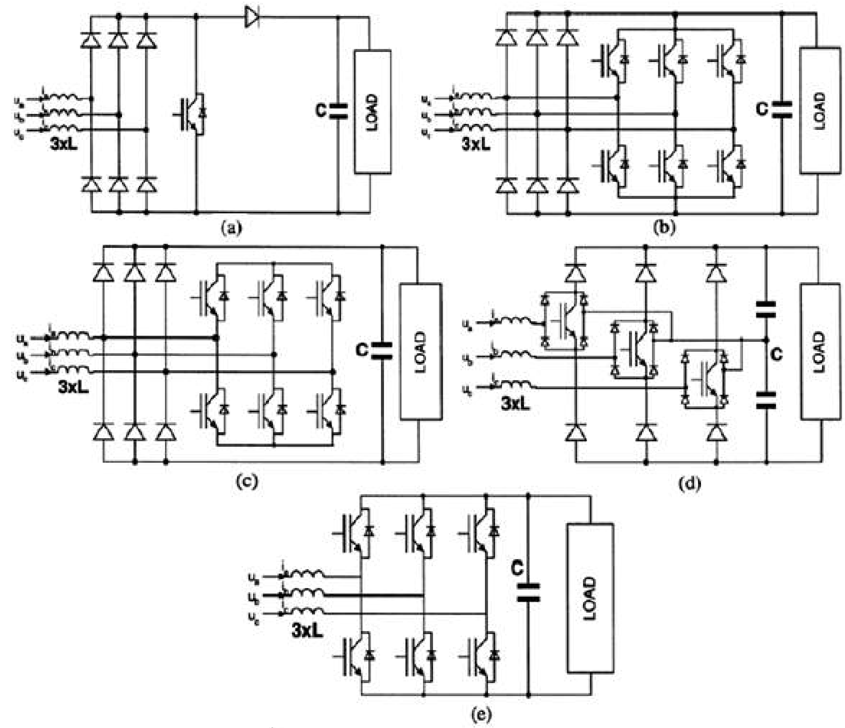

Figure 2.1: Topologies of front end converter (a) simple boost converter (b)pwm converter with regenerative braking (c) pwm converter with active filtering (d) Vienna rectifier (e) universal bridge reversible pwm converter

quency distorton of input current.Fig.(b) and (c) presents three phase front end converter with possibilities of regenerative braking and active filtering respectively.They have a low cost potential and provides low harmonic distortion in line current. Fig.(d) presents Vienna rectifier topology. It gives low switching losses but requred lon typical switches. Fig.(e) represents three phaase universal front end converter topology with bi-directional power flow capabilities. it can also provide unity power factor at line side. However, its disadvantages are high switching losses and low immunity to shoot through faults.

2.3 Current Control Strategies

Power factor corrected ac-dc converter topologies invariably use current control techniques to achieve near unity power factor and reduce current distortion (THD) 5 at the converter input/utility [4-6]. Hence ac to dc converters with current control strategies have gained importance in high performance applications such as UPS with high performance index, fast response and high accuracy. Among various current control schemes, Hysteresis Control, Predictive Control and Linear Control are widely used. The current control schemes and their operating principle are briefly presented below:

2.3.1 Linear Control

In linear control scheme the actual current (actual) is compared to the reference current (ref) to obtain the current error (error). The error is processed by a proportional-integral controller to provide a modulating signal for a PWM modulator. The modulator produces gate pulses for the converter switches. The pulses are of constant frequency with varying pulse width, which depends upon the magnitude of the modulating signal produced by the current controller. The controller parameters are tuned to optimize the PWM pulses such that the input current maintains near sinusoidal waveform with distortion less than 5 and power factor near unity.

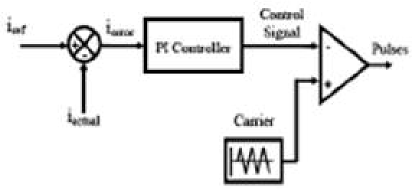

Figure 2.2: Linear current control

2.3.2 Predictive Control

In predictive current control scheme the switch voltage is predicted at the beginning of each modulation/switching period. The prediction is based on the current error, input voltage, switching frequency and input filter inductor and load variables. The predicted switch voltage (V sw) is compared with double-edge triangular carrier signal to generate PWM pulse to the switches. The carrier signal is chosen for fixed frequency operation but the amplitude of the carrier signal is modulated to accommodate the load voltage/current variation. In every switching/ modulation cycle, the switch voltage reference is predicated and used to generate gate pulses. This technique uses additional information along with error signal that improves converter dynamic performance but also increases cost on sensors and complexity in control.

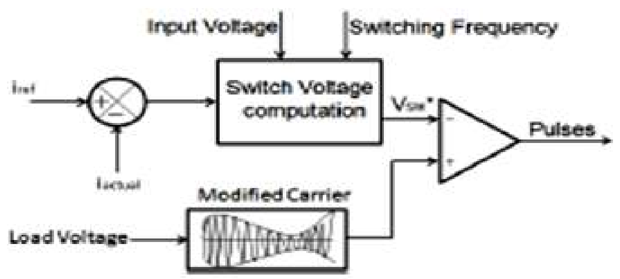

Figure 2.3: Predictive current control

2.3.3 Hysteresis Control

In hysteresis control scheme the actual line current (actual) is measured. The reference current (ref) with desired magnitude and shape is derived from the voltage controller output. The instantaneous values of actual and ref is compared using hysteresis comparator with hysteresis band (I). The result of comparison is the comparator output signal, which is used to control converter switches to make it ON/OFF. Thus, the converter switches and their operation force input current to follow the desired reference within hysteresis band. Hence, hysteresis current control technique is simple, accurate, and robust and hence advantage.

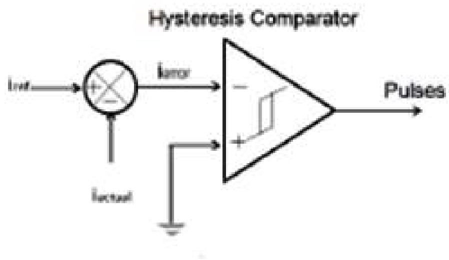

Figure 2.4: Hysteresis current control

The hysteresis controllers can be broadly classified into two categories.[4]

(a) Conventional hysteresis controller.

(b) Space vector based hysteresis controllers.

In the conventional hysteresis controller, three independent hysteresis controllers are used for the three-phases and the state of each leg of the inverter is independently determined by the hysteresis controller, in the respective phase. However, due to a lack of co-ordination among individual HCCs of the three phases, a high switching frequency may occur and the current error is not strictly limited. On the other hand, the space phasor based hysteresis controllers operate on the current error space phasor, which reflects the combined effect of the current errors on the three-phases of the supply current. The current error space phasor is kept within a boundary by choosing an supply voltage vector which will bring back the error space phasor, whenever the error space phasor goes beyond this boundary. The space phasor based hysteresis controllers utilize the zero vector also along with the non-zero vectors and this results in reducing the switching frequency.

Space vector modulation hysteresis current control techniques (SVM-HCC) have been proposed in research papers in order to enhance the performance of the basic HCC approach [2], [3]. They combine features of the hysteresis current control with the advantages of the classical space vector pulse-width Modulation (SVPWM) used to implement voltage control loops.

The SVM-HCC coordinates the switching activities of the hysteresis controllers to reduce both the current ripple and the PWM switching frequency. Similarly to the SVPWM techniques, SVM-HCC systematically includes the zero voltage in the generated PWM pattern in order to reduce the load current ripple [4], [5].

2.4 Proposed Topology and control scheme for Three Phase Front- End Converter

Among various topologies discussed, PWM reversible boost converter is found to be the most suitable. This topology provides bidirectional power flow capability, draws near sinusoidal current from ac mains with less Total Harmonic Distortion (THD) and maintains unity power factor at the supply side. It also stabilizes the dc output voltage.

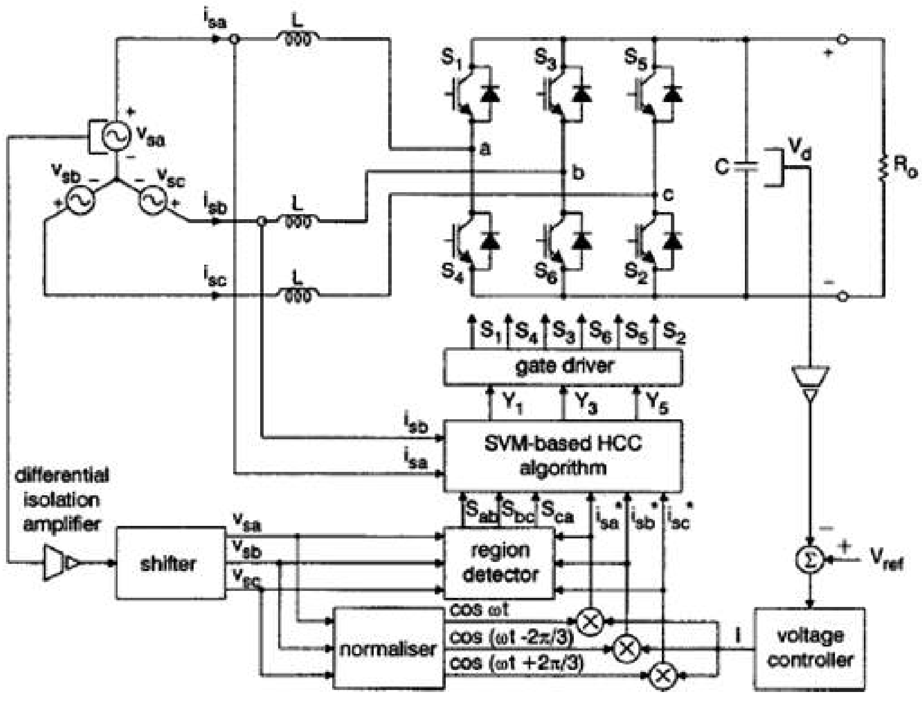

Figure 2.5: Block diagram of proposed Three Phase Front -End Converter using SVM-HCC technique

Chapter 3

Operation, Modelling and Design of Front End Converter

3.1 Steady State Operation of Front End Converter

Figure 3.1 shows basic diagram of the threephase boost type front end converter. uL is the line voltage and uS is the bridge converter voltage controllable from de the dcside. A general phasor diagram and diagrams for both rectification and regeneration operation at unity power factor (UPF) is shown in Figure 3.2[6]

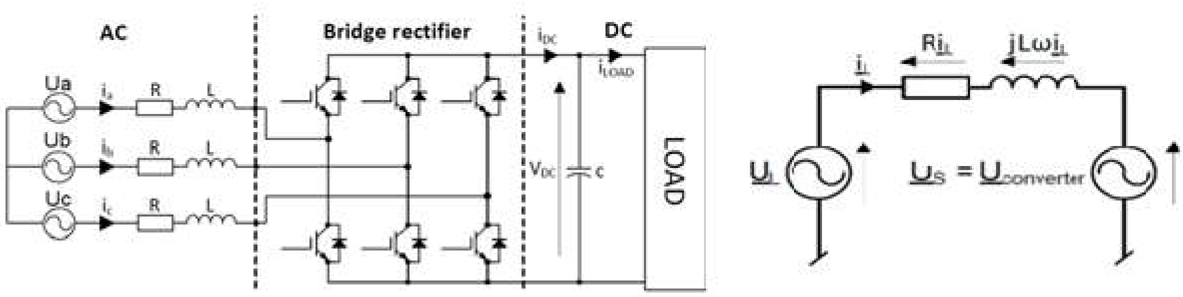

Figure 3.1: Front End Converter Block diagram and equivalent circuit

The line current iL is controlled by the voltage drop across the inductance L interconnecting the two voltage sources (line and converter). When we control the phase angle and the amplitude of converter voltage uS , we control indirectly the

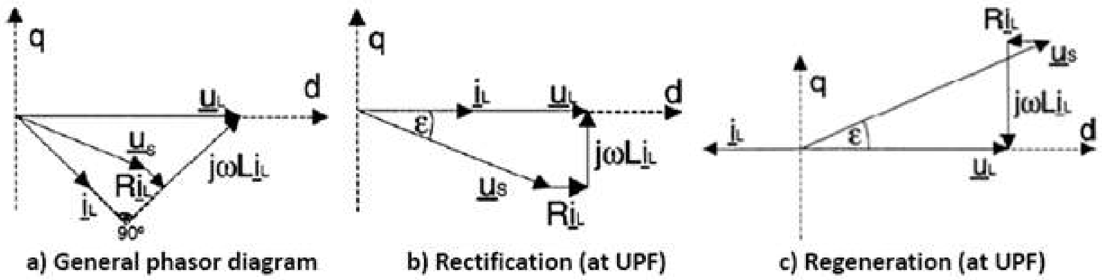

Figure 3.2: Phasor diagrams

phase and amplitude of the line current. In this way, the average value and sign of the dc current is subject to control that is proportional to the active power conducted through the converter. The reactive power can be controlled independently with a shift of the fundamental harmonic current IL with respect to voltage UL.[8]

3.2 Mathematical Model of Front End Converter

The universal Bridge- Reversible PWM Converter topology is shown in Fig.3.3.The converter model is defined by four basic equations, one for each phase voltage and one for dc link current availability. Therefore the mathematical model of FEC in the three phase stationary coordinates can be obtained as follows:

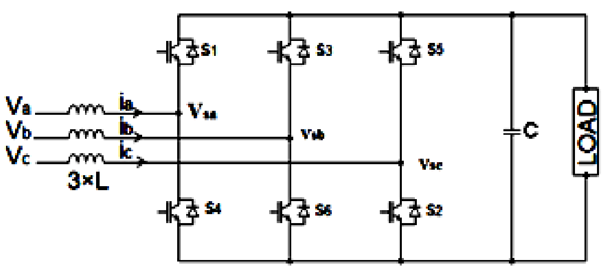

Figure 3.3: Universal Bridge- Revesible Front - End Converter

3.2.1 Description of Input Voltage and Input Current

The three phase line voltage and current are

$$\begin{aligned} v_a &= V_m \cos(\omega t) \\ v_b &= V_m \cos(\omega t - \frac{2\Pi}{3}) \\ v_c &= V_m \cos(\omega t - \frac{4\Pi}{3}) \end{aligned} \qquad (2.1)$$

$$\begin{aligned} i_a &= I_m \cos(\omega t) \\ i_b &= I_m \cos(\omega t - \frac{2\Pi}{3}) \\ i_c &= I_m \cos(\omega t - \frac{4\Pi}{3}) \end{aligned} \qquad (2.2)$$

Assuming balanced three phase supply system without neutral connections,

$$v_a + v_b + v_c = 0 \qquad (2.3)$$
$$i_a + i_b + i_c = 0 \qquad (2.4)$$

3.2.2 Front End Converter Mathematical Model

Using four basic equations of three phase vltages and load current for steady state operation of front end converter can be written as (2.4) and (2.5), respecively.Here Sa , S b , Sc are the switching functions. Definition of the three-phase bridge switching function are Sa , S b , Sc : Sx = l (x= a, b, c) on behalf of turn on the upper switch while Sa , S b , Sc : Sx = 0 (x= a, b, c) on behalf of turn off the upper switch while turn on the lower one.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \qquad (2.4)$$

$$C \frac{dV_{dc}}{dt} = i_a S_a + i_b S_b + i_c S_c - \frac{V_{dc}}{R_L} \qquad (2.5)$$

3.3 Design of Front End Converter

3.3.1 Specification of three phase front end converter

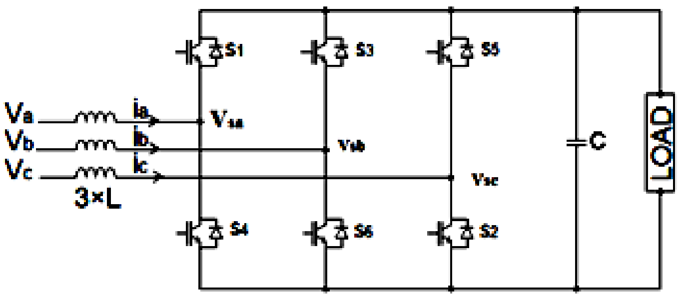

Figure 3.4: Three phase Front - End Converter

Table 4.3.1 lists the specifications for which the 3-phase, 2-level rectifier has been designed and built. Assuming the input current to be a pure sinusoid and the rectifier to be operating at UPF with an efficiency of 90

Table:4.3.1 Design Specification

Quantity	*Rated Value*
Output DC power (P dc)	1kW
Input 3 phase AC line-line voltage	100- 110 V
Frequency of input voltage	50 Hz +/– 5%
Output DC Voltage (V dc)	400 V
Switching frequency (Fs)	10kHz
Controller Platform	PIC

3.3.2 Design of an Inductor

The value of filter inductor L (Fig. 4.3.1) is decided by limiting the voltage drop across it and also from the switching frequency current ripple. The voltage drop across the inductor is limited to 10

P = 3 V I Cos

So, I = 5.248 A

And I max = 7.42 A

Assuming a purely sinusoidal input current it can be seen that the voltage drop across the inductor is given by,

w* L * Ia = 10 of 110 V

w* L * Ia = 11 V

So, L = 4.72 mH

3.3.3 Design of a Capacitor

The band width of voltage loop should be much slower than that of current controller as the voltage loop has to be much slower than current control loop. Assuming the bandwidth much slower than current controller i.e. 30 times lesser than current controller.[7]

Current controller frequency: 10 kHz

Voltage controller frequency: 0.33 kHz

Now, assuming a ripple of 1 of 400 V = 4 V

So, V = 4 V

t = 1/0.33 kHz = 3.03 mS

Now, Io = Pout / Vout

= 1000/400

= 2.5 A

Now, C = I out * t / V

C = 1893 F

3.3.4 Calculation of Maximum Switching Frequency possible

Fs (max) = Vd / (4.h.Ls) where h = Hysteresis Band

= 20 kHz

Chapter 4

Simulation and Result Analysis

In this chapter simulation and results for hysteresis control of rectifier as well as the proposed Space Vector - Hysteresis Current Controlled Front - End Converter are presented. The results indicate a well defined harmonic spectrum of input currents and a significant reduction in the total harmonic distortion (THD) of input current for Space Vector- Hysteresis Current Controller based control over the hysteresis based control strategy.[2]

Various simulation tools available for simulation of power electronic and drive system. MATLAB has been chosen in this work due to its versatility. To verify the design, the system is simulated in MATLAB/SIMULINK.

4.1 System Specification for Simulation

Supply voltage = 110 V (RMS)

Line inductance = 5 mH

Output capacitance = 2200 F

Reference DC voltage = 400 V

4.2 Simulation of Hysteresis Current Controlled three phase Front- End Converter

The simulation model shown in fig. 5.1 includes of a three-phase rectifier, reference current generation and three hysteresis current controllers for three individual phases.[4] Three-phase rectifier is made of six IGBTs (Insulated Gate Bipolar Transistor),an inductor is connected in each phase between the supply and the rectifier and a capacitor is connected at the output dc link. The reference current is generated from the output dc link voltage, by comparing it with a reference voltage. The dc voltage error is then processed in the voltage controller. The normalized input source voltages are multiplied with the output of the voltage controller to obtain three-phase reference current. This reference current is then compared with the actual input current and the error is processed in the hysteresis current controller which generates the gate signals. These gate signals are given to the IGBTs to obtain the appropriate result.[11]

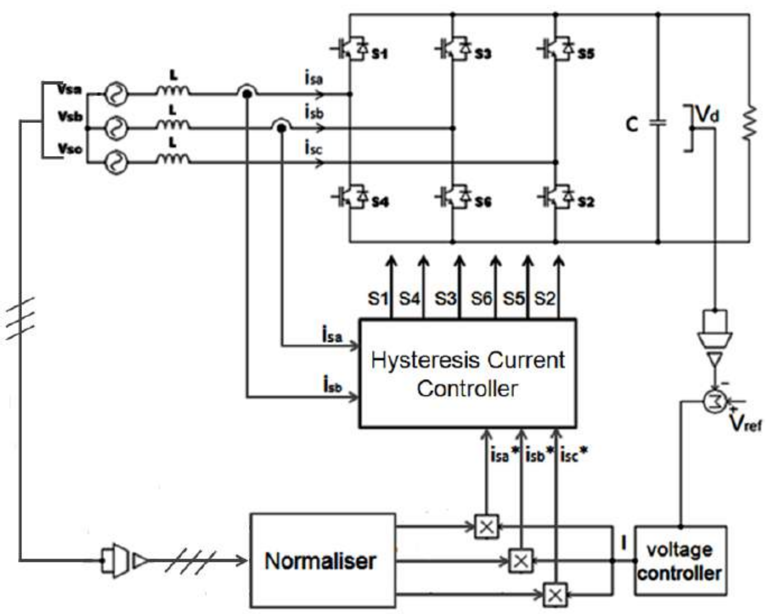

Figure 4.1: Simulink block diagram of Front End Converter using Hysteresis Current Control

4.2.1 With Resistive Load

Following are the simulation results with Resistive load of 50 Ohm. Three-phase input current is shown in figure 4.2

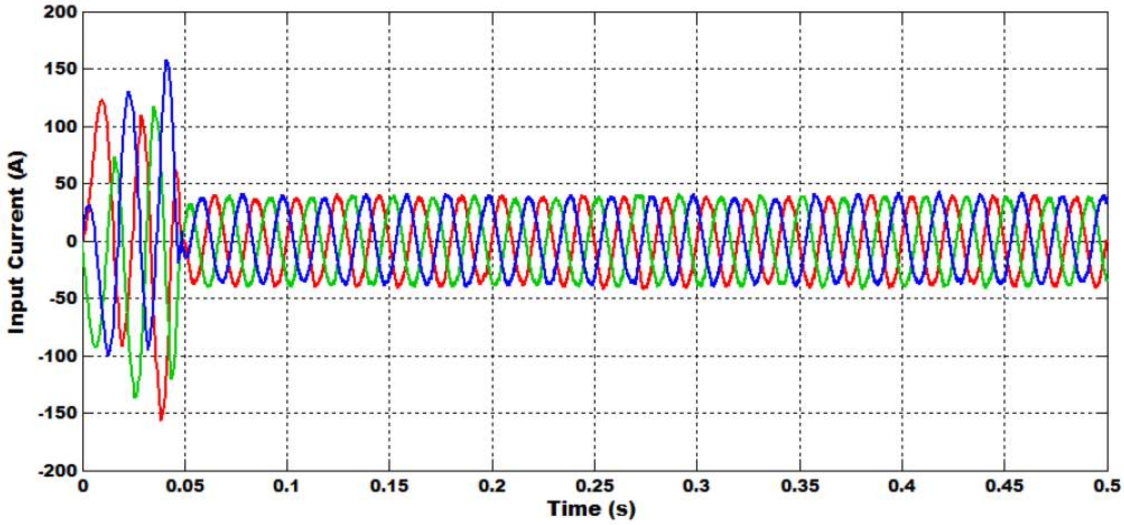

Figure 4.2: Three phase current

The input voltage waveform and input current waveform for phase A with unity power factor is shown in figure.4.3.Also the input current of phase A is nearly a sinusoidal and is n phase with voltage of phase A.

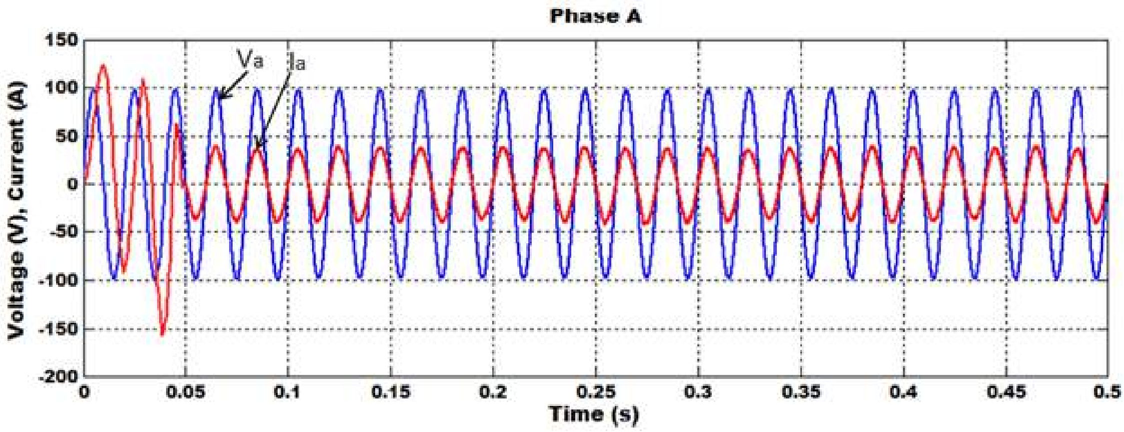

Figure 4.3: Input Voltage and Current for Phase A

The DC output voltage is shown in fig.4.4.

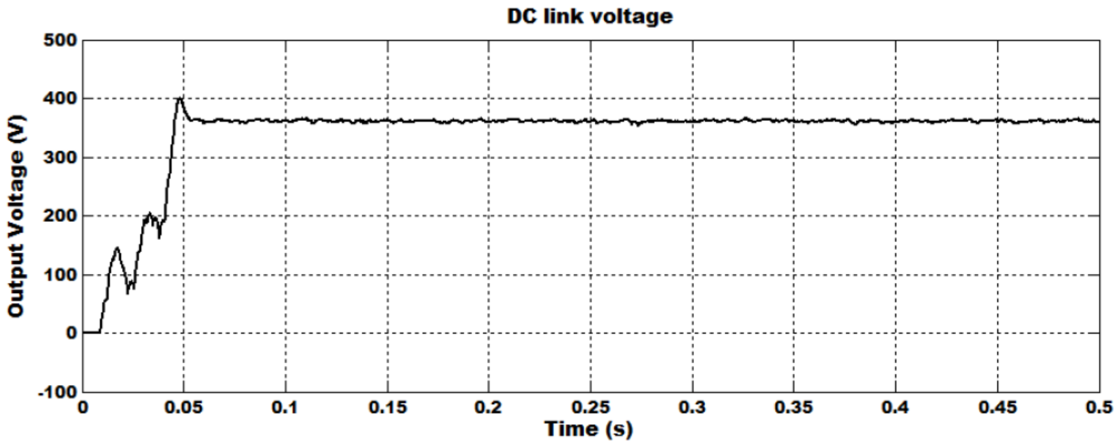

Figure 4.4: DC output voltage

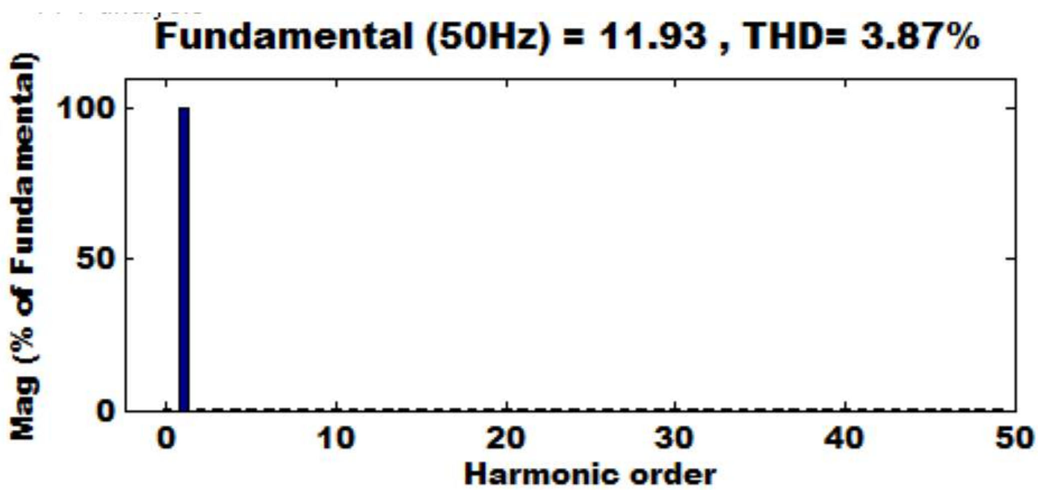

Figure 4.5: FFT analysis of input current of phase A

The FFT analysis of input current gives THD of 3.87 as shown in fig 4.5.

4.3 Simulation of Space Vector Modulation based Hysteresis Current Controller for Front End Converter

The block diagram of proposed space vector modulation based hysteresis current controller is shown in fig.4.6.It consists of power circuit made of six IGBT switches, input filter inductor and a dc link capacitor supplies by three phase balanced input supply. The input voltage , line current and DC link voltage are sensed by ac coltage sensosrs, ac current sensors and dc voltage sensor respectively.The dc voltage sensor output is compared with reference dc link voltage and erros occured has been passed through PI controller. The generated reference are multiplied by respective supply voltage phase profile template to get in phase operation of voltage and current.Decoupled current controller is utilised to get dc link voltage regulation and reduced harmonics in line current with nearly unity power factor at input side.

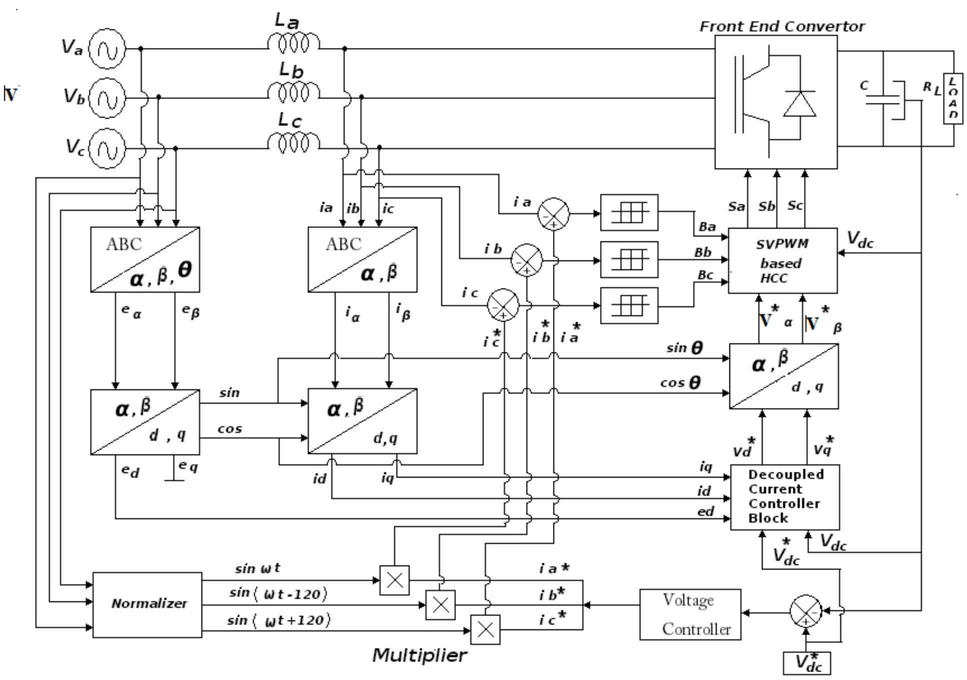

Figure 4.6: Simulink Block diagram of SVM based HCC Front End Converter

4.3.1 With R-L Load

Input voltage and current for phase A are shown in fig.4.6.It is seen that input voltage and line current of phase A are in phase with each other giving unity power factor at line side.Also the line current drawn is nearly sinusoidal.

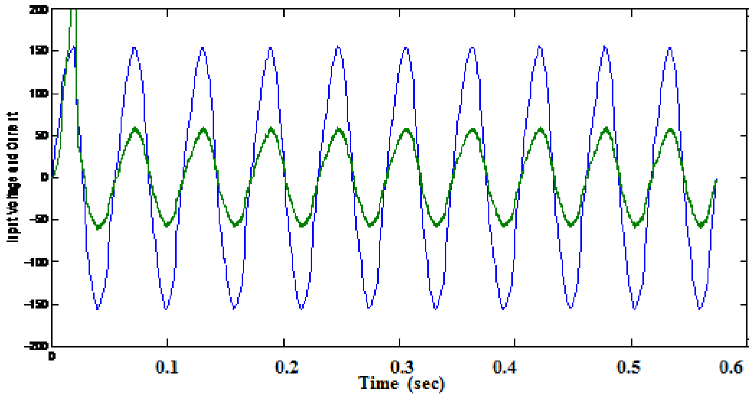

Figure 4.7: Input voltage and current for phase A

Output Voltage across capacitor is shown in figure 4.7.The dc link voltage across this capacitor remains constant as per the commanded value of reference voltage.

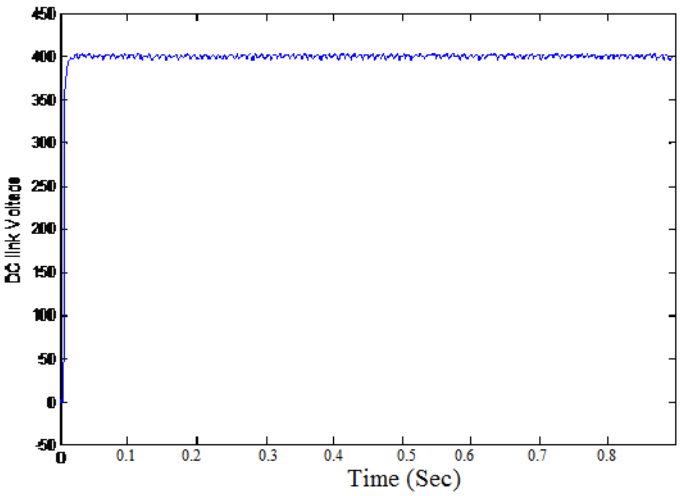

Figure 4.8: DC link Voltage

FFT analysis of line current for phase A is shown in fig.4.9. The results shows that the line current THD is 3.59 .

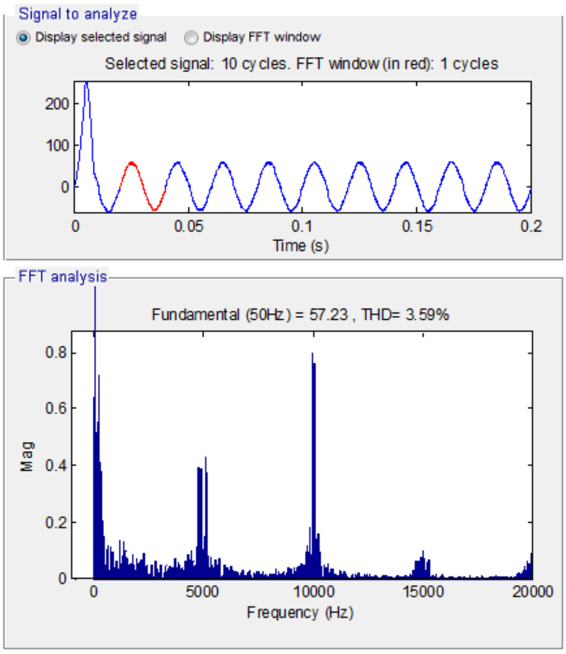

Figure 4.9: FFT analysis Line Current for phase A

4.3.2 Transient Response with change in load

The simulation results for transient condition under load variation for phase A current and voltage is shown below in fig. 4.10.It is observed that the controller works correctly under load varition to maintain power factor of line side unity.

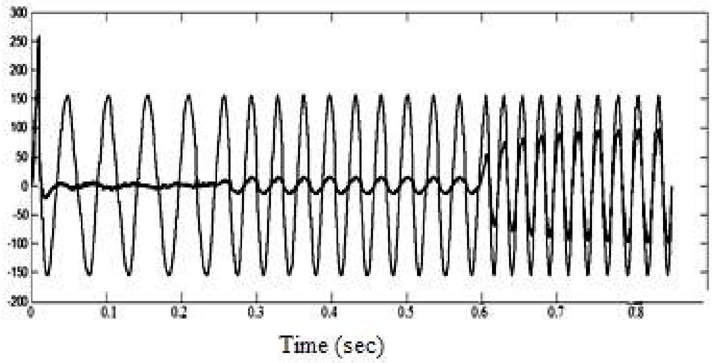

Figure 4.10: ILine voltage and current for Phase A for load variation 500 to 50 at t=0.25 Sec and 50 to 5 at t=0.6 Sec

DC Link Voltage Transient response for Change in Load is shown in fig.4.11 below.It is observed that the controller is working effectively to maintain dc link constant at a commnded reference voltage under load variation .

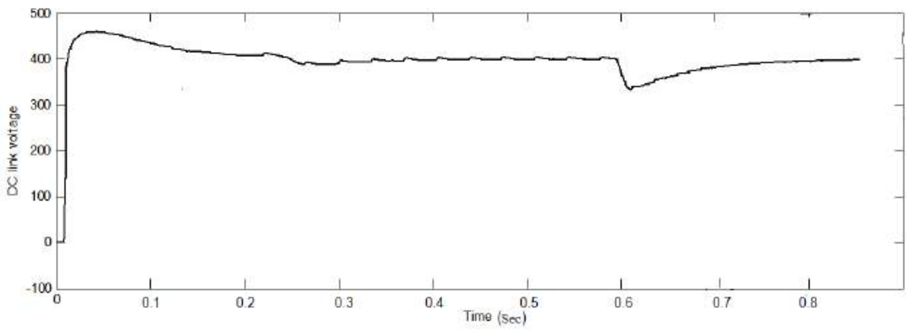

Figure 4.11: DC link voltage for load variation from 500 to 50 at t=0.25 Sec and 50 to 5 at t=0.6 Sec

4.3.3 Regenerative action

The control strategies has also been checked for verifying its effectiveness for regenerative action.Fig.4.12 shows the voltage and current for phase A under regenerative operation of front end converter. It is seen that the unity power factor is maintained, as current and voltage are 180 degree out of phase due to reverse power flow.

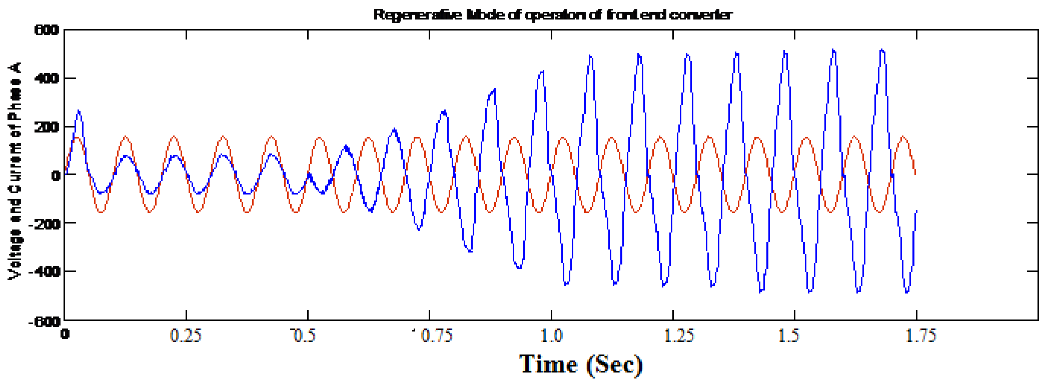

Figure 4.12: Input voltage and current of phase A for regenerative action of converter

4.4 Simulation Result Analysis

From the analysis of simulation of three phase front end converter under staedy state and transient conditions of load variation it is observed that by applying control algorithm of SVM- Hysteresis Current Control, the voltage and current of AC side are both in-phase and also the voltage output of DC side is maintaned at reference voltage. When conventional hysteresis current control method is adopted it has the THD of Input -current is about 3.61 but with SVPWM HCC the THD is only 3.59.From the simulation result analysis under regerative action it is seen that he proposed controller is not only suitable for steady state and transient variations but also working effectively for regenerative action of front end converter providing bi-diectional power flow to FEC.

Chapter 5

Implementation of three phase Front - End Converter

This chapter includes the proposed block diagram of FEC hardware, introduction to PIC 18f2420 , generation of PWM signals using PIC , shematic diagram of various components needed in hardware building of FEC and their results are discussed.

5.1 Proposed hardware system for three phase front end converter

The block diagram of proposed FEC is shown in the figure 5.1.The hardware system of FEC for power quality improvement is consists of the power circuit and a control circuit.The power circuit consists of Input supply voltage, three phase variac, input line inductors, six IGBT module, dc link capacitor and load.The control circuit consists of PIC microcontroller PWM generator circuit, DC and AC voltage sensors for sensing DC link voltage and AC input voltages respectively.The ac line currents are sensed by line current sensors.The deadband circuit and opto coupler has also been shown in the diagram.

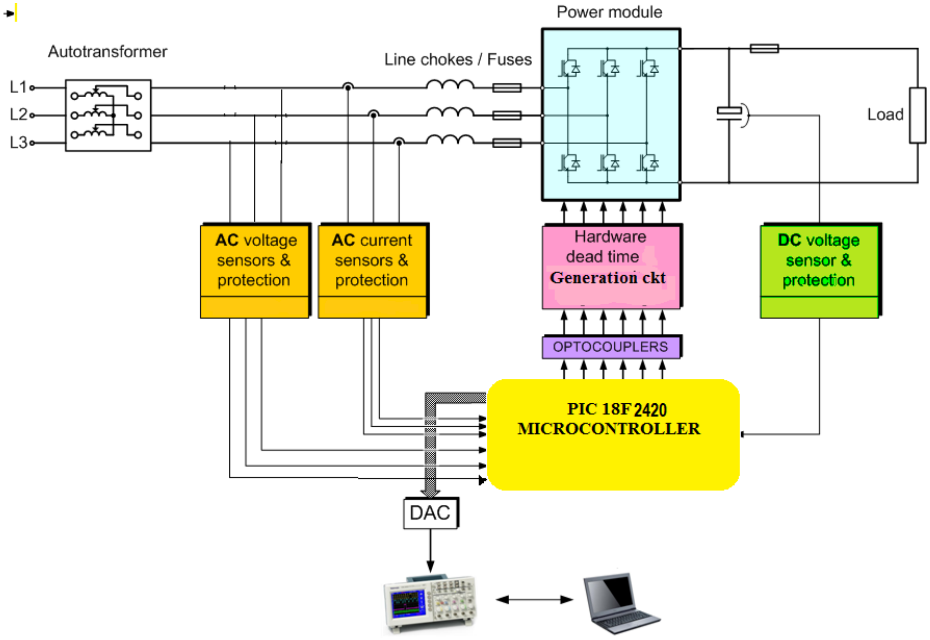

Figure 5.1: Proposed block diagram for hardware implementation

5.2 Introduction to PIC18f2420 microcontroller

PIC is a PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1650 originally developed by General Instrument's Microelectronics Division. The name PIC was originally an acronym for "Programmable Interface Controller". PICs are popular with developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes,availability of low cost or free development tools, and serial programming (and reprogramming with flash memory) capability. Microchip Technology has produced a range of micro-controllers with different bits such as 8-bit micro-controller (i.e. PIC16, PIC17, PIC18), 16-bit microcontrollers (i.e. PIC24) and 16-bit digital signal controllers (i.e. dsPIC30 and dsPIC33F). Some of the PIC micro-controllers use flash memory and some can be electronically erased. Different characteristics of micro-controllers cater to different purposes as well.

5.3 Hardware for PIC micro controller for PWM generation

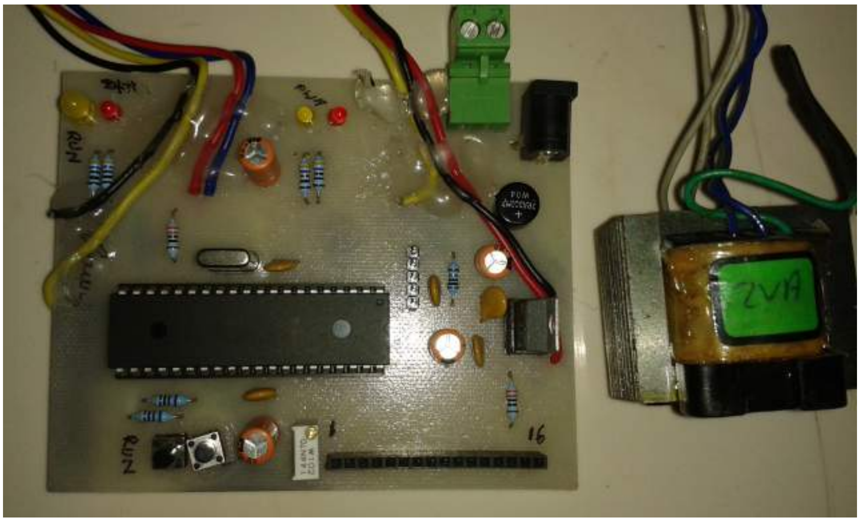

Figure 5.2: PIC micro controller board circuit

Figure 5.2 shows the PIC microcontroller board circuit. Three inputs Xa, Xb, and Xc are given to pin RB0, RB1, and RB2 respectively of PIC microcontroller. Two analog inputs are given to PIC microcontroller. One is variable output frequency port at pin AN0, and another is variable modulation port at pin AN1 SV-PWM algorithm is implemented in PIC microcontroller by PIC18f2024

5.4 Flow chart for SV-PWM signal generator program

The program would proceed by entering a loop with counter 8 as each output pattern has 8 time columns (note that each array contains 8 binary codes in it). For each looping, one binary code is taken from the output array and then sent to Port B through library function output b to be displayed. Next one binary code is taken from the time array to be inserted into the library function delay (ms delay) to enable the output pattern to be delayed for a certain amount of time(based on the

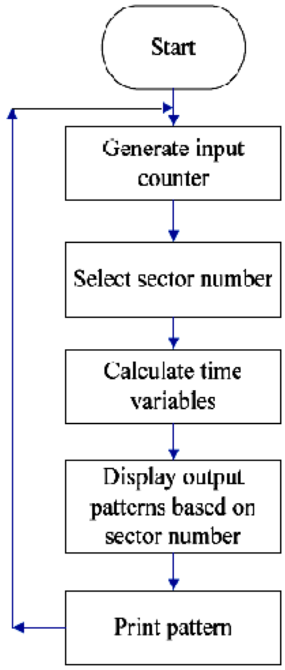

Figure 5.3: Flowchart of program for SVM pattern generation

time variable of the time column)It is important to note that each sector has different pattern and also different values of ta, tb and t0 as the value of phase or angle differs from time to time. However, for a single sector, the pattern would alter in terms of pulse size when the phase increases from the initial angle of the sector till the final angle of the sector.For instance, for sector 1, the pulse size for all three switching states (or phases) would alter starting from the 1st degree till the 60th degree, but the output pattern would be the same in the range of phase of 1 degree to 60 degrees.

5.5 Hardware Results and Analysis

This section includes the hardware results of PWM generator circuit, circuit for dead-band generation and its output results with analysis.

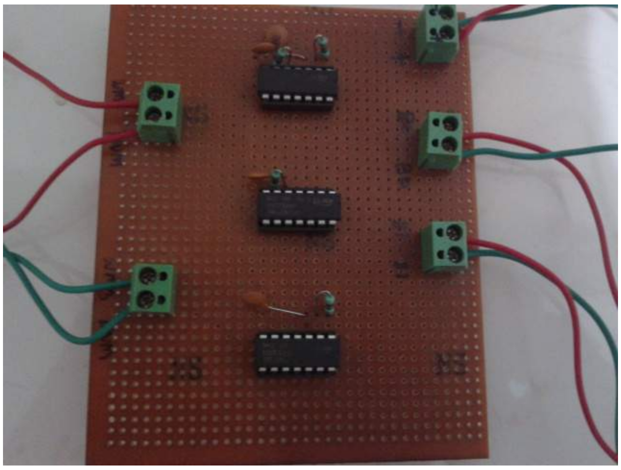

Figure 5.4: Deadband generator circuit

5.5.1 Deadband generator circuit

Deadband circuit should be incorporated prior to the driver card as there should be sucient deadband between the two switches of one leg of inverter which operate in complementary fashion. The amount of deadband to be provided depends on thevalues of R, C provided as in fig 5.4.The results of deadband circuit is shown in fig 5.5

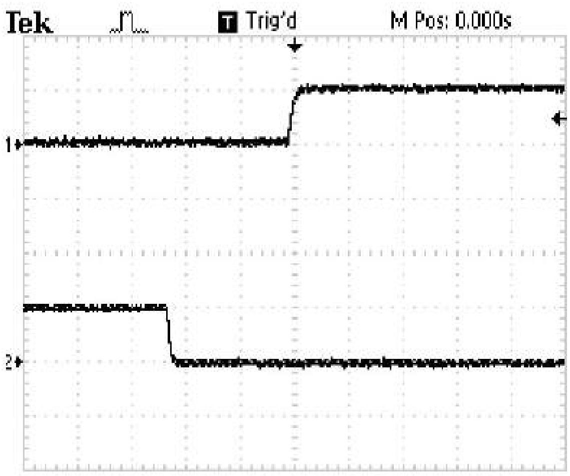

Figure 5.5: Results of Deadband generator circuit

5.5.2 Simulation and Hardware results of PWM generation circuit

The PWM signals for six IGBTs are shown in the figure 5.6 below for openloop operation of front end converter which are taken from proteus software scope.The first two waveforms are the PWM output required to trigger leg A IGBTs i.e. IGBT 1 and 4. Similerly the third and forth signals are the signals of pwm used to trigger leg B IGBT i.e. IGBT 3 and 6 as shown n fig 5.7.

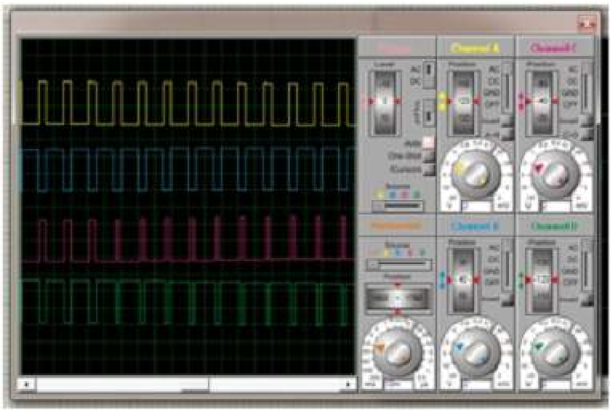

Figure 5.6: Simulation results of PWM generation circuits for leg A and leg B of FEC

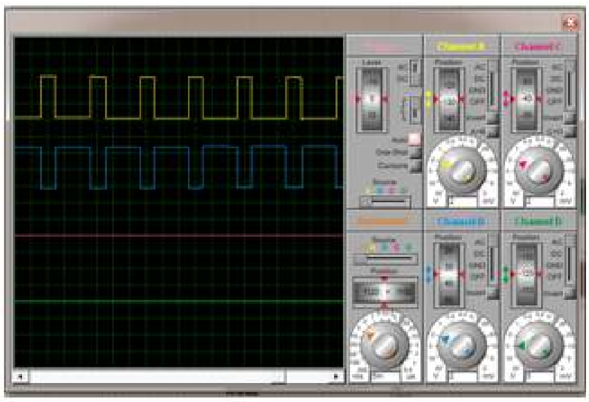

Figure 5.7: Simulation results of PWM generation circuits for leg C of FEC

The hardware circuit results of pwm generator circuit for pwm signals of leg A, B and C are shown in fig 5.8, fig 5.9 and fig 5.10 respectively.

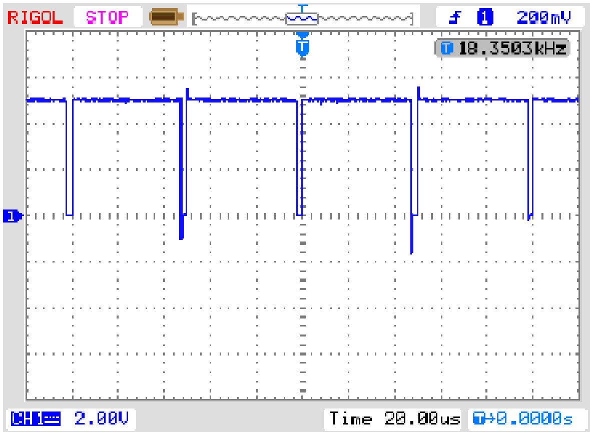

Figure 5.8: Hardware results of PWM generation circuits for leg A of FEC

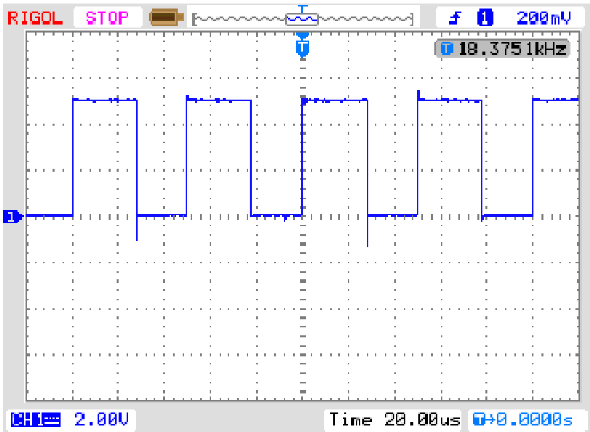

Figure 5.9: Hardware results of PWM generation circuits for leg B of FEC

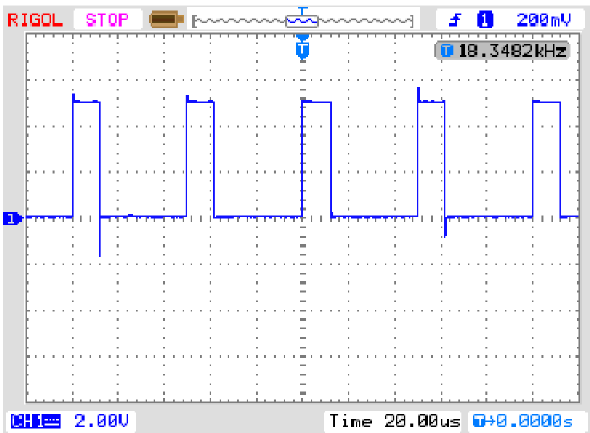

Figure 5.10: Hardware results of PWM generation circuits for leg C of FEC

Chapter 6

Conclusion and Future work

6.1 Conclusion

In this project work three-phase power factor corrector topologies are studied which provides low harmonic content in the input current and unity power factor at the supply side. Among the various topologies described, three-phase universal bridge converter with revesible power flow capability is used which draws nearly sinusoidal current from the ac mains and maintains unity power factor at the supply side. Also, the dc output voltage can be regulated. With this converter this converter topology the power can also flow in either direction, which is required in many motor drive applications.

Th SVM-HCC technique has been apllied for contolling purpose.It is also observed that unity power factor is obtained for both steady state and transient conditions Irrespective of the load variation, the dc output voltage is maintained constant which shows the effectiveness of applied control strategy. The

6.2 Future work

The future work to be done includes:

Troubleshooting of closed loop operation of converter with variable supply voltage

Troubleshooting for generation of SVm-HCC PWM signals using PIC controller

Use of multi level converter for power quality improvement.

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