THREE PHASE BOOST RECTIFIER DESIGN

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A thesis submitted in partial
Fulfillment of the requirement for the award of the
Degree of Master of Electrical Power Engineering

Faculty of Electrical and Electronic Engineering
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JULY 2012

ABSTRACT

An electric power can be converted from one form to another form by using power electronics devices. The function of power electronics circuits by using semiconductor devices as switch is modifying or controlling a voltage. The goal of power electronics circuits are to convert electrical energy from one form to another, from source to load with highest efficiency, high availability and high reliability with the lowest cost, smallest size and weight. The term rectification refers to the power circuit whose function is to alter the ac characteristic of the line electric power to produce a “rectified”ac power at the load side that contain the dc value In this project, a study has done for the two types of rectifier topology of alternating current to direct current voltage of a three-phase boost rectifier with pulse width modulation (PWM) and a three-phase boost rectifier with active power filter (APF). Power factor, shape distortion and voltage can be increased as much as seen through two types of this topology if it is connected to the non-linear loads in power systems. Three phase rectifier with pulse-width modulation (PWM) is one of controlled rectifier consist six pulses divides into two groups which are top group and bottom group. For top group, IGBT with its collector at the highest potential will conduct at one time. The other two will be reversed. Thus for bottom group, IGBT with the its emitter at the lowest potential will conduct. This project also observes the current, voltage waveform and the harmonics component when the active power filter (AFC) placed in series with non-linear load. Type of rectifier used is uncontrolled rectifier. In this work MATLAB/SIMULINK power system toolbox is used to simulate the system Results of simulations carried out, the advantages and disadvantages, the increase in voltage and waveform distortion for the system under consideration can be shown

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An electric power can be converted from one form to another form by using power electronics devices. The function of power electronics circuits by using semiconductor devices as switch is modifying or controlling a voltage. The goal of power electronics circuits are to convert electrical energy from one form to another, from source to load with highest efficiency, high availability and high reliability with the lowest cost, smallest size and weight. The term rectification refers to the power circuit whose function is to alter the ac characteristic of the line electric power to produce a “rectified”ac power at the load side that contain the dc value In this project, a study has done for the two types of rectifier topology of alternating current to direct current voltage of a three-phase boost rectifier with pulse width modulation (PWM) and a three-phase boost rectifier with active power filter (APF). Power factor, shape distortion and voltage can be increased as much as seen through two types of this topology if it is connected to the non-linear loads in power systems. Three phase rectifier with pulse-width modulation (PWM) is one of controlled rectifier consist six pulses divides into two groups which are top group and bottom group. For top group, IGBT with its collector at the highest potential will conduct at one time. The other two will be reversed. Thus for bottom group, IGBT with the its emitter at the lowest potential will conduct. This project also observes the current, voltage waveform and the harmonics component when the active power filter (AFC) placed in series with non-linear load. Type of rectifier used is uncontrolled rectifier. In this work MATLAB/SIMULINK power system toolbox is used to simulate the system Results of simulations carried out, the advantages and disadvantages, the increase in voltage and waveform distortion for the system under consideration can be shown

ABSTRAK

Kuasa eletrik boleh diubah daripada satu bentuk ke bentuk yang lain dengan menggunakan litar peranti kuasa elektronik.Fungsi litar elektronik berkuasa dengan menggunakan peranti semiconductor sebagai suis untuk mengawal dan mengubah arus voltan.Matlamat litar elektronik berkuasa adalah untuk mengubah kuasa elektrik kepada bentuk yang lain, daripada sumber kuasa kepada beban dengan tahap kecekapan yang tertinggi, perihal boleh didapati yang tertinggi ,perihal yang dapat dipercayai tertinggi dengan kos yang paling murah ,saiz dan berat yang paling kecil.Istilah rektifikasi merujuk kepada litar kuasa yang berfungsi untuk mengubah ciri arus ulang alik dalam talian kuasa elektrik untuk menghasilkan arus ulang alik pada beban yang mengandungi nilai arus terus Dalam projek ini , kajian dilakukan bagi dua jenis topologi penerus dari arus ulang alik kepada arus terus iaitu penerus panaik voltan tiga fasa dengan pemodulatan lebar denyut (PWM) dan pengubah penaik voltan tiga fasa dengan penapis kuasa aktif (APF). Faktor kuasa, bentuk herotan dan seberapa banyak voltan dapat dinaikkan dilihat melalui dua jenis topologi ini jika ia disambungkan kepada beban tidak linear dalam sistem kuasa. Penerus tiga fasa dengan pemodulatan lebar denyut (PWM) adalah salah satu penerus terkawal yang mengandungi enam denyutan Ia di bahagikan kepada dua bahagian iaitu bahagian atas dan bahagian bawah, yang mana masing-masing mengandungi tiga komponen IGBT. Pada bahagian atas salah satu daripada pemungut IGBT yang menerima voltan pincang hadapan akan beroperasi. Dua lagi IGBT dalam keadaan pincang songsang. Begitu juga yang berlaku di bahagian bawah, pemancar IGBT yang menerima voltan pincang songsang akan beroperasi. Projek ini juga melihat arus, bentuk gelombang voltan dan komponen harmonik apabila penapis kuasa aktif (AFC) diletakkan secara bersiri dengan beban yang tidak linear. Jenis penerus yang digunakan adalah dari jenis penerus yang tidak dikawal. Dalam kerja-kerja ini MATLAB / Simulink kuasa sistem toolbox digunakan untuk mensimulasikan sistem. Hasil daripada simulasi yang dijalankan, kelebihan dan kekurangan, peningkatan voltan dan herotan gelombang bagi sistem yang dikaji dapat ditunjukkan.

CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOLS

AC	-	Alternate Current
DC	-	Direct Current
KVL	-	Kirchhoff Voltage Law
KCL	-	Kirchhoff Current Law
APF	-	Active Power Filter
THD	-	Total Harmonic Distortion
PWM	-	Pulse Width Modulation
GPWM	-	Generalized Discontinuous Pulse Width Modulation
icompA, *B C*	-	Reference currents
PI	-	Proportional Integral
PLL	-	Phase Locked Loop
HBCC	-	Hysteresis Band Current control
α	-	Alpha
β	-	Beta
PFC	-	Power Factor Correction
PF	-	Power Factor
Vas,Vbs, Vcs	-	Input AC side voltage
Ia,Ib,Ic	-	Phase current
ra,rb,rc	-	Per phase resistance
I_L	-	Load Current
S_{11}, S_{21}, S_{31}	-	Switching function on top devices
S_{12}, S_{22}, S_{32}	-	Switching function on bottom devices
R_L	-	Load resistance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

A switching power rectifier in the power system is convert one level of electrical energy into another level of electrical energy. Converters in the AC to DC conversion field are the most widespread [G. Chesi ,2009] and the operation of a converter can be explained in terms of the input quantities, output quantities, and the switching pattern used to obtain the preferred output. In industrial applications where three-phase ac voltages are available, it is preferable to use three-phase rectifier circuits, compared to single-phase rectifiers. Three-phase rectifiers have the following advantages compared with single-phase rectifiers [Mohan, N., Undeland, T., and Robbins ,1995]

a. higher output voltage for a given input voltage

b. lower amplitude ripples, i.e. output voltage is smoother

c. higher frequency ripples, simplifying filtering

d. higher power-handling capability

e. higher overall efficiency

Type of semiconductor device used in the rectifier are different following application as [Enrique Acha ,1997] :

a. Uncontrolled rectifiers - Diodes as the switches
b. Phase-controlled rectifiers - SCR (silicon controlled rectifiers)
c. Pulse-width modulation rectifiers - IGBT.s (insulated gate bipolar transistors) or power MOSFET.s (metal oxide field-effect transistors)

Among three-phase AC to DC rectifiers, boost-type topologies are frequently used because of continuous input currents and high output voltages. The ability to control the system to obtain unity power factor operation of a boost rectifier is important feature of the rectifier topology. The power factor (PF) is defined as the ratio of working power to apparent power. The power quality problems, such as large values of harmonics, poor power factor and high total harmonic distortion, are usually associated with operation of three phase AC to DC converters. An increase in the current harmonics and a decrease in the displacement power factor in AC power lines produced by diode and thyristors are a serious problem, thereby highlighting the importance of the boost rectifier in minimizing these problems.

Active power filter (APF) or pulsewidth-modulation (PWM) rectifiers in distribution systems represents the best solution, in terms of performance and effectiveness, for elimination of harmonic distortion as well as power factor correction, balancing of loads, voltage regulation and flicker compensation. *Sinusoidal PWM* [P. Wood , 1981] is technique employed where the sinusoidal waveform or modulation signal is compared with a very high frequency triangle or carrier signal to obtain the switching pulses for the device.

The shunt APF, connected in parallel with the non-linear load, is commonly utilized to compensate for current disturbances while the series APF is utilized to compensate for voltage disturbances.

The aim of the project is to study an existing three-phase boost rectifier and design a new three-phase boost rectifier topology with minimum value of current harmonics. In this project, trends and future prospects in new three-phase boost rectifier topology with pulsewidth modulation (PWM) and active power filter (APF) are presented and the simulation result will be shown. A method of identification of supply current will be developed by using MATLAB/Simulink for elimination of the harmonics of current and to obtain a sinusoidal current of line.

1.2 Problem of Statement

From the study in this project, there are a large number of switching converter topologies and composite switching converters are possible. The power quality problems, such as large values of harmonics, poor power factor and high total harmonic distortion, are usually associated with operation of three phase AC/DC converters especially nonlinear load. There have been many approaches to mitigate the harmonics in the rectifier system. They include the following:

a. active power filters;
b. six-switch pulsewidth-modulation (PWM) rectifiers;
c. power-factor correction (PFC) by boost converters;
d. multipulse rectifiers;
e. harmonic current injection method.

1.3 Objective of Project

The objective in this project is to develop and compare in term of method or topology of three phase boost rectifier which more efficient and able to solve the nonlinear problem with optimum way. Six-switch pulsewidth-modulation (PWM) rectifiers and active power filter (APF) will be used in this project. The APC topology is unique because the configuration is more reliable. A failed shunt filter does not immediately affect the loads side.

1.4 Scope of Study

The scope of this project is to study the three phase boost rectifier characteristic and effect of the harmonics on non linear loads. The simulation of this project is base on three phase system with six-switch pulsewidth- modulation (PWM) and Uncontrolled rectifier with Active Power Filter (APF) . Modeled by using MATLAB Simulink to analysis the distorted source current waveform drawn by the nonlinear load. At the end of this project, analyze and compare two rectifier topology in term of harmonic currents and the d.c voltage..

1.5 Thesis Outline

The thesis is organized into 5 chapters namely the introduction, literature reviews, methodology, simulations and results analysis, conclusion and recommendation.

Chapter I discuss the background and general idea of the proposed project. The objective and scope of this project are state in this chapter.

Chapter II conducts a detailed literature survey on the previous work done in three phase boost The chapter also includes sections on the past work done in Pulsewidth Modulation (PWM) boost rectifier and boost rectifier with active power filter (APF)

Chapter III details on research methodology of each design state. Two topologies for the connection of boost rectifier; pulsewidth modulation and active power filter are discussed in this chapter with operation of the system.

Chapter IV displays the simulation result and analyze the compensation two different three phase boost rectifier topologies;pulsewidth modulation and active power filter subject to a typical nonlinear load. The simulation design and the result of each stage will be observed.

Chapter V summarizes the work done in the thesis and concludes with suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review on the various works previously done on three phase boost rectifier. A three-phase system has certain inherent advantages over a single-phase system. In this chapter discusses the nature of three-phase rectifier and reports the different types of three phase topologies. The topologies are discussed and various strengths and weakness highlighted.

2.2 Boost Derived Rectifier Topologies

Three-phase boost PFC power rectifier have traditionally been the preferred topology for high power applications due to their symmetric current drawing characteristics. A disadvantage to any boost derived topology is the inability to control startup inrush currents and output short circuit conditions, unless bi-directional power flow is possible. The following subsections describe various boost derived topologies.

2.2.1 Three-Phase Six Switch Boost Rectifier

A common six switch boost rectifier topology has the ability to operate as a rectifier as well as an inverter due to the bidirectional power flowing capabilities

(Figure 2.1). It also has good current quality and low EMI emissions [V. Blasko, V. Vaura and W. Niewiadomski ,1998] . The use of bidirectional switches also results in the ability to control the output voltage down to zero, thus, eliminating the problem that boost topologies have with regard to startup inrush currents and output short circuit protection. Unidirectional switches can be used for simplicity at the expense of current control capabilities. The converter is controlled by an output voltage loop for output regulation, and inner current loops which shape the input currents according to their sinusoidal references. The input inductors form part of the boost topology and, as such, work at the switching frequency. As a result, input inductors operating at switching frequencies are smaller in size compared with line frequency input inductors.

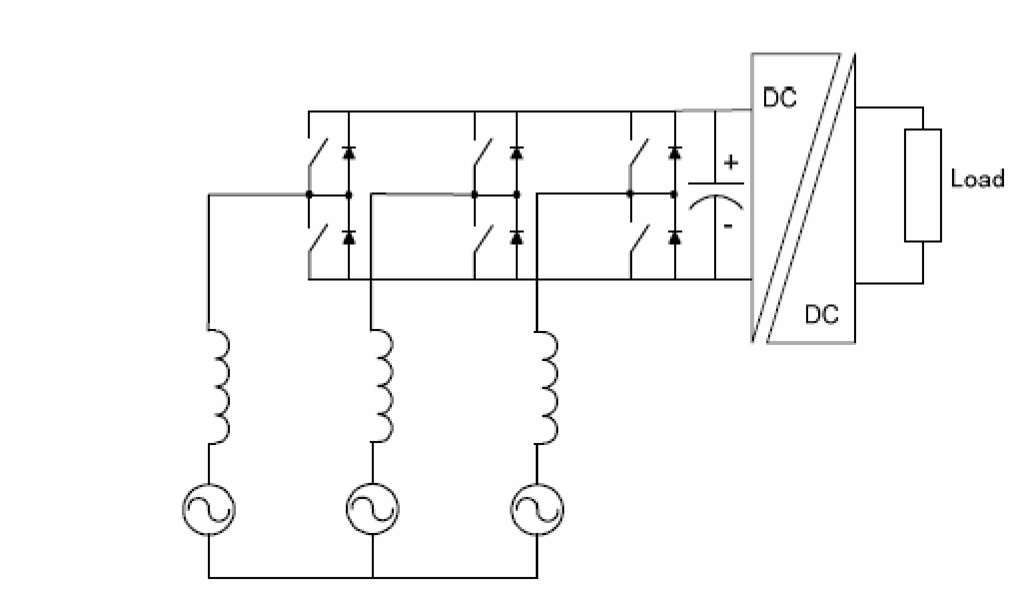

Figure 2.1 : Three-Phase Six Switch Boost Rectifier

2.2.2 Three-Phase Four Switch Boost Rectifier

The boost derived rectifier shown in Figure 2.2 **,** and proposed in [Abraham Pressman,1991] , has three boost inductors in them AC lines, four active switches and two series connected capacitors. The boost derived rectifier is capable of bi-directional power flow and, thus, is able to control the output voltage down to zero. The converter performs PFC by taking advantage of the fact that if two of the three line currents in a balanced three-phase system are controlled, the third is automatically constrained. This removes the need for a third converter leg. A disadvantage is that even with a slight imbalance in the supply system, the converter performance may deteriorate considerably. DC-DC converter stage is still needed to provide isolation, voltage transformation and ripple reduction.

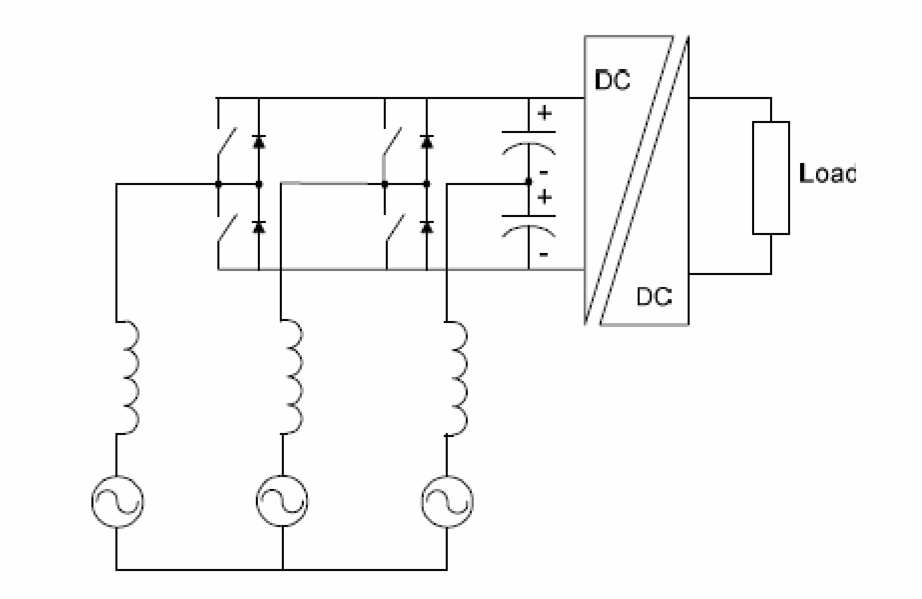

Figure 2.2: Four Switch Boost Power Converter System

2.2.3 Three Switch Boost Power Converter

The three switch boost derived converter proposed in [S. Zheng and D. Czarkowski,2007] works on the principle of current control. When two switches are conducting, the phase with the larger supply voltage is connected to the positive rail, while the phase with the smaller supply voltage is connected to the negative rail (Figure 2.3). As a result, the phase shift angle between the modulation references and supply voltages can be at most 30^o. Accordingly, this topology cannot be used for bi-directional power flow. As a result, this topology suffers from startup inrush currents and, also, uncontrolled negative half cycles on all phases and fluctuations in the DC bus voltage. DC-DC converter stage is still needed to provide isolation, voltage transformation and ripple reduction.

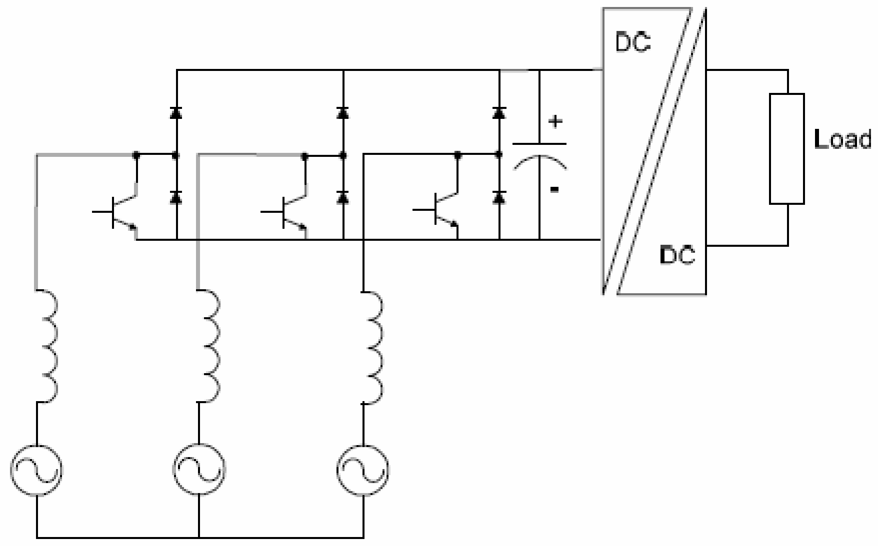

Figure 2.3 : Three Switch Boost Power Converter System

2.2.4 Vienna Rectifier

Another three-switch boost derived converter, also called the Vienna rectifier, is a unidirectional three-level PWM converter (Figure 2.4) and, as a result, suffers from startup inrush currents. The input stage creates a DC voltage across the two switches connected to the transformer primary. These two switches, in turn, regulate the voltage being applied to the primary of the transformer. Accordingly, they are able to control the output voltage generated [D.M. Mitchell ,1980] The Vienna rectifier has a complex control system and requires special semiconductor module fabrication.

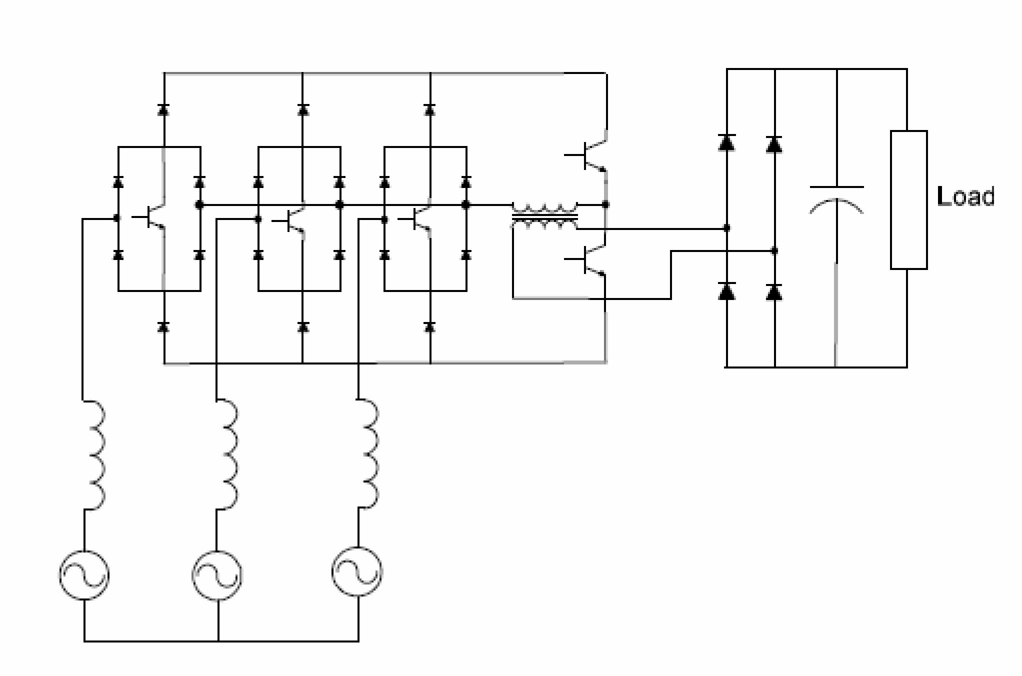

Figure 2.4: Vienna Rectifier

2.2.5 Single Switch Boost Power Converter

The single switch boost converter topology proposed in [T. Nussbaumer, M.L. Heldwein, G. Gong, S. Round, and J. Kolar,2008] has an LC type input filter and, with the boost switch turned on at a constant frequency, the duty cycle is controlled such that the input current is always discontinuous (Figure 2.5). During the on-period of the boost switch, all three input phases become shorted through the input inductors, the six rectifier diodes and the boost switch. The three input currents begin simultaneously to increase at a rate proportional to the instantaneous values of their respective phase voltages. The specific peak current values during each on-interval are proportional to the average values of their input phase voltages during the same on-interval. The result is that each AC line current is a discontinuous waveform made up of a train of triangular pulses bounded by a sinusoidal envelope.

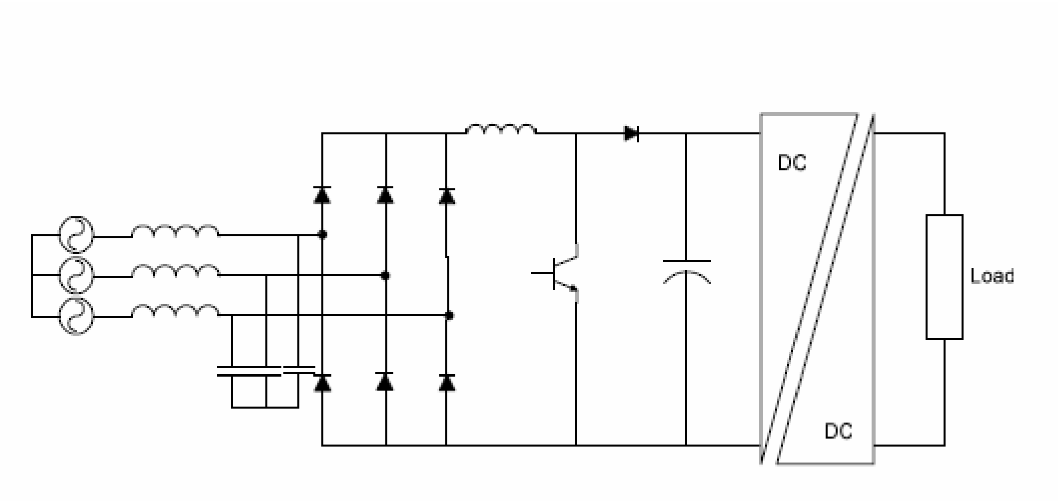

Figure 2.5 : Single Switch Boost Power Converter

2.3 Boost Rectifier with Harmonic Circuit

The quantity of input current harmonics is an important parameter to unsure the performance of a switching mode.

2.3.1 Three-Phase, Single Switch Boost Rectifier

The single switch boost rectifier proposed in [Q. Huang and F. C. Lee,1996] to reduce the magnitude of the 5th harmonic in the input current. The fifth-order-harmonic trap filter, which consists of inductances and capacitance place at the input of the power stage. The harmonic-trap inductance can be utilized as a part of the differential-mode input filter formed by the addition of filter. One problem in using a harmonic trap in a harmonic generating power system is the possibility to excite harmonic resonances. Both series and parallel resonances may occur in a power system due to the existence of the filter and power line reactive components.

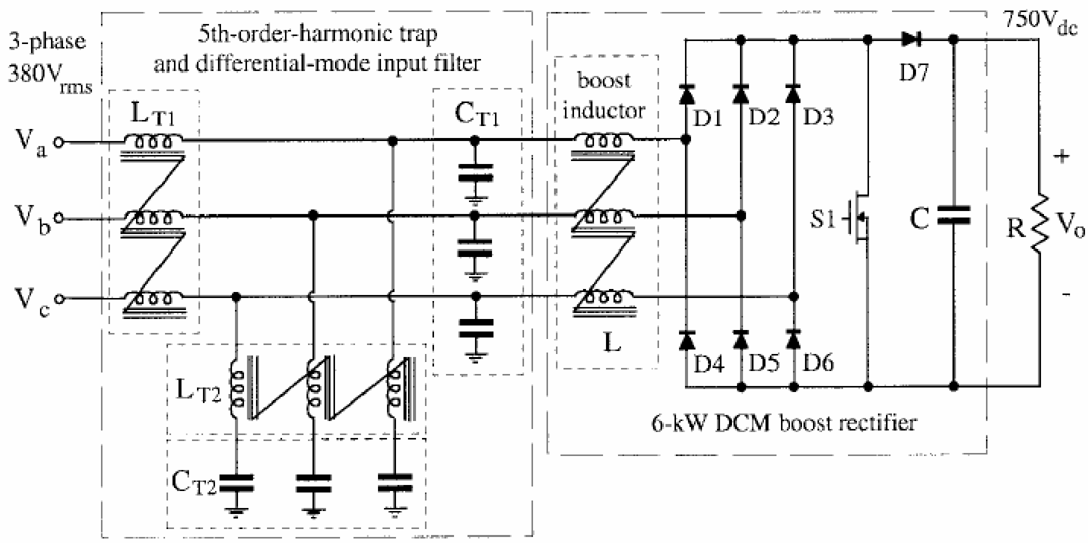

Figure 2.6: Single-switch three-phase DCM boost rectifier with 5th-harmonic trap.

The harmonic-injection method does not increase the voltage stress of the boost switch. In the technique presented in [Y. Jang and M. M. Jovanovic,1997] , a voltage signal which is proportional to the inverted ac component of the rectified three-phase line-to-line input voltage is injected into the output-voltage feedback loop to vary the duty cycle of the rectifier within a line cycle in order to reduce the fifth-order harmonic and improve the THD of the rectifier input currents.

2.4 Modulation Techniques

There are two different types of modulation techniques applied for pulse width modulation (PWM)[P. Wood ,1981]

2.4.1 Sinusoidal PWM

Technique employed where the sinusoidal waveform or modulation signal is compared with a very high frequency triangle or carrier signal to obtain the switching pulses for the device. The modulation and the carrier signals are compared such that when the sine wave is higher in magnitude the corresponding value of the switching pulse is high (has a value = 1) and when the sine wave is lower than the carrier, the pulse is low (has a value = 0). This is shown graphically in figure 2.7.

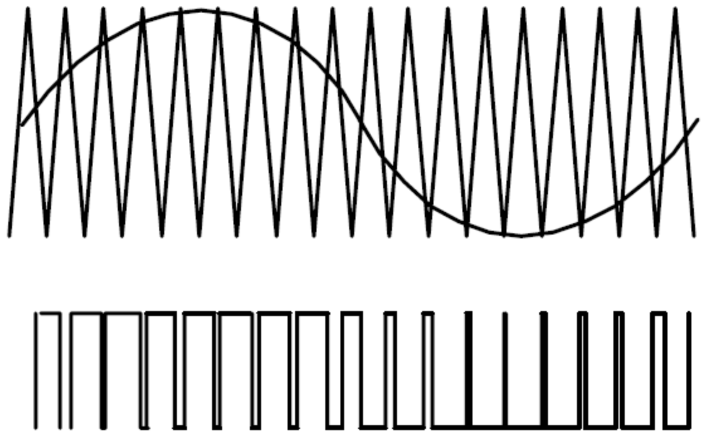

Figure 2.7 : Sine-triangle PWM

2.4.2 Generalized Discontinuous pulse width modulation (GDPWM).

Technique is represents the ac side voltages of the converter as a space vector. Each active state is represented as a vertex of a hexagon, while the null vectors are represented at the centre of the hexagon. Depending on the sector in which the reference vector lies, the switching times are calculated to generate the desired reference vector.

2.5 Active Power Filter

There are various types of active power filters and these active power filters can be classified into different categories based on the system configuration, the power circuit, the control strategy and techniques. Normally, active power filters can be classified into shunt , series or hybrid active passive power filter. The shunt active filter shown in figure 2.8. is the most fundamental system configurations where the shunt active power filter is controlled to draw and inject compensating current, I_c * to the power system and cancel the harmonic currents on the AC side of a general purpose rectifier. Thyristor or diode rectifier normally used in shunt active power filter.

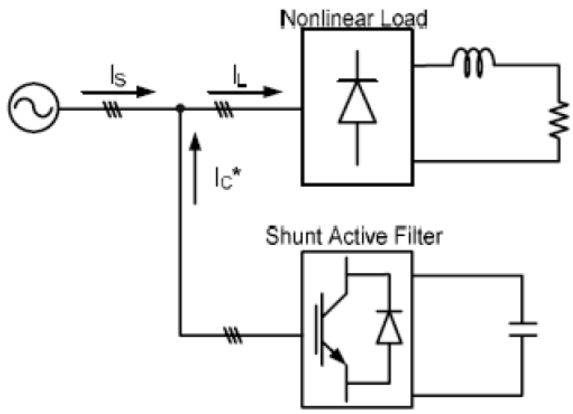

Figure 2.8. Shunt active power filter

The series active power filter show as figure 2.9 is connected in series with the utility by a matching transformer. The compensation voltage V_C* is used to cancel the voltage harmonics of the load with high capacitance in the DC side.

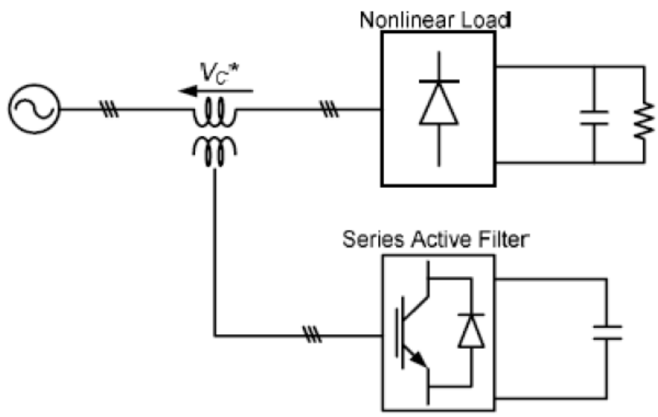

Figure 2.9 . Serie active power filter

The advantages of the active filtering process over the passive one caused much research to be performed on active power filters for power conditioning and their practical application. [Hirofumi Akagi,1994] By implementing the active power filters for power conditioning; it provides functions such as reactive power compensations, harmonic compensations, harmonic isolation, harmonic damping, harmonic termination, negative-sequence current or voltage compensation and voltage regulation. Active power filter consists of an inverter with switching control circuit. The inverter of the active power filter will generate the desired compensating harmonics based on the switching gates provided by the controller. The total harmonic distortion (THD) of a current or voltage is equal to the effective value of all the harmonics divided by the effective value of fundamental.

The equation of a distorted current is:

$$\text{Total Harmonic Distortion (THD)} = \frac{IH}{IF} \tag{2.1}$$

The equation of a distorted voltage is:

$$\text{Total Harmonic Distortion (THD)} = \frac{VH}{VF} \tag{2.2}$$

The IEEE Standard 519-1992 specifies the maximum percentage THD permitted for both current distortion and voltage distortion. [Theodore R.Bosela] . The THD in voltage and current are defined as:

$$THD = \frac{\sqrt{\sum Vn^2}}{V1}\ x\,100\,\% \qquad (N = 2,3,4\ldots\ldots\infty) \tag{2.3}$$

$$THD = \frac{\sqrt{\sum In^2}}{I1}\ x\,100\,\% \qquad (N = 2,3,4\ldots\ldots\infty) \tag{2.4}$$

Where Vn an In = the amplitide of that harmonic relative to the fundamental

n = harmonic nimber

CHAPTER 3

METHODOLOGY

3.1 Introduction

As explained in Chapter 1, rectifiers are power electronic systems that convert input ac power to output dc power. The operation of a converter can be explained in terms of the input quantities, output quantities, and the switching pattern used to obtain the preferred output. The best configuration of a boost rectifier is using pulse -width modulation technique. The pulse-width modulated rectifiers can be further divided on the basis of the relationship between the ratios of the input and output voltages. Boost rectifier has an output dc voltage that is higher in magnitude than the peak value of the ac input voltage. The switching pattern of the switches in the converter is obtained in accordance with Kirchhoff voltage law (KVL) and Kirchhoff current law (KCL). There are eight different switching modes for the boost rectifier. MATLAB-Simulink as the digital simulation tool are use in this project to simulate the three phase boost rectifier design with PWM and APF. Mastering the simulation tool and literature reviews are done first.

3.2 Development of Three Phase Boost Rectifier Design

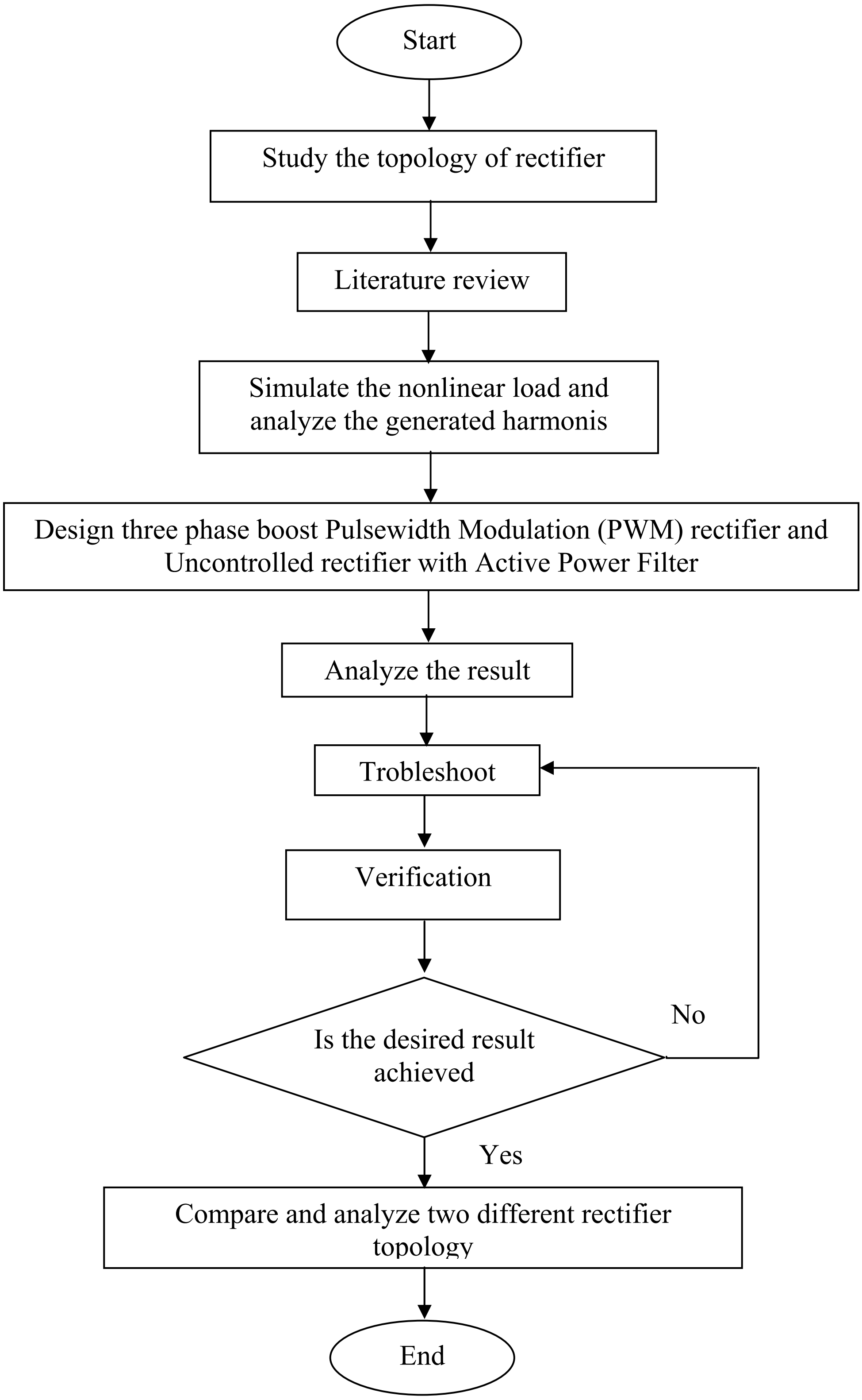

Figure 3.1: Flow chart of Three-Phase Boost Rectifier Design

3.3 Operation of Three Boost Rectifier

The application areas of the boost rectifier are varied and exhaustive due to the efficient utilization of power in the rectification process, and the boosting of the output voltage. The topology of the three-phase boost rectifier is shown in figure 3.2. The parameters of the rectifier are as defined in table 1

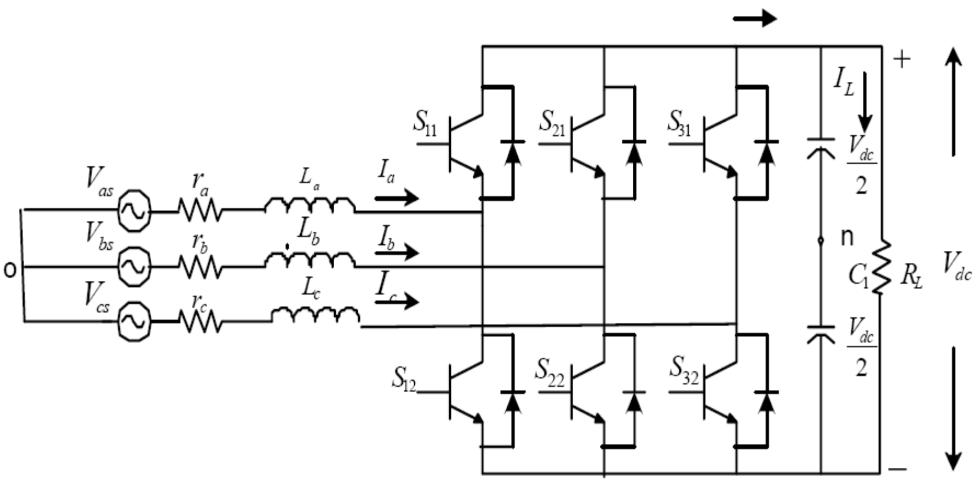

Figure 3.2: Topology of Three Phase Boost Rectifier

Table 3.1.: Variable used for three-phase boost rectifier model

Vas,Vbs, Vcs	Input AC side voltage
Ia,Ib,Ic	Phase current
ra,rb,rc	Per phase resistance
I_L	Load Current
S_{11}, S_{21},S_{31}	Switching function on top devices
S_{12}, S_{22} .S_{32}	Switching function on bottom devices
R_L	Load resistance
C	DC side capasitor

The three-phase boost rectifier comprises of six switches that are switched using sinusoidal pulse width modulation technique. In general, the operation of a converter can be explained in terms of the input quantities, output quantities, and the switching pattern used to obtain the desired output. The switching pattern of the switches in the converter is obtained in accordance with Kirchhoffs voltage law (KVL) and Kirchhoffs current law (KCL). The ON and .OFF. states of a single switch are assumed to have values 0 and 1.

In a three-phase rectifier, the input ac voltages are defined and the output dc voltage is dependent on the input quantities as well as the switching pattern of the rectifier. The switching pattern for any converter can be expressed as a function, which is a mathematical representation of the switching pattern, called an existence function. [P. Wood,1981]

There are two different types of existence functions, modulated and unmodulated. Modulated existence functions have pulses of varying widths, and unmodulated functions have pulses of uniform width. The operating modes of the boost rectifier are the same as that of a three-phase voltage source inverter. There are eight different switching modes for the boost rectifier. As explained earlier the ON and OFF states are assigned the values 1 and 0, respectively.

Table 3.2: Switching mode for boost rectifier

S.No	S_{11}	S_{21}	S_{31}
1	0	0	0
2	0	0	1
3	0	1	0
4	0	1	1
5	1	0	0
6	1	0	1
7	1	1	0
8	1	1	1

From the above eight possible switching modes, only six modes can be used in synthesizing a dc voltage, and are called active states. The two states (1 and 8) are called null states as these states do not result in an output dc voltage and are thereby inactive.

Equations (3.1) to (3.3) show that at no instant of time can the top and bottom devices of the same leg be ON simultaneously

$$S_{11} + S_{21} = 1 \tag{3.1}$$

$$S_{21} + S_{22} = 1 \tag{3.2}$$

$$S_{31} + S_{32} = 1 \tag{3.3}$$

3.4 Model of Three Boost Rectifier

The model of the three-phase rectifier is shown in figure 3.2. The switching modes and the different types of modulation schemes have been discussed in chapter II The next step in the analysis is the derivation of the model equations of the boost rectifier. In this section, the model equations of the boost rectifier are derived in the abc reference frame and then transformed to the qd reference frame

The voltage equations for the boost rectifier in the abc reference frame are:

$$V_{as} = I_a\, Z + (S_{11} - S_{21})\frac{Vdc}{2}Vno \tag{3.4}$$

$$V_{bs} = I_b\, Z + (S_{21} - S_{22})\frac{Vdc}{2}Vno \tag{3.5}$$

$$V_{cs} = I_c\, Z + (S_{31} - S_{32})\frac{Vdc}{2}Vno \tag{3.6}$$

The phase resistances and inductances are assumed to be balanced i.e. ra = rb = rc and La = Lb = Lc,where the phase impedance is

$$Z = r_i + jL_{ip} \quad I = a, b, c$$

$$p = \frac{d}{dt} \tag{3.7}$$

The phase voltages are assumed to be balanced and have a peak value of Vm. Hence the phase voltages can be defined as

$$V_{as} = V_m \cos(\omega t + \emptyset_v) \tag{3.8}$$

$$V_{bs} = V_m \cos\left(\omega t + \emptyset_v - \frac{2\pi}{2}\right) \tag{3.9}$$

$$V_{cs} = V_m \cos\left(\omega t + \emptyset_v + \frac{2\pi}{2}\right) \tag{3.10}$$

ϕv is the voltage phase angle and ω is the frequency of the voltage in rad/sec. Vno is the neutral voltage

Substituting Equations (3.1) - (3.3) in (3.4) - (3.5), the voltage equations for the boost rectifier can be expressed in terms of the switching functions of the top devices as:

$$V_{as} = I_a\ Z + (2S_{11} - 1)\frac{Vdc}{2}Vno \tag{3.11}$$

$$V_{bs} = I_a\ Z + (2S_{21} - 1)\frac{Vdc}{2}Vno \tag{3.12}$$

$$V_{cs} = I_a\ Z + (2S_{31} - 1)\frac{Vdc}{2}Vno \tag{3.13}$$

The phase impedance Z can be substituted for in Equations (3.11) to (3.13) by substituting equation (3.7).

$$V_{as} = rI_a + LpI_a + (2S_{11} - 1)\frac{Vdc}{2}Vno \tag{3.14}$$

$$V_{bs} = rI_b + LpI_b + (2S_{21} - 1)\frac{Vdc}{2}Vno \tag{3.15}$$

$$V_{cs} = rI_c + LpI_c + (2S_{31} - 1)\frac{Vdc}{2}Vno \tag{3.16}$$

$$p = \frac{d}{dt}$$

The final state equation that completes the system model for the boost rectifier is the capacitor voltage equation. The capacitor voltage equation for the boost rectifier is expressed in terms of the load current I_L and the dc current at the output of the rectifier

$$CpV_{dc} = I_p - \frac{V_{dc}}{R_L} \tag{3.17}$$

Where I_p the output is current defined in terms of the switching functions of the top devices as:

$$I_p = S_{11}I_a + S_{21}I_b + S_{31}I_c \tag{3.18}$$

Substituting equation (3.16) in (3.15)

$$CpV_{dc} = S_{11}I_a + S_{21}I_b + S_{31}I_c - \frac{V_{dc}}{R_L} \tag{3.19}$$

The next step in the analysis is the elimination of the neutral voltage in equations 3.14 to 3.16. The neutral voltage is eliminated by adding equations (3.14) to (3.16). As the system voltages V_{as}, V_{bs} and V_{cs} are balanced

$$V_{as} + V_{bs} + V_{cs} = 0$$

Hence the neutral voltage can be expressed in terms of the switching functions as

$$V_{no} = -\frac{V_{dc}}{3}[2S_{11} + 2S_{21} + 2S_{31} - 3] \tag{3.20}$$

Using equation (3.20), the neutral voltage can be eliminated in the voltage equations 3.14 to 3.16 resulting in

$$V_{as} = rI_a + LpI_a + \frac{Vdc}{2}\left(\frac{2}{3}S_{11} + \frac{2}{3}S_{21} + \frac{2}{3}S_{31}\right) \tag{3.21}$$

$$V_{bs} = rI_b + LpI_b + \frac{Vdc}{2}\left(-\frac{1}{3}S_{11} + \frac{2}{3}S_{21} + \frac{1}{3}S_{31}\right) \tag{3.22}$$

$$V_{cs} = rI_c + LpI_c + \frac{Vdc}{2}\left(-\frac{1}{3}S_{11} - \frac{1}{3}S_{21} + \frac{2}{3}S_{31}\right) \tag{3.23}$$

The simulation of the three-phase boost rectifier is using the following equations:

$$V_{as} = rI_a + LpI_a + \frac{Vdc}{2}\left(\frac{2}{3}S_{11} + \frac{2}{3}S_{21} + \frac{2}{3}S_{31}\right) \tag{3.24}$$

$$V_{bs} = rI_b + LpI_b + \frac{Vdc}{2}\left(-\frac{1}{3}S_{11} + \frac{2}{3}S_{21} + \frac{1}{3}S_{31}\right) \tag{3.25}$$

$$V_{cs} = rI_c + LpI_c + \frac{Vdc}{2}\left(-\frac{1}{3}S_{11} - \frac{1}{3}S_{21} + \frac{2}{3}S_{31}\right) \tag{3.26}$$

$$CpV_{dc} = S_{11}I_a + S_{21}I_b + S_{31}I_c - \frac{V_{dc}}{R_L} \tag{3.27}$$

The switching functions for the rectifier are obtained by sine-triangle PWM. The modulation signals are chosen to have a magnitude of 0.8 and the frequency of the modulation signals (which is equal to the frequency of the supply voltages) is taken as 50Hz. The load resistance is assumed to be 50Ω

3.5 Active Power Filter using closed loop concept

Block diagram of three phase active power filter with Hysteresis current controller show as figure 3.3 in the system configuration and design that was based on pulse-width modulated (PWM) voltage source inverter. The filter was shunt-connected with the load that being compensated. The basic concept is for the harmonic current cancellation so that the current being supplied from the source was sinusoidal.

The desired compensated harmonics *icompA**,*icompB**and *icompC* *of each phase are used as the reference currents in the system. This allows the proposed active power filter to produce the output current, *icompA*, *icompB* and *icompC* according to the reference current *icompA**,*icompB* *and *icompC* *from the instantaneous active and reactive power calculation.

The feedback current signal is the actual output current, *icomp* , of the inverter which needs to be injected back into the power line. The current error signal is acquired from the difference between the referencecurrent, *icomp* *and the feedback or actual current, *icomp* . This current error signal is then fed into hysteresis controller to generate the switching pattern of the VSI. Hysteresis control schemes are based on a nonlinear feedback loop with two-level hysteresis comparators. Six sets of appropriate gate switching signals are generated and are sent to the voltage source inverter. The desired compensated current of each phase is generated by the three phase inverter and is injected back into each power line to compensate the distorted lines current. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal which will cancel the harmonic from the nonlinear load.

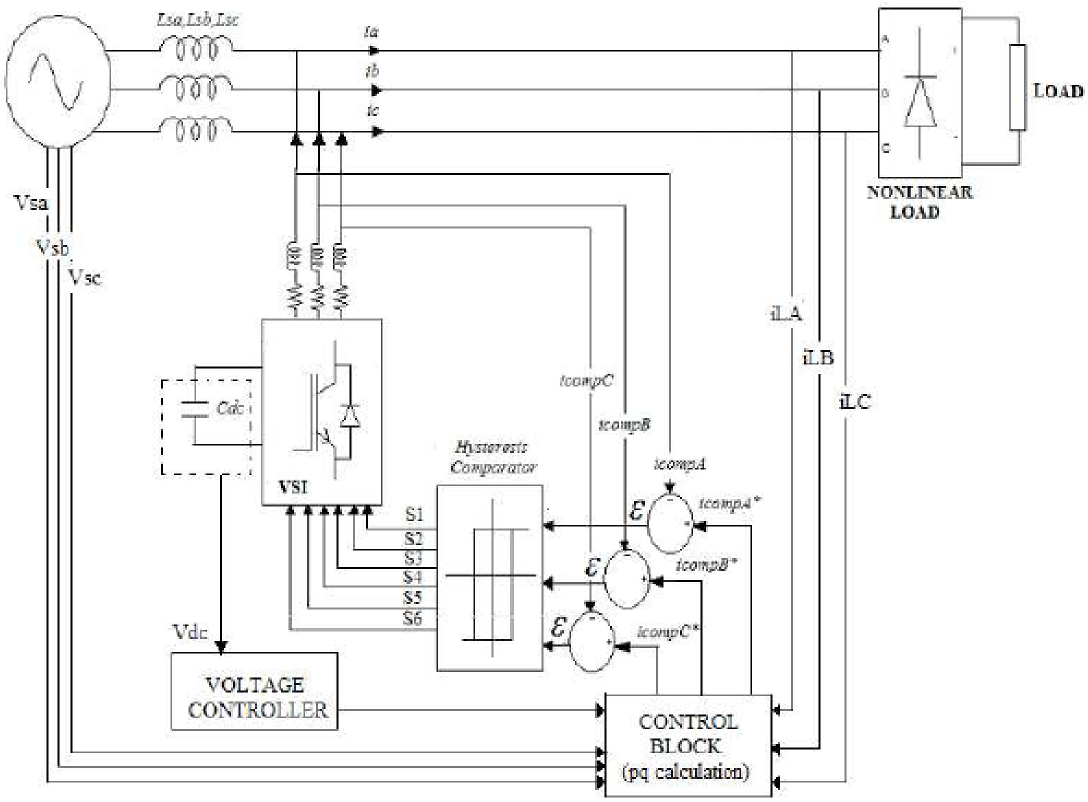

Figure 3.3: Block diagram of three phase active power filter with Hyteresis current control

3.5.1 Hyteresis Current Control

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