Model AC-Voltage Controller Using SVPWM Technique to Improve Power Quality

Case Study: Dire Dawa National Cement Share Company

AMBESSA SORI GIDA

A Thesis Submitted to the Program Chair of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Specialization in Power Electronics)

Office of Graduate Studies
Adama Science and Technology University

Adama
January, 2019

Model AC-Voltage Controller Using SVPWM Technique to Improve Power Quality

Case Study: Dire Dawa National Cement Share Company

Ambessa Sori Gida

ID No:GSR/0029/09

Advisor:

Kemal Ibrahim (PhD)

A Thesis Submitted to the Program Chair of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Specialization in Power Electronics)

Office of Graduate Studies

Adama Science and Technology University

Adama

January, 2019

Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by **Ambessa Sori** have read and evaluated his thesis entitled **"Model AC-Voltage Controller Using SVPWM Technique to Improve Power Quality"** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master's in **Electrical Power and Control Engineering (Specialization in Power Electronics Engineering).**

KEMAL IBRAHIM (PhD)	_______________	_______________
Supervisor /Advisor	Signature	Date
______________________________	_______________	_______________
Chairperson	Signature	Date
______________________________	_______________	_______________
Internal Examiner	Signature	Date
______________________________	_______________	_______________
External Examiner	Signature	Date

Declaration

I hereby undersigned, declare that this **MSc** thesis is my original work and has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been duly acknowledged.

Name: Ambessa Sori

Signature: _____________

This **MSc** thesis has been submitted for examination with my approval as thesis advisor.

Name: Dr. Kemal Ibrahim

Signature: ________________________

Date of submission: ___________________

Supervisor's/Advisor's Approval Sheet

To: Electrical Power and Control Engineering department

Subject: Thesis Submission

This is to certify that the thesis entitled **"Model AC-Voltage Controller Using SVPWM Technique to Improve Power Quality"** submitted in partial fulfillment of the requirements for the **Degree of Master's in Electrical Power and Control Engineering (Specialization in Power Electronics),** the Graduate program of the department of Electrical Power and Control Engineering and has been carried out by **Ambessa Sori** Id. No. **GSR/0029/09** under my supervision.

Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Dr.Kemal Ibrahim	____________________	_______________
Name of major Advisor/supervisor	Signature	Date

ACKNOWLEDGEMENT

First and foremost, I take this opportunity to give glory to the almighty God, without whom the completion of this thesis work would have been impossible.

Next I would like to thank School of Electrical Engineering and Computing for their provision of necessary coordination during my thesis progress and work.

Again, I would like to express my sincere gratitude to my advisor, Dr. Kemal Ibrahim, for his expert guidance, patience, constructive comments, suggestions, encouragement and supports for the successful completion of this thesis work. He has been a constant source of inspiration throughout lifespan of my thesis.

It’s my pleasure to convey my special gratitude to my Wife Wubnesh Erena, and my sincerely thanks go to my family, friends and everyone whose constant concern and support reinforced my personal efforts, contributing to the completion of this thesis work.

I also would like to thank my uncle Dr.Girma Beka Researcher at Dept.of Microelectronics School of Electrical and Information Einginering,Xi’am jiaotong University in China, who have been a constant source of inspiration and support throughout my academic career.

Last but not least, my acknowledgement is extended to Electrical power and Control Engineering Department and all staff member for their help throughout the course they taught for this thesis work too.

TABLE OF CONTENTS

CONTENT'S **PAGE**

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms	Definition
$(V_{Ao})_1$	Fundamental frequency component of V_{Ao}
AVR	Automatic Voltage Regulator
CSI	Current Source Inverter
CVT	Constant Voltage Transformer
GUI	Graphical User Interface
SDG	Standby Diesel Generator
MATLAB	Matrix Library
NCSC	National Cement Share Company, Dire Dawa, Ethiopia.
Pf	Power factor
PQ	Power Quality
PWM	Pulse Width Modulation
RMS	Root Mean Square
SMPS	Switch-Mode Power Supplies
SPWM	Sinusoidal Pulse Width Modulation
SVPWM	Space Vector Pulse Width Modulation
THD	Total Harmonic Distortion
VC	Voltage Controller
VSI	Voltage Source Inverter

SYMBOLS

E	Total Energy Loss
E_{avr}	Average Energy Loss
f	Voltage and Current Variable
h	Harmonic number
I	Current
I_L	Maximum Demand load Current
I_n	Magnitude of Individual Harmonic components
I_{sc}	Short Circuit Current at point of Common Coupling or Transformer
K_d	Derivative gain, a tuning parameter
K_i	Integral gain, a tuning parameter
K_p	Proportional gain, a tuning parameter
m	Modulation index
n	Harmonic Order
θ	Load angle
P	Load Demand Power
V	Voltage
V_A	Pole Voltage
V_{av}	Average Three Phase Voltage
V_{max}	Voltage Magnitude of Extreme Phase
V_n	Nominal Voltage
V_{rms}	Root Mean Square of output Voltage
SP	Set Point
t	Time or instantaneous time

ABSTRACT

The Automatic Voltage Regulator (AVR) has more switching loss, voltage sag and Total Harmonics Distortion. This is an issue of industrial applications today in Dire Dawa National Cement Share Company (NCSC). The causes of the problems in the factory include sudden load changes, power system faults (short circuited) and reducing of its efficiency. In power electronic devices various Pulse-Width-Modulation (PWM) techniques have been developed for industrial applications. Out of the various methods, the Space Vector Pulse Width Modulation (SVPWM) based voltage control has established to the most versatile. It is providing better sinusoidal wave form of both voltages and currents, fast switching, less sags and total harmonic distortion. In this thesis works, using MATLAB R2013a Simulink software. AC-voltage controller using SVPWM techniques are analyzed, designed and simulated to reduce the sags and total harmonics that are dominant in NCSC of induction motor. The THD values of AVR and SVPWM are compared. The modeled THD values of current were highly reduced compared with the THD value measured from the company of the existing AVR controller in NCSC. This improves the power quality problems in this factory by adjusting the THD of voltage from 3.266% to 1.60%; and similarly THD of current from 33.2% to 1.27%.

Key Words: *AVR, Power quality, SVPWM-AC controller, Voltage sag and Harmonics.*

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

AC voltage controllers are widely used to obtain variable AC voltage from fixed AC source. They are extensively employed in many applications such as industrial heating, lighting control, soft starting of induction motors and speed controllers for fans and pumps. Triacs or thyristors pairs (anti-parallel) connected are usually employed as the power control elements of such Controllers [6]. Such techniques offer some advantages as simplicity and ability of controlling large amount of power economically. However, delayed firing angle causes discontinuity and plentiful harmonics in load current, the size of the passive circuit becomes bulky and also a lagging power factor occurs at the AC side even though the load is completely resistive especially when the firing angle increases [4, 5, 10,].

Pulse in terms of power electronics, sudden change of rise for ON condition and sudden change of decay for OFF condition in a specified interval of time by the user or by the automated system. Rise or decay is the electromagnetic field, voltage or current parameters of electric power leads to generate a pulse. Pulse density modulation (PDM), Pulse width modulation (PWM),pulse frequency modulation (PFM), amplitude modulation (AM),pulse code modulation (PCM) are introduced by the researchers to operate the various electronic, communication and power electronic systems. In this paper, presenting a review based on space vector PWM methods, their operation, and utilization for the area of power electronics. The arrangement of power electronic switches in a specified design to build the inverter [32]. To operate the inverter for the required outs, it has to switch ON and switch OFF the arranged switches in a sequential order. To ON or OFF the switch, the pulse is needed. Based on the parameters of the pulse, the switches are performing the required needs. Generation of the pulse is done by various methods. These methods are called pulse generation methods [1][32]. The control of switches in the inverter is done by varying the width of the pulse has been called pulse width modulation (PWM).

The switching mode power conversion gives high efficiency; but the main disadvantages of Automatic Voltage Regulator (AVR) is that harmonics are generated at the supply and load sides due to the non-linearity of switches when compared with the space vector Pulse Width Modulation [12]. The harmonic currents generated by the power electronics related-equipment flow through the utility system and cause various power quality problems. Most of the power switches have different operating conditions; thus, they generate different order and different amplitude harmonics [11]. Due to the increasing application of power electronic equipment's, more and more energy is transmitted at non-sinusoidal voltage and current, and the harmonic problem is more and more serious. The harmonic limitations are very important issues so that power systems are preserved from the effect of harmonic pollution.

One of the well-known methods is the SVPWM control technique [9].The advantages of SVPWM control technique to be gained include nearly sinusoidal input-output current/voltage wave-forms, better input power factor, better transient response, elimination of the low order harmonics and, consequently, smaller input output filter parameters. On the other hand, control by switching is often accompanied by extra losses due to the switching losses.

A Space vector Pulse Width Modulation control method is required to get a desired fundamental frequency voltage and to eliminate higher order harmonics as much as possible. Space vector SVPWM is considered a better technique of PWM implementation owing to its associated Advantages like better fundamental output voltage, better harmonic performance and easier implementation in digital signal processor and microcontrollers. SVPWM can be efficiently executed in a few microseconds, achieving similar results compared with other PWM methods.

Recently, PWM AC voltage controller has been developed and used extensively in AC-AC converter circuit. One of the most popular PWM adopted in AC-AC circuit is "fixed-duration pulse PWM". However, to enhance the performance of AC voltage controller, various strategies were presented for improving the waveform quality of this circuit. They presented the results of current harmonics reduction due to their approach.

1.1.1. Performance and waveform quality in AC voltage Controller

The output waveform of PWM AC voltage controller is not pure sinusoidal waveform and contains harmonics [4]. It is well known issue that harmonics often reduce performance, waveform quality and efficiency of system. The input of PWM AC voltage controller is usually connected with the utility grid which assumed as pure sinusoidal source. Thus, the harmonic distortion of input voltage is not occurred and is not considered for evaluating performance of this circuit. However, the input current which is the same as output current contains harmonics because of its non-sinusoidal output waveform. This current harmonic causes the current harmonic distortion (THD_i), low input power factor and loss. Thus, to enhance the performance of the system, current harmonic distortion needs to be reduced [2]. The total harmonic distortion of current in PWM AC voltage controller can be measured and determined by (1.1)[2]; if load value is assumed to be R-L loads with known value; and, each harmonic current can be determined by (1.2)[2].

$$\mathrm{THD_i} = \frac{\sqrt{\sum_{n=2}^{\infty} \mathrm{I_n}^2}}{\mathrm{I_1}} \tag{1.1}$$

$$\mathrm{I_n} = \frac{\mathrm{V_n}}{\sqrt{\mathrm{R}^2 + (2\pi \mathrm{f} \mathrm{L})^2)}} \tag{1.2}$$

Where

$\mathrm{THD_i}$ is the total harmonic distortion of current.

n is the n^{th} harmonic order,

$\mathrm{V_n}$, $\mathrm{I_n}$ are rms value of n^{th} harmonic order, voltage and current respectively,

$\mathrm{V_1}$, $\mathrm{I_1}$ are rms value of fundamental, voltage and current respectively,

R, L are resistance and inductance value of load,

f is frequency of fundamental Voltage.

Similarly, the output voltage (V_{rms}) and total harmonic distortion of voltage (THD_v) in PWM AC voltage controller can be determined by (1.3) and (1.4) [6].

$$\mathrm{V_{rms}} = \sqrt{\sum_{n=1}^{n} \mathrm{V_n}^2} \tag{1.3}$$

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \tag{1.4}$$

$$\mathrm{Pf} = \frac{\cos\theta}{\sqrt{1 + \mathrm{THD_i}^2}} \tag{1.5}$$

Equation (1.5) shows the input power factor of any PWM AC voltage controller circuit when $\mathrm{THD_i} < 5\%, \mathrm{THD_V} < 40\%$. Clearly, total current harmonic distortion causes the reduction of input power factor.

Where

Pf is the power factor

θ is the Load angle

$\cos\theta$ is the power factor existing at previous system

1.1.2. National Cement Share Company Overview

Dire Dawa National Cement Share Company is located in eastern Ethiopia just at the entrance of the queen city of Dire Dawa at 515km, from Addis Abeba. This company produces ordinary Portland cement and Portland Pozzolana Cement. It has the following energy source supplies.

A. Energy Sources of National Cement Share Company

This NCSC is using two Energy Sources. The Electrical power from the Ethiopian Electric Utility (EEU) supply and the other one is from the Diesel Generators.

B. Power network of National cement Share Company

The main busbar of the NCSC gets its supply from two different sources. These are

1. Power from EEU(Ethiopian Electric Utility)
2. Power from Diesel Generator.

The standby Diesel Generator system (SDG) produces 800KVA; P.f is 0.89 and supplies power to all loads of the factory during power interruption from the main power supply of EEU. Where the loads are distributed from Main distribution board (MDB-1 and MDB-2). The power distribution in NSCC is hierarches as shown in figure 1.1.

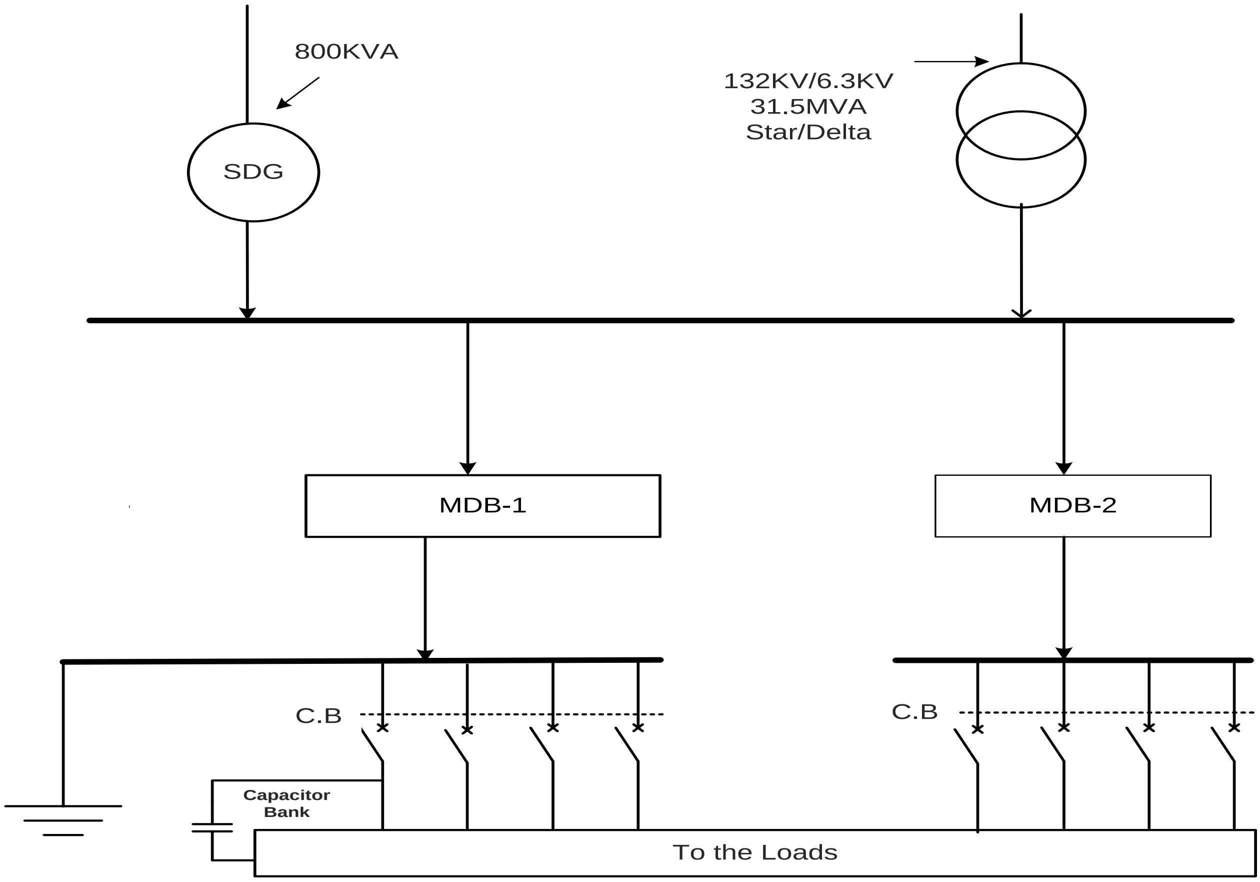


Figure 1.1: Single line diagram of NCSC power Supply.

1.2. Statement of the problems

The presence of high THD and voltage sag are engaged in AVR controller because of the unwanted harmonics and sags occurs at NCSC .These problems are overcome by modeling an electronic Ac voltage Controller using SVPWM technique to mitigate the problems like voltage sag and harmonics distortion, which are the main problems challenged in Dire Dawa NCSC.

1.3. Significance of the study

If AVR are substituted by SVPWM technique the following advantages of pulse width modulations are obtained.

- ✓ Little heat whilst working.
- ✓ Low power consumption and THD.
- ✓ High power handling capability.
- ✓ Wide linear modulation range.
- ✓ Less total harmonic distortion in the spectrum of switching waveform.
- ✓ Easy implementation and less computational calculations.

1.4. Aim and Objective of the study

This study aimed to deal with the effect of power quality problems like Voltage sag and THD on Dire Dawa NCSC. As this Company has load which are very sensitive to disturbances in the Voltage supply, it is very important to know how different process react when power disturbance is occur and how to minimize by using SVPWM techniques. To achieve this aims the following General and Specific objectives have been identified.

1.4.1. General objective

The main objective of this thesis is to Design AC-Voltage Controller using SVPWM techniques to improve the power quality problems that exhibited at NCSC by reducing the Voltage sag and harmonics distortions.

1.4.2. Specific objective

- ✓ To identify the root cause of power quality problems in NCSC.
- ✓ To analyze the power quality control through the SVPWM technique.
- ✓ To design AC voltage controller by using SVPWM technique.
- ✓ To simulate and analyze Ac voltage controller.

1.5. Limitations (Scope) of the study

The scope of this thesis is to mitigate the voltage sag and harmonics problems by designing AC Voltage Controller using SVPWM technique and analyzes the power quality in Dire Dawa National Cement Share Company.

1.6. Software Tools

MATLAB/Simulink is a software tool used in this thesis work for modeling and simulation purpose. Simulink is an important input/output device GUI block diagram simulator. It contains a Command Window and Library Editor of Tools from which we can build input/output devices; continuous and discrete time model of simulations. MATLAB is a power full high performance tool to validate your ideas by creating field like conditions using computer. It integrates computation, visualization and programming.

Typical uses include:

- ✓ Math and computation
- ✓ Algorithm development
- ✓ Data acquisition
- ✓ Modeling, simulation, and prototyping
- ✓ Data analysis, exploration, and visualization

1.7. Thesis Organization

This thesis comprises of six chapters. Chapter one deals with the complete introduction of the thesis work, statements of the problem , significance of the study, the objective of the thesis work and the way the thesis is organized. It also gives a basic idea of the content present in the thesis. Chapter two deals with the literature review and its introduction are also given for the further references. In this chapter varies pulse width modulations of three phase and power quality problems are reviewed. The working of the basic voltage source inverter with space vector pulse width modulation and its circuit operation techniques is explained.

Chapter three deals with methodology through which data collection and mitigation technique has been organized. A detailed study on the space vector pulse width modulation is explained and the way the harmonics are reduced for space vector pulse width modulation, using MATLAB R2013a is also explained. The system design and description of the thesis work dealt under Chapter four. Chapter five deals with the simulation result and discussion and Simulink output voltage and current of THD obtained from the simulation of the AC voltage Controller by SVPWM technique. Chapter six deals with conclusions made and recommendation for this thesis work.

CHAPTER TWO

LITERATURE REVIEW

2.1. Theoretical Background

Pulse-width modulation (PWM) is a technique where the duty ratio of a pulsating waveform is controlled by another input waveform. The intersections between the reference voltage wave form and the carrier wave form give the opening and closing times of the switches. These PWM are used to control both the frequency and the magnitude of the voltages applied to motors [29]. The three techniques used to generate their respective output PWM signals are Sinusoidal pulse width modulation (SPWM), Third-harmonic-injection pulse-width modulation (THIPWM), and space vector pulse width modulation (SVPWM), which are then compared based on harmonic content and distortion using the total harmonic distortion (THD) measure of various output voltages.

The sinusoidal pulse-width modulation (SPWM) technique produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage. The variations in the amplitude and frequency of the reference voltage change the pulse-width patterns of the output voltage but keep the sinusoidal modulation [15, 32]

In three-phase SPWM, a triangular voltage waveform (V_T) is compared with three sinusoidal control voltages (V_a, V_b, and V_c), which are 120^0 out of phase with each other and the relative levels of the wave forms are used to control the switching of the devices in each phase leg of the inverter.

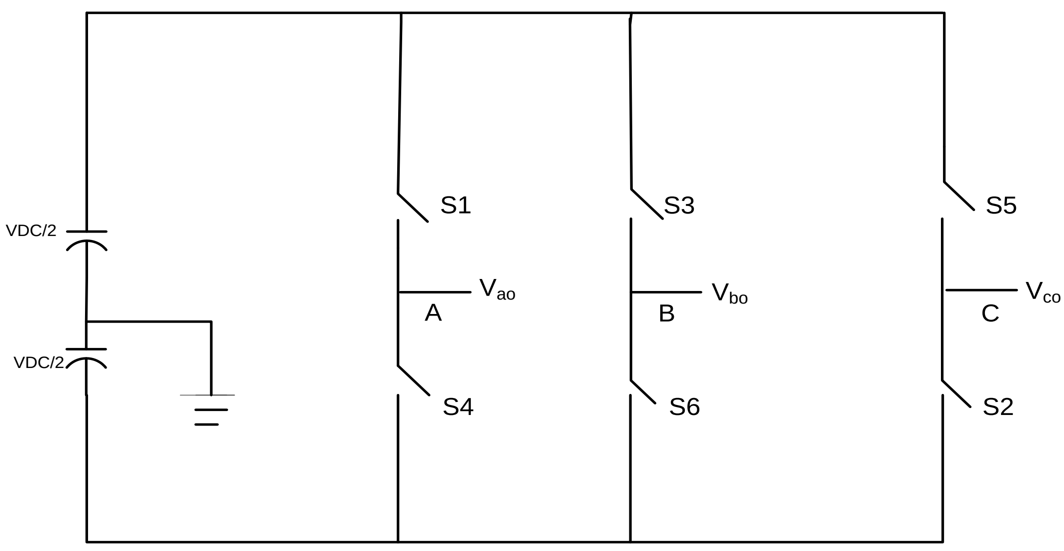


Figure 2.1: Three phase sinusoidal PWM inverter [15]

Switches in figure 2.1, at each phase make up one leg open and close in a complementary fashion. That is, when one switch is open, the other is closed and vice-versa. The output pole voltages V_{ao},V_{bo} and V_{co}, of the inverter switch between $\frac{-Vdc}{2}$ and $\frac{+Vdc}{2}$ voltage levels where V_{dc} is total DC voltage. The peak of the sine modulating waveform is always less than the peak of the triangle carrier voltage waveform. When the sinusoidal waveform is greater than the triangular waveform, the upper switch is turned on and the lower switch is turned 'OFF'. Similarly, when the sinusoidal waveform is less than the triangular waveform, the upper switch is 'OFF' and the lower switch is 'ON'. Depending on the switching states, either the positive or negative half DC bus voltage is applied to each phase.

The sinusoidal PWM is the simplest modulation scheme to understand but it is unable to fully utilize the available DC bus supply voltage. Due to this problem, the third-harmonic injection pulse-width modulation (THIPWM) technique was developed to improve the inverter performance [2, 32].The THIPWM is implemented in the same manner as the SPWM, that is, the reference waveforms are compared with a triangular waveform. As a result, the amplitude of the reference waveforms does not exceed the DC supply voltage $\frac{Vdc}{2}$, but the fundamental component is higher than the supply voltage V_{dc}.

Another method for increasing the output voltage about that of the SPWM technique is the space vector PWM (SVPWM) technique. Compared to THIPWM, the two methods have similar results but their methods of implementation are completely different. In the SVPWM technique, the duty cycles are computed rather than derived through comparison as in SPWM. The SVPWM technique can increase the fundamental component by up to 27.39% that of SPWM [32, 10]. The fundamental voltage can be increased up to a square wave mode where a modulation index of unity is reached.

Space Vector Pulse Width Modulation (SVPWM) was first introduced by the German researchers in the mid of 1980s [26]. This technique showed several advantages over the traditional pulse width modulation (PWM) technique and Automatic Voltage Regulator (AVR) [3]. SVPWM technique can maximize the output voltage and also reduce the switching number at the same carrier frequency of the PWM method. A number of pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply [4, 5]. The most widely used PWM schemes for three-phase voltage source inverters are carrier based sinusoidal PWM and space vector PWM (SVPWM). There is an increasing trend of using space vector PWM (SVPWM) because of their easier digital realization and better DC bus utilization [10, 14].

SVPWM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic non-zero vectors forming a hexagon. A circle can be inscribed inside the state map and corresponds to sinusoidal operation. The area inside the inscribed circle is called the linear modulation region or under-modulation region. As seen in Figure 2.2, the area between the inside circle and outside circle of the hexagon is called the nonlinear modulation region or over-modulation region [1, 2]. The concepts in the operation of linear and nonlinear modulation regions depend on the modulation index, which indirectly reflects on the inverter utilization capability.

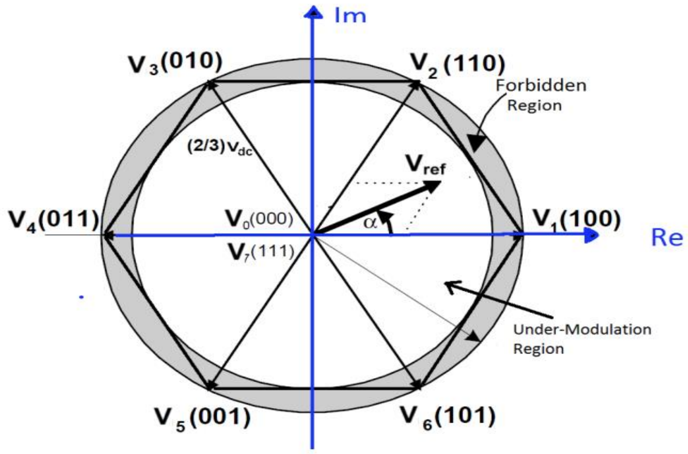


Figure 2.2: under-modulation and over-modulation regions in space vector representation.

2.1.1. Space Vector PWM in Over Modulation Region

Over-modulation aims to extend the linear operation region of the SVPWM, which leads to a better utilization of the DC bus voltage and enhances the power utilization of the voltage source inverter [21]. Several approaches to over-modulation have been proposed to extend the linear region of SVPWM over the years. It is an advanced method and possibly the best technique for variable frequency drive applications. The modulation index (m) of the over-modulation region ranges from 0.907 up to 1 [11].The over-modulation range can be considered as one region or it is the region below the forbidden region but above the circle or under modulation regions can be seen in figure 2.2. In this thesis, the over-modulation region is considered as one region with one modes of operation depending on the modulation index values. The actual voltage vector keeps the angular speed of a modified reference vector constant, but its amplitude changes over time. The over-modulation region starts when the reference voltage exceeds the hexagon boundary, and the m is larger than 0.907. The boundary between the under-modulation zone and over-modulation region starts when m=0.907 and the boundary between the over-modulation region.

2.1.2. Under Modulation of Space Vector PWM

A three-phase inverter has eight possible inverter switching states that can generate eight space vectors; six non-zero vectors or active vectors (V_1 to V_6) and two zero vectors (V_0 and V_7). These vectors are applied during the switching times T_0, T_1, and T_2. According to the time duration equations in the figure 2.1 on under-modulation SVPWM, the average pole voltage vector over one PWM period can be averaged using two adjacent vectors and the null vectors [23]. To generate a rotating space vector with constant amplitude, the reference voltage vector must be limited to the inscribed circle inside the hexagon. The simulation model used to verify the under-modulation SVPWM scheme. The smaller circle represents the operating region of the SPWM technique and the larger inscribed circle represents the operating region of the SVPWM technique in the under-modulation region [22].

The quality of voltage and current delivered by the power utilities has become a major concern of the modern industries. These power quality problems are voltage sag and harmonic which can cause problems to the industries ranging from malfunctioning of equipment to complete plant shutdowns [15].

AC to AC voltage converters operates on the AC mains essentially to regulate the output voltage [27]. Applications of power electronics loads are continually overtaking industry space from other types of loads, especially because of their ability to help the conservation of energy and provide better control over traditional and new processes (Paice 1996). According to Electric Power Research Institute (EPRI), it is estimated about 60% of all electrical power has been processed in some way by solid state methods. The inherent nonlinear nature of the power electronic load places harmonic current/voltage demands and extraneous losses upon the electrical power system [8]. A situation that has raised waveform distortion levels in distribution networks even further is the application of capacitor banks used in industrial plants for power factor correction and by power utilities for increasing voltage profile along distribution lines. The resulting reactive impedance forms a tank circuit with the system inductive reluctance at a certain frequency likely to coincide with one of the characteristic harmonics of the load. This condition will trigger large oscillatory currents and voltages that may stress the insulation [13].

Harmonic distortion is an issue that needs continual attention. The emerging power quality industry is in the process of standardizing the procedure to solve harmonic distortion problems. Kazibwel and Sendaulaz (1992) provided a set of procedures implemented in an expert systems frame work can be used by utilities and their customers to solve harmonic distortion problems. Power electronic systems generate harmonics. Harmonic attenuation is important in the improvement of power quality [12]. For power control, using specified pulse width modulated (PWM) phase control per cycle of the AC supply reduces the harmonic impact of many AC-to-AC electronic controllers [7].But the automatic voltage regulator (AVR) is used to regulate the voltage generally. It takes the fluctuate voltage and changes them into a constant voltage more than the SVPWM techniques. The fluctuation in the voltage mainly occurs due to the variation in load on the supply system. The variation in voltage damages the equipment of the power system. The variation in the voltage can be controlled by installing the voltage control equipment at several places likes near the transformers, generator, feeders, etc., the voltage regulator is provided in more than one point in the power system for controlling the voltage variations [16].The process control to maintain a constant desired voltage of an alternator and voltage regulation of alternator is defined as the change in its terminal voltage when the full load is removed, keeping field excitation and speed control divided by the rated terminal voltage [20].

$$\%\ \text{Voltage regulation} = (V_0 - V_r) * \frac{100}{V_r}, \qquad (2.1)$$

Where; V_r = Rated terminal voltage

V_0= No load induced emf.

A different approach to SPWM is based on the space vector representation of voltages in the d, q plane. The d, q components are found by park transform, where the total power, as well as the impedance, remains unchanged. Figure 2.2 shows eight space vectors in according to eight switching positions of inverter, V_{ref} is the phase-to-center voltage which is obtained by proper selection of adjacent vectors V_1 and V_2.The main aim of modulation techniques is to get less harmonic distortion, less switching time and large modulation ratio. For this reason, many modulation techniques have been improved recently, SVPWM technique has become more popular because of achieving the goals mentioned above [1, 16]. $V_{max} = \frac{V_{dc}}{2}$: For Sinusoidal PWM and $V_{max} = \frac{V_{dc}}{\sqrt{3}}$: For Space Vector PWM, Where, V_{dc} is DC-link voltage. This means that Space Vector PWM can produce about 15 percent higher than sinusoidal PWM in output voltage [32].

2.2. Power Quality problems

In general way, many power quality problems originate in the commercial power grid, which, with its hundredths of kilometers of transmission lines, is subject to atmospheric condition like snow, cyclone, lightning storms, ice, and flooding along with equipment failure, traffic accidents and major switching operations. Also, power problems affecting today's technological equipment are often generated locally within a facility from any number of situations, such as local construction buildings, heavy start up loads, and faulty distribution system components. Power quality problem or power quality disturbance, is generally defined as any change in power, voltage, current, or frequency that interferes with the normal operation of electrical equipment [28].

The study of power quality, and ways to control it, is an interest one for electric utilities, large industrial companies like NCSC, and even home users. The study has intensified as equipment has become increasingly sensitive to even minute changes in the power supply voltage, current, and frequency. Unfortunately, different terminology has been used to describe many of the existing power disturbances, which creates confusion and makes it more difficult to effectively discuss, study, and make changes to today's power quality problems. Due to this, The Institute of Electrical and Electronics Engineers (IEEE) has attempted to address this problem by developing a standard and definitions of power disturbances [29]. The standard (IEEE Standard 1159-1995, "IEEE Recommended Practice for Monitoring Electrical Power Quality") describes many power quality problems based on the wave shapes of which are:-

i. Voltage Transient
   - ✓ Impulsive transient
   - ✓ Oscillatory transient

ii. Short duration voltage variation
   - ✓ Voltage Interruption
   - ✓ Voltage Sag
   - ✓ Voltage Swell

iii. Long duration voltage variation
   - ✓ Under voltage
   - ✓ Over voltage
   - ✓ Sustained interruption

iv. Waveform distortions
   - ✓ DC offset
   - ✓ Harmonics
   - ✓ Inter harmonics
   - ✓ Notching
   - ✓ Noise

v. Voltage unbalance

vi. Voltage fluctuations

vii. Frequency deviations

This thesis would conform to these categories and include graphics, which should clarify the differences between individual power quality disturbances.

2.2.1. Short Duration Voltage Variation

This category encompasses RMS-voltage variations that stay for a period time which is less than 1-minute most of the time. Short-duration voltage variations are caused by faulty conditions, energization of large loads, or intermittent loose connections in power wiring. The impact on the voltage during the actual fault condition is of the short-duration variation until protective devices operate to clear the fault. Depending on the type of fault and the system conditions, the short duration voltage variation may be either a voltage sag (dip), voltage rise (swell), or interruption.

Short Duration Voltage of Voltage Sag or Dip

Voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. This Voltage sag is most frequently happened in the Dire Dawa NCSC, Most voltage sags do not go below 50 percent of the nominal voltage, and they normally last from 3 to 30 cycles. Voltage sags are the most significant power quality (PQ) problem facing in dire dawa NCSC and other industrial customers today, and they can be a significant problem for large commercial customers as well.

A Voltage sag as seen below in Figure 2.3 is a reduction of AC voltage at a given frequency for the duration of 0.5 cycles to 1 minute's time with its voltage magnitude 0.1 to 0.9 pu. Voltage Sags are usually caused by system faults, and are also often the result of switching on loads with heavy start up currents. They are also caused by energization of heavy loads, or starting of large motors that draw very large amount of current at start up [21]

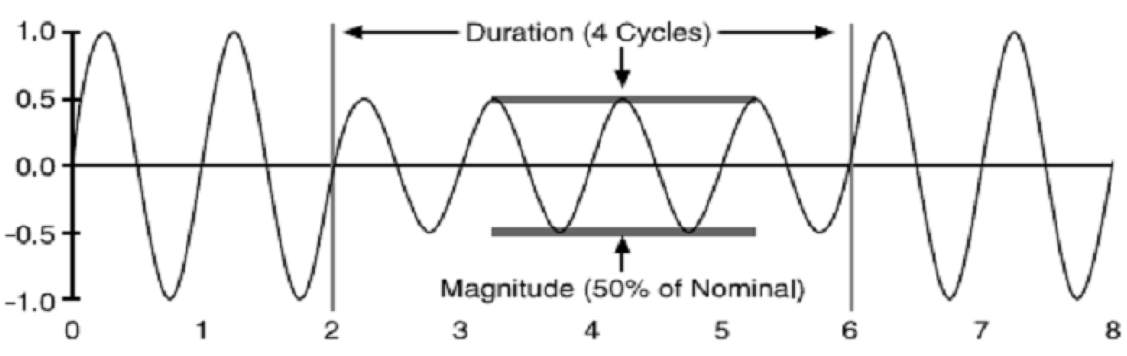


Figure 2.3: Voltage sag [26].

There are two sources of voltage sags; external (on the Ethiopian Electric utility lines up to your end user facility) and internal (within your end user facility in our case NCSC). Ethiopian Electric Utilities continuously try to provide the most reliable and consistent electric power possible. In the course of normal Ethiopian Electric utility operations, however, many things can cause voltage sags as well in Dire Dawa NCSC. Storms (heavy atmospheric phenomena) are the most common cause of external Voltage sags and momentary interruptions in most areas of the Dire Dawa storm especially during rainy season passing through an area can result in dozens of major and minor PQ variations, including Voltage sags. For example, consider how PQ would be affected by a lightning strike on or near a power line or by wind sending tree limbs into power lines. Other common causes of external voltage sags are ice storms, animals (particularly camels, apes, squirrels which are mostly available around NCSC), and the start-up of large loads at neighboring facilities. Internal causes of voltage sags can include starting major loads and grounding or wiring problems in the Systems.

Whether or not voltage sag causes a problem will depend on the magnitude and duration of the Voltage sag and on the sensitivity of your equipment. Many types of electronic equipment are sensitive to voltage sags, including variable speed drive controls, motor starter Contactors, robotics, programmable logic controllers, controller power supplies, and control relays. Much of this equipment is used in applications that are critical to an overall process, which can lead to very expensive downtime when voltage sags occur.

If the facility is having frequent voltage sag problems, a good place to start is with identifying the type of Voltage sags weather it is external or internal, and ask about the Ethiopian Electric utility statistics regarding performance in our area if it is line problem(132KV), You should also look into possible internal causes. But whether the causes are mainly external or internal, you should consider taking charge of the problem and working toward a cost effective solution for your facility.

Solutions to Voltage Sag Problems

The first step toward a cost-effective solution is to understand the sensitivity of electronic equipment to momentary interruptions and voltage sags[24]. To find this information by consulting the equipment manufacturer’s specifications (name plates) and testing data, and can also test the sensitivity of the equipment to voltage sags using a measuring device called a sag generator, which generates voltage sags and records the responses of the equipment. There are several possible solutions to voltage sag problems. Generally, the least expensive approach is to purchase controls and other electronic equipment designed with a greater tolerance to voltage sags. Information on these tolerances should be included in the equipment’s specifications. Another inexpensive and simple solution is to adjust the trip thresholds of sensitive equipment. When identify a relay that is inadvertently tripping during a voltage sag, then change its settings either the voltage threshold or the trip delay. However, only doing this if the trip settings were set too conservatively, so it is important to understand what they were designed to protect. Another option is to install a coil hold-in device. These devices are designed to mitigate the effects of voltage sags on individual relays and contactors. Coil hold-in devices are installed between the relay or contactor coil connection terminals and the incoming alternating current (AC) control line. They allow a relay or contactor to remain engaged until the voltage drops to about 25 percent of nominal, significantly improving its voltage sag tolerance without interfering with emergency shut OFF functions. The best application for this type of device is to support relays and contactors in an emergency OFF circuit, master control relay, or motor control circuit. Coil hold-in devices normally are small enough to be installed next to the contactor, relay, or motor starter.

The next level of potential solutions in terms of cost is to consider modifying the power supplied to the sensitive equipment. For example, it may be possible to substitute a direct current (DC) operated power supply for an AC supply. This would allow to use simple capacitors or batteries to help support the DC bus. This is the approach that high-reliability telecommunications systems commonly use. The remaining solutions for voltage sag problems involve installing some form of power conditioning device. These solutions increase in cost with the size and scope of the equipment or circuits being protected. There are several technologies that serve as quick acting voltage regulators on the AC power supply. One of the most common of these is an SVPWM techniques applied on the AC voltage controllers and uninterruptible power supply (UPS). UPSs have the disadvantage of relying on a battery, which has a limited life, generates hydrogen gas (requiring ventilation), and becomes hazardous waste when it is disposed of at the end of its useful life. A UPS can be installed OFF-line, which is cheaper, or on-line, which doubles the cost but adds the ability to filter out all types of voltage disturbances, including spikes and harmonic distortions. Another common quick-acting voltage regulator is a constant voltage transformer (CVT).CVTs provide sag ride-through and also filter spikes, but they are not able to protect against interruptions, either momentary or sustained. CVTs are often used for relatively constant, low-power loads, and have the advantage of lower operating and maintenance costs than UPSs, because CVTs don't require batteries [23].

2.2.2 .Wave Form Distortion

Waveform distortion is defined as any steady-state deviation of the voltage and/or current waveform from an ideal sine wave of the power frequency. It is principally characterized by its spectral contents which are investigated using a Fourier transform, expressions [18].

There are five primary types of waveform distortion:-

- ✓ DC offset
- ✓ Harmonics
- ✓ Inter-harmonics
- ✓ Notching and Noise.

Harmonics

Harmonic distortion figure 2.4 is the corruption of the fundamental sine wave at frequencies that are multiples of the fundamental. (e.g., 150 Hz is the third harmonic of a 50 Hz fundamental frequency; (3 X 50 = 150). Symptoms of harmonic problems include overheated transformers, neutral conductors, and other electrical distribution equipment, as well as the tripping of circuit breakers and loss of synchronization on timing circuits that are dependent upon a clean sine wave trigger at the zero crossover point.

Harmonic distortion has been a significant problem with information technology (IT) equipment in the past, due to the nature of switch-mode power supplies (SMPS). These non-linear loads, and many other capacitive designs, instead of drawing current over each full half cycle, "sip" power at each positive and negative peak of the voltage wave. The return current, because it is only short term, (approximately 1/3 of a cycle) combines on the neutral with all other returns from SMPS using each of the three phases in the typical distribution system. Instead of subtracting, the pulsed neutral currents add together, creating very high neutral currents, at a theoretical maximum of 1.73 or times the maximum phase current. An overloaded neutral can lead to extremely high voltages on the legs of the distribution power, leading to heavy damage to attached equipment. At the same time, the load for these multiple SMPS is drawn at the very peaks of each voltage half-cycle, which has often led to transformer saturation and consequent overheating. Other loads contributing to this problem are variable speed motor drives, lighting ballasts and large legacy UPS systems. Methods used to mitigate this problem have included over-sizing the neutral conductors, installing K-rated transformers, and harmonic filters.

Spurred on by the remarkable expansion of the IT industry over the last decade, power supply design for IT equipment has been upgraded via international standards. One major change compensates for electrical infrastructure stresses caused, in the recent past, by large clusters of IT equipment power supplies contributing to excessive harmonic currents within a facility. Many new IT equipment power supplies have been designed with power-factor corrected power supplies operating as linear, non-harmonic loads. These power supplies do not produce the waste current of harmonics [19].

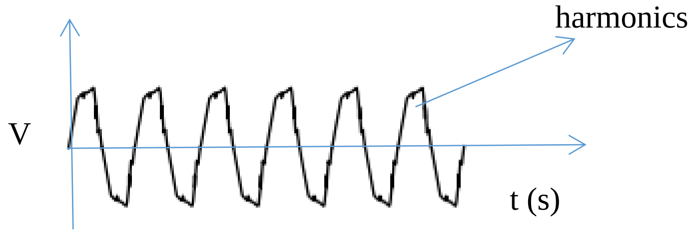


Figure 2.4: typical harmonic waveform distortion [19].

2.2.3. Voltage Unbalance or Imbalance

Simply put, a voltage imbalance (as the name implies) is when supplied voltages are not equal. While these problems can be caused by external utility supply, the common source of voltage imbalances is internal, and caused by facility loads. More specifically, this is known to occur in three phase power distribution systems where one of the legs is supplying power to single phase equipment, while the system is also supplying power to three phase loads. In general these imbalances show as heating, especially with solid state motors. Greater imbalances may cause excessive heat to motor components, and the intermittent failure of motor controllers.

Voltage unbalance is a condition in which the maximum deviation from the average of the three phase voltages or currents, divided by the average of the three phase voltages or currents, expressed in percentage. Voltage imbalance can be the result of blown fuse in one phase of a three phase capacitor bank. Severe voltage imbalance greater than 5% can cause damage to sensitive equipment as a standard [19].

$$\text{Voltage Unbalance} = \frac{V_{max}-V_{av}}{V_{av}} * 100, \tag{2.2}$$

Whereas;

V_{av} − Average three phase voltage.

V_{max} − voltage magnitude of extreme phase.

Voltage imbalance in three phase systems where the rms values of the voltages in each phase or the phase angle differences between consecutive phases are not equal, can affect the ratio of negative sequence and positive sequence voltage components. This can result in large differences between the highest and lowest values of voltage magnitude and phase difference. The voltage imbalance leads to large load current imbalances.

CHAPTER THREE

METHODOLOGY

3.1. Introduction

The methodology of this thesis work involves a number of different tasks that are performed to lead towards completion. This is followed by the literature review where all the theoretical and technical in chapter two, Literature and background of different power quality problems and Automatic Voltage Regulators with space vector pulse width modulation techniques has been discussed. The major causes of problems and options to reduce them are highlighted with reference to different Authors are also discussed. Under this chapter, data have been collected and analyzed. After analysis of the data, mitigation solutions have been presented and modeled. Next to this, the data analysis method has been employed to identify the type and level of the problem found in the factory. When the level of the problem identified is beyond the limit of the IEEE standard; then the mitigations are designed and modeled. Design of the thesis has been implemented by using MATLAB R2013a Simulink software for modeling and simulation the results.
The collected data from the secondary winding of transformers with respective ratings of 31.5MVA, and 132/6.3KV.

The Dire Dawa NCSC factory has two sections:
Ethiopian electric utility transformer power Supply 132KV line is step down to 6.3KV at rating of 31.5MVA and the Generator power supply at rating of 800KVA.Based on those the modeling of Ac voltage control using the SVPWM techniques by using matlab r2013a.

3.2. Space Vector Pulse Width Modulation

The space vector PWM (SVM) method is an advanced, computation-intensive PWM method and is possibly the best method among the all PWM techniques for variable-frequency drive application. Because of its superior performance characteristics, it has been finding wide spread application in recent years.
Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM)[1].It is used for the creation of alternating current (AC) wave forms; most commonly to drive three phase AC powered motors at varying speeds from AC using multiple Converters. There are various variations of SVPWM that result in different quality and computational requirements. One active area of development is in the reduction of total Harmonic distortion (THD) created by the rapid switching inherent to these algorithms.
To implement space vector modulation a reference signal V_{ref} is sampled with a frequency $\mathrm{f_s}$ $(T_s = \frac{1}{\mathrm{f_s}})$ The reference signal may be generated from three separate phase references using the $(\alpha\beta\gamma)$ transform. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and the switching losses therefore switching time duration for zero state knows the values of we can construct a symmetrical switching pattern for two consecutive periods of T_0, as shown in Figure 3.1.

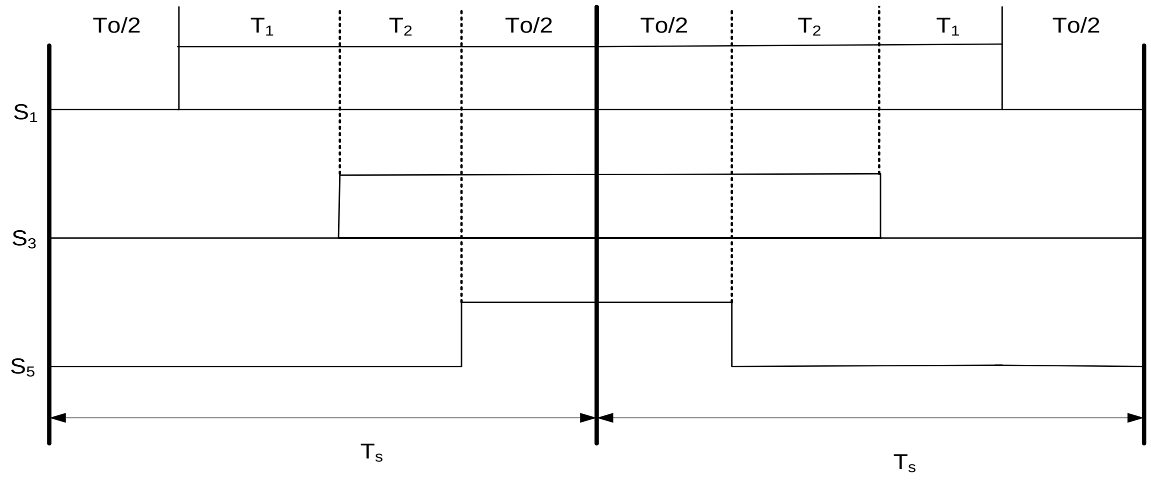


Figure 3.1: Switching Pattern of SVM for two consecutive of Period T_s [4]

3.2.1. Principle of Space Vector Pulse Width Modulation

A three-phase mathematical system can be represented by a space vector. For example, given a set of three-phase voltages, a space vector can be defined by (3.1) [4].

$$V(t) = \frac{2}{3}\left[V_a(t)e^{j0} + V_b(t)e^{j\frac{2\pi}{3}} + V_c(t)e^{j\frac{4\pi}{3}}\right], \quad (3.1)$$

Where $V_a(t)$, $V_b(t)$, and $V_c(t)$, are three sinusoidal voltages of the same amplitude and frequency but with "+ or –"120^o phase shifts. The space vector at any given time maintains its magnitude. As time increases, the angle of the space vector increases, causing the vector to rotate with a frequency equal to that of the sinusoidal waveforms. When the output voltages of a three-phase six-step inverter are converted to a space vector and plotted on the complex plane, the corresponding space vector takes only on one of six discrete angles as time increases. The central idea of SVWPM is to generate appropriate PWM signals so that a vector with any desired angle can be generated.

Use orthogonal coordinates to represent the three-phase two-level inverter in the phase diagram. There are eight possible inverter states that can generate eight space vectors. These are given by the complex vector expressions as (3.2) [4].

$$V_k = \begin{cases} \frac{2}{3}V_{dc}e^{j(k-1)\frac{\pi}{3}}, \text{if } k = 1,2,3,4,5,6 \\ 0\,, \text{if } k = 0,7. \end{cases}, \quad (3.2)$$

The entire space is divided into six equal-size sectors of 60^o. Each sector is bounded by two active vectors. V_0 and V_7 are two voltage vectors with zero amplitude located at the origin of the hexagon. The eight active and non-active state vectors are geometrically drawn in chapter two figures 2.2.

The reference voltage vector V_{ref} rotates in space at an angular velocity $\omega = 2\pi f$, where f is the fundamental frequency of the inverter output voltage. When the reference voltage vector passes through each sector, different sets of switches in Table 3.1 has been turned ON or OFF. As a result, when the reference voltage vector rotates through one revolution in space, the inverter output varies one electrical cycle over time. The inverter output frequency coincides with the rotating speed of the reference voltage vector. The zero vectors (V_0 and V_7) and active vectors (V_1 to V_6) do not move in space. They are referred to as stationary vectors. Figure 2.2 shows the reference vector V_{ref} in the first sector.

The six active voltage space vectors are shown on the same graph with an equal Magnitude of 2/3(V_{dc}) and a phase displacement of 60^o. The inverter cannot produce a desired reference voltage vector directly. It is possible to decompose the reference vector in to vectors that lay on two adjacent active vectors and two zero vectors, which are located at the center of the hexagon.

Figure 3.2 shows circuit model of a single phase inverter with a center taped grounded DC bus. Inverter pole voltage (VA) as shown figure 3.2 is the voltage between the outputs of the inverter leg and the mid potential point of the input DC supply, and the Load phase voltage are identical provided the load is a balanced tree phase load, and figure 3.2 illustrates principle of pulse width modulation.

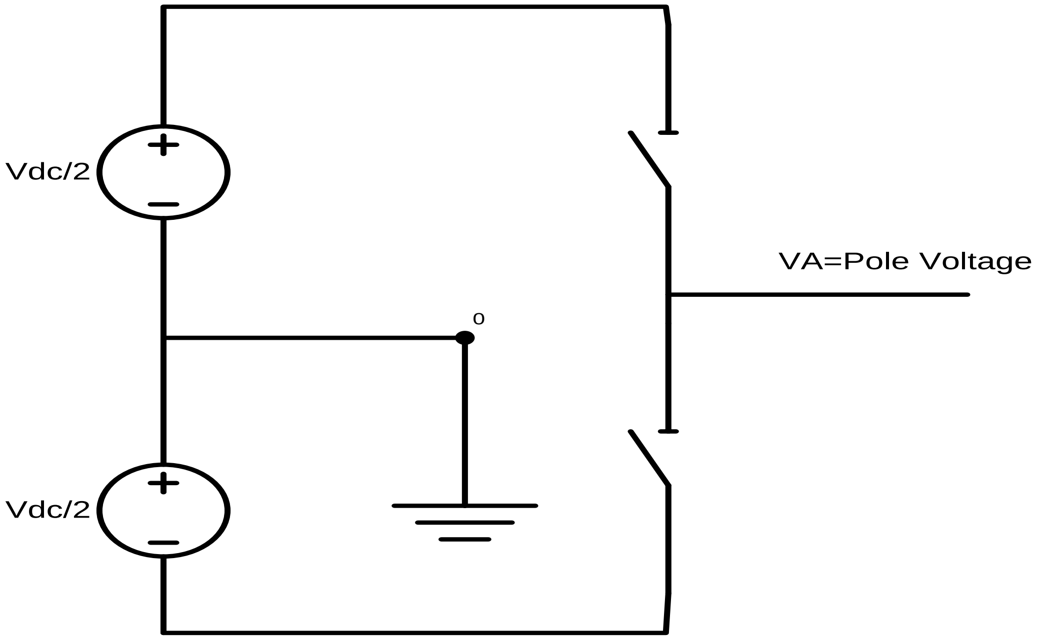


Figure 3.2: circuit model of single phase inverter [2].

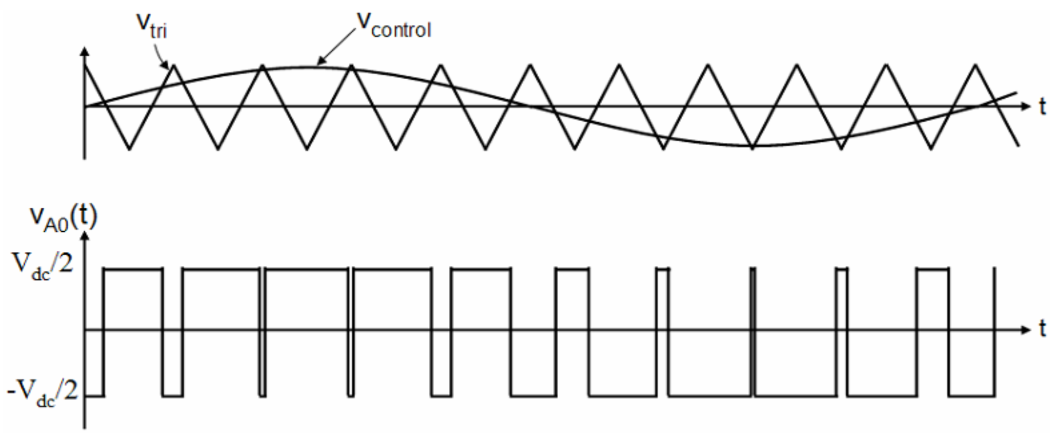


Figure 3.3: pulse width modulation [2].

As depicted in Figure 3.3, the inverter output voltage is determined in the following model (3.3) up to (3.5) [2, 21]:

When $V_{control} > V_{tri}$, $V_{Ao} = \frac{V_{dc}}{2}$ (3.3)

When $V_{control} < V_{tri}$, $V_{Ao} = -\frac{V_{dc}}{2}$ (3.4)

Also, the inverter output voltage has the following features:
PWM frequency is the same as the frequency of V_{tri}.
Amplitude is controlled by the peak value of $V_{control}$ (V_c)
Fundamental frequency is controlled by the frequency of Voltage or carrier (triangular) signal Value V_{tri}.
Modulation index (m) is defined as:

$$m = \frac{V_{control}}{V_{tri}} = \frac{\text{Peak of } (V_{Ao})1}{(V_{dc}/2)}, \tag{3.5}$$

Where, (V_{Ao})1 : Fundamental frequency component of V_{Ao}.
Generally, Principle of Space Vector PWM when the circuit model of a typical three-phase voltage source PWM inverter is shown in Figure. 3.5. s_1 to s_6 are the six power switches that shape the output, which are controlled by the switching variables a, a′, b, b′, c and c′. When an upper transistor is switched ON, i.e., when a, b or c is 1, the corresponding lower transistor is switched OFF, i.e., the corresponding a′, b′ or c′ is 0. Therefore, the ON and OFF states of the upper transistors s_1, s_3 and s_5 can be used to determine the output voltage.

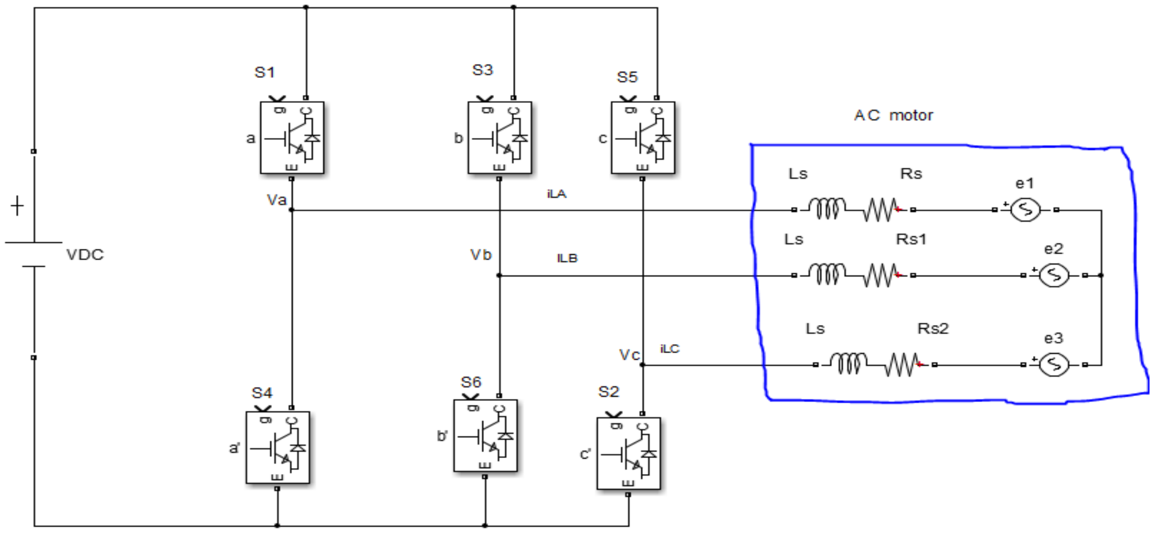


Figure 3.4: Three-phase voltage source PWM inverter.

The relationship between the switching variable vector $[a \quad b \quad c]^T$ and the line-to-line voltage vector $[V_{ab} \quad V_{bc} \quad V_{ca}]^T$ is given by (3.6) [24]in the following:

$$\begin{matrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{matrix} = V_{dc} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{3.6}$$

Also, the relationship between the switching variable vector $[a \quad b \quad c]^T$ and the phase voltage vector $[V_{an} \quad V_{bn} \quad V_{cn}]^T$ [24] can be expressed below.

$$\begin{matrix} V_{an} \\ V_{bn} \\ V_{cn} \end{matrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{3.7}$$

As illustrated in Figure 3.5, there are eight possible combinations of ON and OFF patterns for the three upper power switches. The ON and OFF states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power transistors are determined. According to equations (3.6) and (3.7), the eight switching vectors, output line to neutral voltage (phase voltage), and output line-to-line voltages in terms of DC-link V_{dc}, are given in Table 3.1 and Figure 3.5 show the eight inverter voltage vectors (V_0 to V_7).

Table 3.1: Switching vectors, phase voltages and output line to line voltages

Voltage vectors	Switching vectors			Line to neutral Voltage			Line to line Voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

(Note that the respective Voltage should be multiplied by V_{dc})

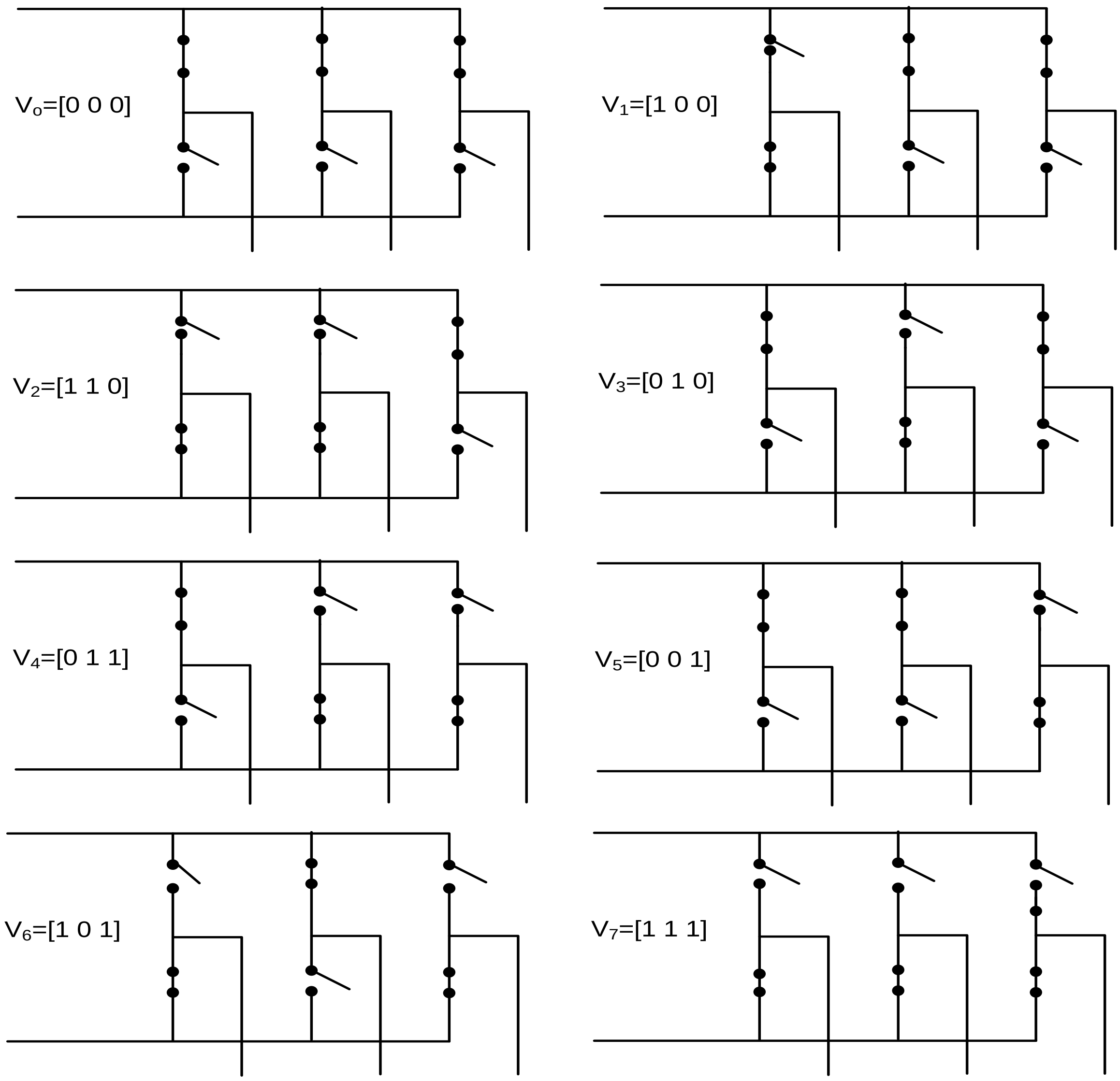


Figure 3.5: The eight inverter voltage vectors (V_0 to V_7) [6].

Space Vector PWM (SVPWM) refers to a special switching sequence of the upper three power transistors of a three-phase power inverter. It has been shown to generate less harmonic distortion in the output voltages and or currents applied to the phases of an AC motor and to provide more efficient use of supply voltage compared with Sinusoidal modulation technique as shown in above figure 3.6.

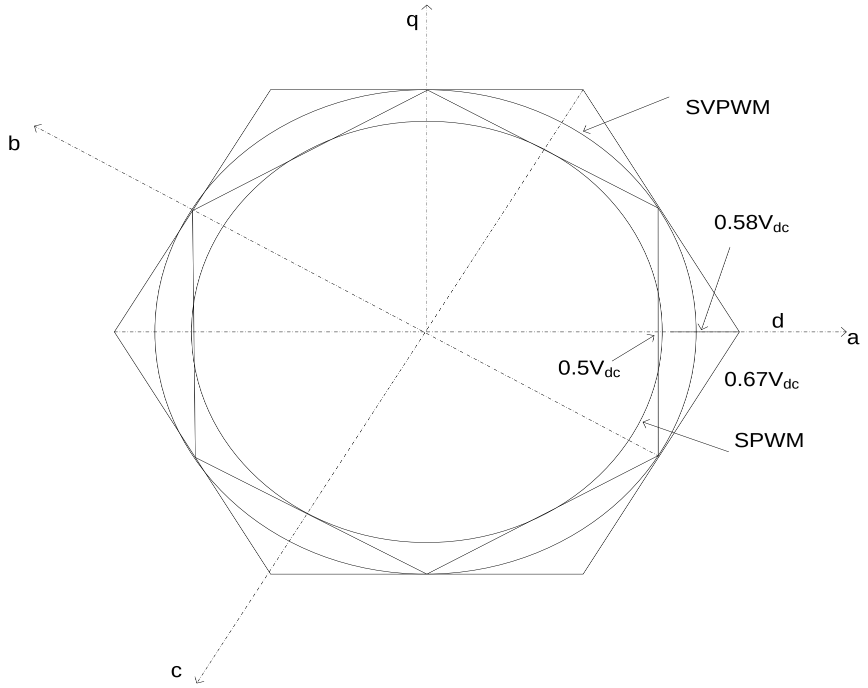


Figure 3.6: locus comparison of maximum linear control voltage in sine PWM and

SVPWM.

To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary dq reference frame that consists of the horizontal (d) and vertical (q) axes. Relating the three phase voltages and currents in terms of "ωt" is difficult to handle directly. It can be transformed into two reference frames by using Park's transform (Bernard Adkins and Harley 1975) and their relationships are shown in equation (3.8) [30].The relation between these two reference frames is become;

$$f_{dqo} = K_s f_{adc} \tag{3.8}$$

$$\text{Where,}\quad k = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{3.9}$$

$$f_{dqo} = \left[f_d f_q f_o\right]^T, f_{abc} = [f_a f_b f_c]^T \tag{3.10}$$

f denotes either a Voltage or a current variable.

This transformation is equivalent to an orthogonal projection of $[a \quad b \quad c]^T$ on to the two-dimensional perpendicular to the vector $[1 \quad 1 \quad 1]^T$ (the equivalent d-q plane) in a three-dimensional coordinate system. As a result, six non-zero vectors and two zero vectors are possible. Six nonzero vectors ($V_1 - V_6$) shape the axes of a hexagonal as shown in figure 3.7, and feed electric power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V_0 and V_7) are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by $V_0, V_1, V_2, V_3, V_4, V_5, V_6,$ and V_7.

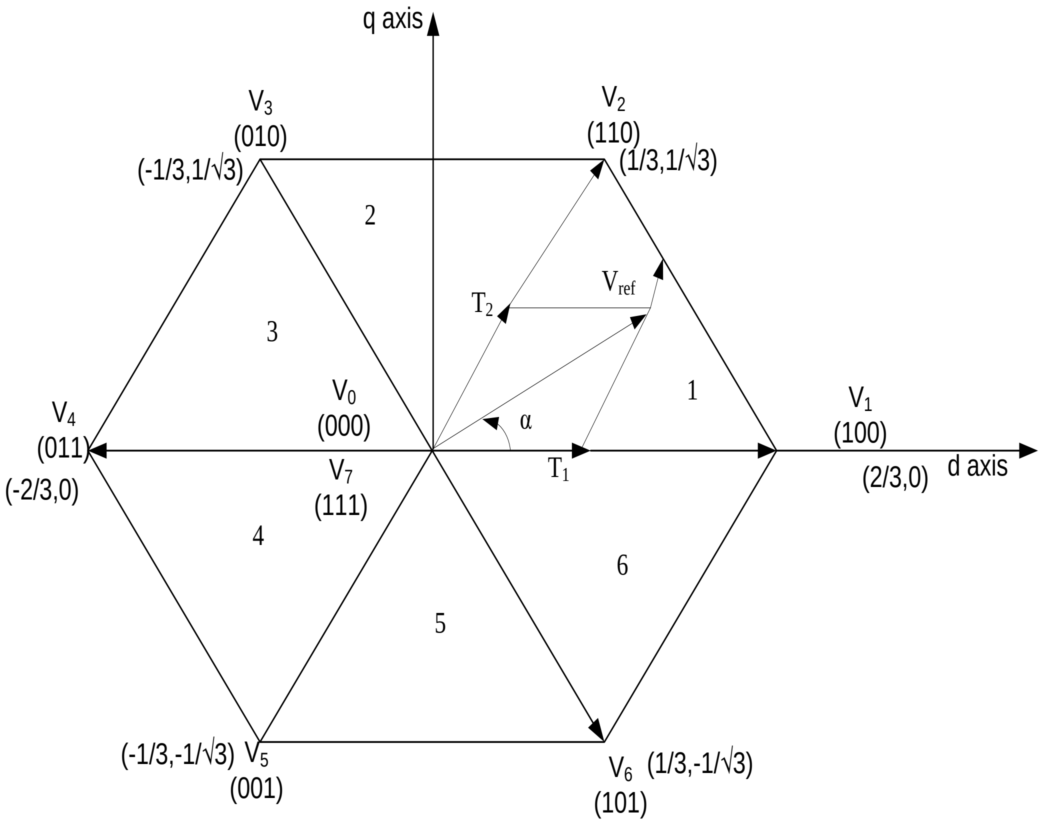


Figure 3.7: Basic switching vectors and sectors.

The same transformation can be applied to the desired output voltage to get the desired reference voltage vector V_{ref} in the d-q plane.
The objective of space vector PWM technique is to approximate the reference voltage vector V_{ref} using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period, T to be the same as that of V_{ref} in the same period.

3.2.2. Sector Determination

It is necessary to know in which sector the reference output lies in order to determine the switching time and sequence. The identification of the sector where the reference vector is located is straight forward. The phase voltages correspond to eight switching states six non-zero vectors and two zero vectors at the origin. Depending on the reference voltages, V_d, V_q the angle of the reference vector can be used to determine the sector as per Table 3.2.

Table 3.2: Sector definition.

Sector	**Degrees**
1	$0< \theta \leq 60^0$
2	$60< \theta \leq 120^0$
3	$120< \theta \leq 180^0$
4	$180< \theta \leq 240^0$
5	$240< \theta \leq 300^0$
6	$300< \theta \leq 360^0$

3.2.3. Space vector PWM can be implemented by the following steps

Step1. Determine V_d, V_q, V_{ref} and angle (α).

Step2. Determine time duration T_1, T_2, T_0.

Step3. Determine the switching time of each transistor (S_1 to S_6).

Step1. Determine V_d, V_q, V_{ref}, and angle (α).

From Figure 3.8, the V_d, V_q, V_{ref} and angle (α) [28] can be determined as follows:

$$V_d = V_{an} - \frac{1}{2}V_{bn} - \frac{1}{2}V_{cn}\ , \qquad (3.11)$$

$$V_q = \frac{\sqrt{3}}{2}V_{bn} - \frac{\sqrt{3}}{2}V_{cn}$$

$$\propto = \tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega t = 2\pi f t, \propto \epsilon(0,2\pi) \qquad (3.12)$$

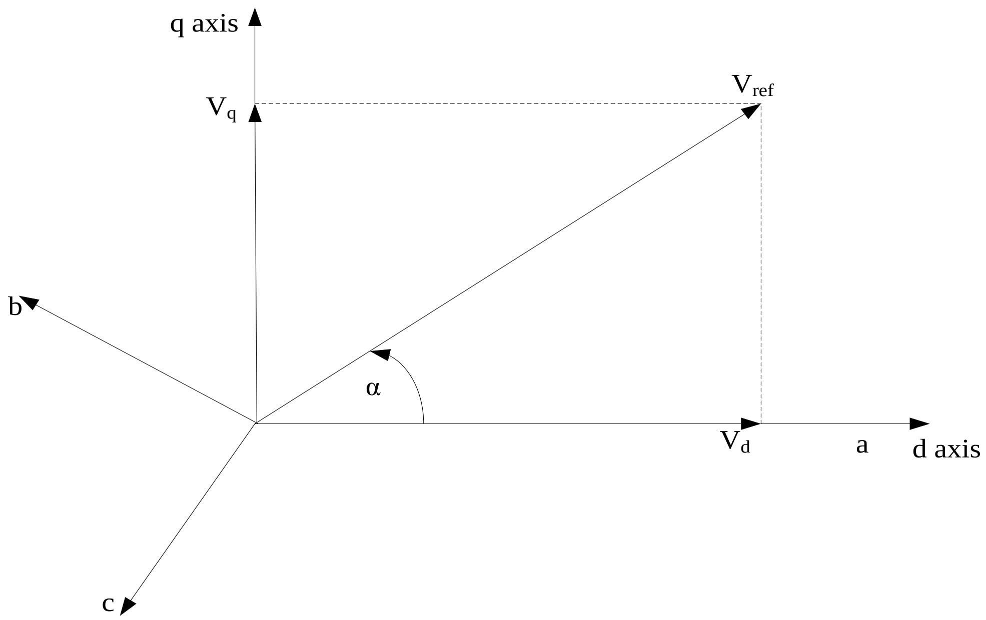


Figure 3.8: Voltage Space Vector and its components in (d, q).

Step2. Determine time duration T_1, T_2, T_0.

From Figure3.9, the switching time duration can be calculated as follows:

-Switching time duration at Sector 1.

At sector 1, V_1 and V_2 are voltage vectors. Assume V_{ref}, (reference voltage vector) makes " α " phase angle difference with V_1. This V_{ref} can be calculated using vector calculus by referring Figure 3.9. T_s is switching time interval at which output voltage of inverter is constant or sampling time of output voltage inverter. T_1 ,and T_2 are switching time duration of voltage space vectors V_1 and V_2 [24] respectively.

$$\int_{0}^{T_z} V_{ref} = \int_{0}^{T_1} V_{1dt} + \int_{T_1}^{T_1+T_2} V_{2dt} + \int_{T_1+T_2}^{T_s} V_0 \quad , \rightarrow \; T_s . V^{-}{}_{ref} = T_1 . V_1 + T_2 . V_2 \qquad 3.13$$

$$T_s |V_{ref}| \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix} = T_1 . \frac{2}{3} V_{dc} . \begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2 . \frac{2}{3} V_{dc} \begin{bmatrix} \cos {}^{\pi}/_{3} \\ \sin {}^{\pi}/_{3} \end{bmatrix}, \qquad 0^{\circ} \le \alpha \le 60^{\circ} \qquad 3.14$$

By rearranging the above equation solve for T_1, T_2 and T_0

$$T_1 = T_s . a \frac{\sin({}^{\pi}/_{3} - \alpha)}{\sin {}^{\pi}/_{3}}, T_2 = T_s . a \frac{\sin(\alpha)}{\sin {}^{\pi}/_{3}} \text{ and } T_0 = T_s - (T_1 + T_2) \qquad (3.15)$$

Where $, T_s = \frac{1}{f_s}$ and $a = \frac{|V_{ref}|}{\frac{2}{3}V_{dc}}$

-Switching time duration at any Sector is as follows

$$T_1 = \frac{\sqrt{3} * T_s * |V_{ref}|}{V_{dc}} \left(\sin \frac{n}{3} \pi \cos\alpha - \cos \frac{n}{3} \pi \sin\alpha \right), \qquad (3.16)$$

$$T_2 = \frac{\sqrt{3} * T_s * |V_{ref}|}{V_{dc}} \left(- \sin \frac{n-1}{3} \pi \cos\alpha + \cos \frac{n-1}{3} \pi \sin\alpha \right), \qquad (3.17)$$

$$T_0 = T_s - T_1 - T_2 \qquad (3.18)$$

Where, n=1 through 6(that is, sector 1 to 6 and $0^{\circ} \le \alpha \le 60^{\circ}$) finally the T_s is

$$T_s = T_0 + T_1 + T_2 \qquad (3.19)$$

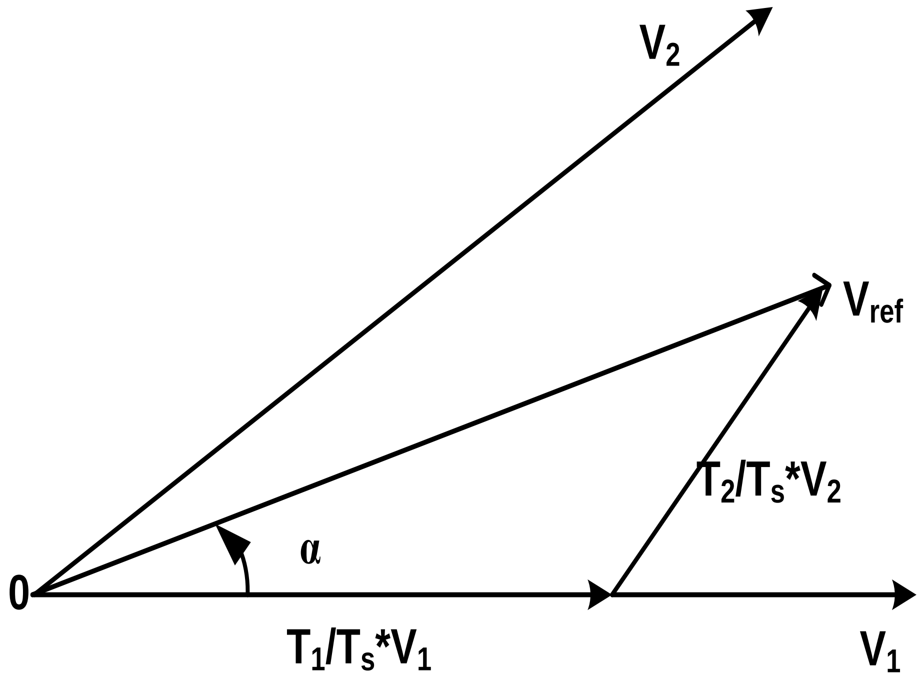


Figure 3.9: reference vector as a combination of adjacent vectors at sector one.

Step 3: Determine the switching time of each transistor (S1 to S6)

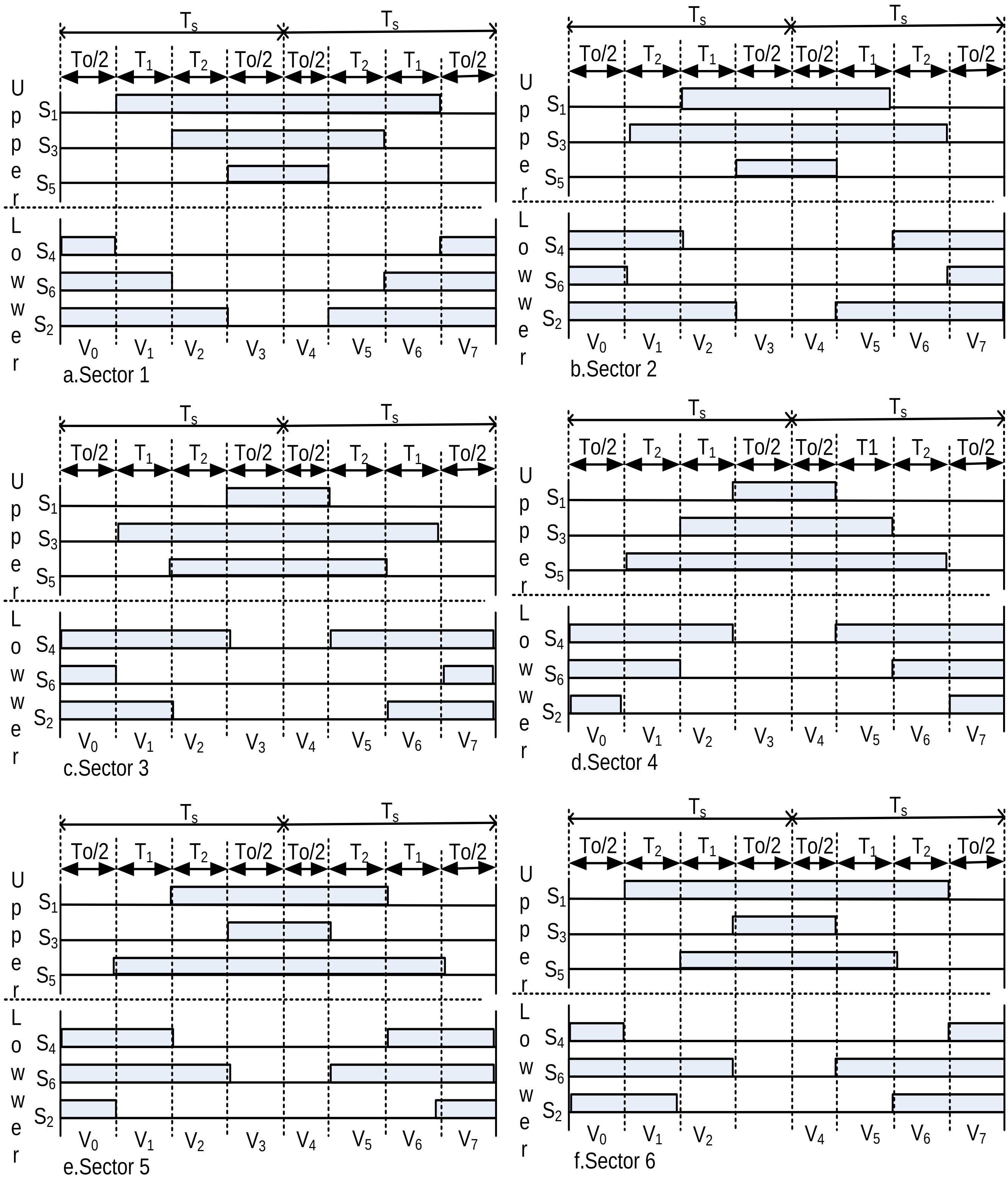


Figure 3.10: SVPWM switching patterns at each sector from sector 1 to 6 [12].

Based on Figure 3.10 [25], the switching time at each sector is summarized in Table 3.3, and it has been built in matlab/Simulink model to implement SVPWM.

Table 3.3: Switching time calculation at each sector of SVPWM [16].

Sector	Upper Switches (S_1,S_3,S_5)	Lower Switches (S_4,S_6,S_2)
1	$S_1=T_1+T_2+T_o/2$ $S_3=T_2+T_o/2$ $S_5=T_o/2$	$S_4=T_o/2$ $S_6=T_1+T_o/2$ $S_2=T_1+T_2+T_o/2$
2	$S_1=T_1+T_o/2$ $S_3=T_1+T_2+T_o/2$ $S_5=T_o/2$	$S_4=T_2+T_o/2$ $S_6=T_o/2$ $S_2=T_1+T_2+T_o/2$
3	$S_1= T_o/2$ $S_3=T_1+T_2+T_o/2$ $S_5=T_2+T_o/2$	$S_4=T_1+T_2+T_o/2$ $S_6=T_o/2$ $S_2=T_1+T_o/2$
4	$S_1= T_o/2$ $S_3=T_1+T_o/2$ $S_5=T_1+T_2+T_o/2$	$S_4=T_1+T_2+T_o/2$ $S_6=T_2+T_o/2$ $S_2=T_o/2$
5	$S_1= T_2+T_o/2$ $S_3= T_o/2$ $S_5=T_1+T_2+T_o/2$	$S_4=T_1+T_o/2$ $S_6=T_1+T_2+T_o/2$ $S_2=T_o/2$
6	$S_1= T_1+T_2+T_o/2$ $S_3= T_o/2$ $S_5=T_1+T_o/2$	$S_4=T_o/2$ $S_6=T_1+T_2+T_o/2$ $S_2=T_2+T_o/2$

3.2.4. State-Space Model

Figure 3.11 shows L-C output filter to obtain current and voltage equations.

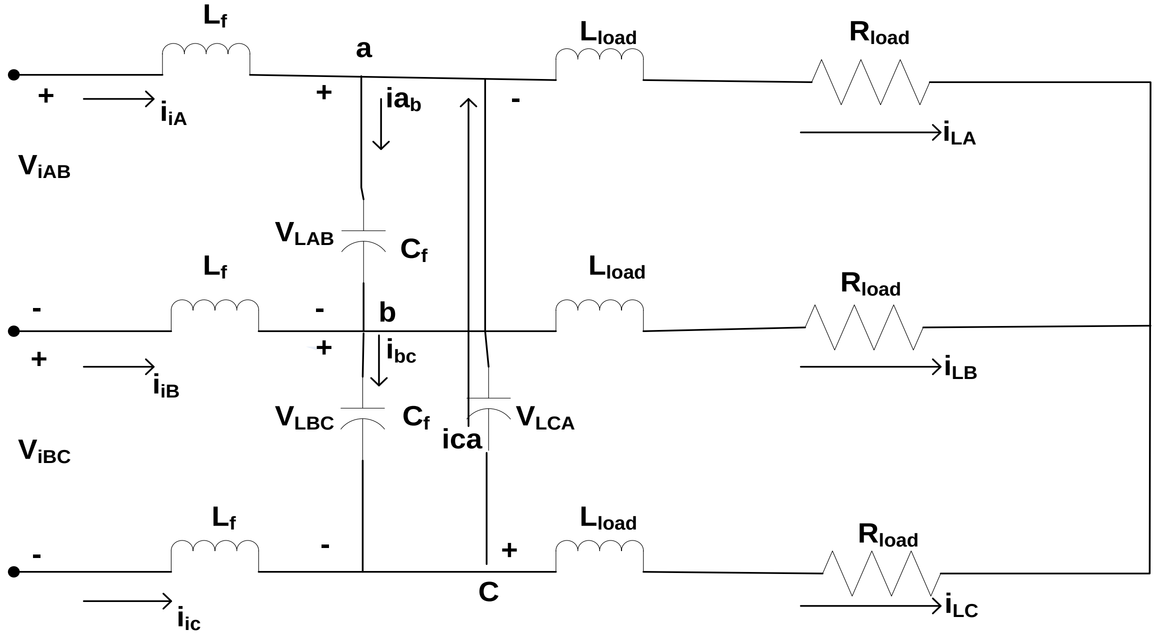


Figure 3.11: L-C output filter for current and voltage equations.

By applying Kirchoff's current law to nodes a, b, and c, on figure.3.11 respectively, the following current equations is derived:

1. at node 'a'

$$i_{iA} + i_{ca} = i_{ab} + i_{LA} \rightarrow i_{iA} + C_f \frac{dV_{LCA}}{dt} = C_f \frac{dV_{LAB}}{dt} + i_{LA} \quad (3.20)$$

2. at node 'b'

$$i_{iB} + i_{ab} = i_{bc} + i_{LB} \rightarrow i_{iB} + C_f \frac{dV_{LAB}}{dt} = C_f \frac{dV_{LBC}}{dt} + i_{LB} \quad (3.21)$$

3. at node 'c'

$$i_{iC} + i_{bc} = i_{ca} + i_{LC} \rightarrow i_{iC} + C_f \frac{dV_{LBC}}{dt} = C_f \frac{dV_{LCA}}{dt} + i_{LC} \quad (3.22)$$

Where,

$$i_{ab} = C_f \frac{dV_{LAB}}{dt}, i_{bc} = C_f \frac{dV_{LBC}}{dt}, i_{ca} = C_f \frac{dV_{LCA}}{dt}$$

Also, (3.18) to (3.20) can be rewritten as the following equations, respectively:

Step 1.Substiract (3.19) from (3.18):

$$C_f \left(\frac{dV_{LCA}}{dt} + \frac{dV_{LCA}}{dt} - 2\frac{dV_{LBC}}{dt} \right) = -i_{iA} + i_{iB} + i_{LA} - i_{LB} \quad (3.23)$$

Step 2.Substiract (3.20) from (3.19):

$$C_f \left(\frac{dV_{LAB}}{dt} + \frac{dV_{LCA}}{dt} - 2\frac{dV_{LBC}}{dt} \right) = -i_{iB} + i_{ic} + i_{LB} - i_{LC} \quad (3.24)$$

Step 3.Substiract (3.18) from (3.20):

$$C_f \left(\frac{dV_{LAB}}{dt} + \frac{dV_{LBC}}{dt} - 2\frac{dV_{LCA}}{dt} \right) = -i_{iC} + i_{iA} + i_{LC} - i_{LA} \quad (3.25)$$

To simplify (3.18) to (3.20), we use the following relationship that an algebraic sum of line to line load voltages is equal to zero:

$$V_{LAB} + V_{LBC} + V_{LCA} = 0 \quad (3.26)$$

Based on (3.24), the (3.21) to (3.23) can be modified to a first-order differential equation, respectively:

$$\frac{dV_{LAB}}{dt} = \frac{1}{3C_f} i_{iAB} - \frac{1}{3C_f} i_{LAB}, \frac{dV_{LBC}}{dt} = \frac{1}{3C_f} i_{iBC} - \frac{1}{3C_f} i_{LBC}, \frac{dV_{LCA}}{dt} = \frac{1}{3C_f} i_{iCA} - \frac{1}{3C_f} i_{LCA} \quad (3.27)$$

Where, $i_{iAB} = i_{iA} - i_{iB}, i_{iBC} = i_{iB} - i_{iC}, i_{iCA} = i_{iC} - i_{iA}$, and

$i_{LAB} = i_{LA} - i_{LB}, \quad i_{LBC} = i_{LB} - i_{LC}, i_{LCA} = i_{LC} - i_{LA}$

By applying Kirchoff's voltage law on the side of inverter output, the following voltage equations can be derived:

$$\frac{dV_{iAB}}{dt} = -\frac{1}{L_f} V_{LAB} + \frac{1}{L_f} V_{iAB}, \frac{dV_{iBC}}{dt} = -\frac{1}{L_f} V_{LBC} + \frac{1}{L_f} V_{iBC}, \frac{dV_{iCA}}{dt} = -\frac{1}{L_f} V_{LCA} + \frac{1}{L_f} V_{iCA} \quad (3.28)$$

By applying Kirchoff's voltage law on the load side, the following voltage equations can be derived:

$$V_{LAB} = L_{Load}\frac{di_{LA}}{dt} + R_{Load}i_{LA} - L_{Load}\frac{di_{LB}}{dt} - R_{Load}i_{LB},$$
$$V_{LBC} = L_{Load}\frac{di_{LB}}{dt} + R_{Load}i_{LB} - L_{Load}\frac{di_{LC}}{dt} - R_{Load}i_{LC}, \quad (3.29)$$
$$V_{LCA} = L_{Load}\frac{di_{LC}}{dt} + R_{Load}i_{LC} - L_{Load}\frac{di_{LA}}{dt} - R_{Load}i_{LA}$$

Equation (3.26) can be rewritten as:

$$\frac{di_{LAB}}{dt} = -\frac{R_{Load}}{L_{Load}}i_{LAB} + \frac{V_{LAB}}{L_{Load}}, \frac{di_{LBC}}{dt} = -\frac{R_{Load}}{L_{Load}}i_{LBC} + \frac{V_{LBC}}{L_{Load}}, \frac{di_{LCA}}{dt} = -\frac{R_{Load}}{L_{Load}}i_{LCA} + \frac{V_{LCA}}{L_{Load}}, \quad (3.30)$$

Therefore, we can rewrite (3.25), (3.26) and (3.27) into a matrix form, respectively:

$$\frac{dV_L}{dt} = \frac{1}{3C_f}I_i - \frac{1}{3C_f}I_L, \frac{dI_i}{dt} = -\frac{1}{L_f}V_L + \frac{1}{L_f}V_i, \frac{dI_L}{dt} = -\frac{1}{L_{load}}V_L - \frac{R_{load}}{L_{load}}I_L \quad (3.31)$$

Where, $V_L = [V_{LAB} \quad V_{LBC} \quad V_{LCA}]^T$, $I_i = [i_{iAB} \quad i_{iBC} \quad i_{iCA}]^T$

$V_i = [V_{iAB} \quad V_{iBC} \quad V_{iCA}]^T$, $I_L = [i_{LAB} \quad i_{LBC} \quad i_{LCA}]^T$

Finally, the given plant model can be expressed as the following continuous-time state space equation

$$X^{-}(t) = AX(t) + BU(t) \quad (3.32)$$

Where,

$$X = \begin{bmatrix} V_L \\ I_i \\ I_L \end{bmatrix}_{9X1}, A = \begin{bmatrix} 0_{3X3} & \frac{1}{3c_f}I_{3X3} & -\frac{1}{3c_f}I_{3X3} \\ -\frac{1}{3L_f}I_{3X3} & 0_{3X3} & 0_{3X3} \\ \frac{1}{L_{load}}I_{3X3} & 0_{3X3} & -\frac{R_{load}}{L_{oad}}I_{3X3} \end{bmatrix}, B = \begin{bmatrix} 0_{3X3} \\ \frac{1}{L_f}I_{3X3} \\ 0_{3X3} \end{bmatrix}_{9X3}, U = [V_i]_{3X1}$$

Note that

- ✓ V_L is load line to line voltage ,
- ✓ I_i is inverter output current, and
- ✓ I_L is the load current are the state variables of the system, and
- ✓ V_i is the inverter output line-to-line voltage
- ✓ U is the control input.

Accordingly the figure 4.2 in chapter four, Block diagram is modeled by using the MATLAB Simulink tools for AC-Voltage Controlled by using SVPWM techniques.

3.3. Harmonic Distortion Standards

IEEE 519-1992 was developed to evaluate harmonic voltages and currents at a point of common coupling (PCC) between the end user and the utility supply system. The

PCC is the location where another customer can be served from the system [25]. The standard allows for the same procedure to be applied by the customer at other locations within a facility but different current limit values could apply in these cases. The harmonic current limits for the PCC are summarized in Table 3.4.

Table 3.4: harmonic current limits for individual end users from IEEE 519-1992. for 69KV<V<161KV.

I_{sc}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20	2.0	1.0	0.75	0.3	0.15	2.5
20-50	3.5	1.75	1.25	0.5	0.25	4.0
50-100	5.0	2.25	2.0	1.25	0.35	6.0
100-1000	6.0	2.75	2.5	1	0.5	7.5
>1000	7.5	3.5	3.0	1.25	0.7	10.0

Whereas:

h -harmonic number.

I_{sc} - Short circuit current at the point of common coupling.

I_L - Maximum demand loads current (fundamental frequency component) at the point of common coupling. It can be calculated as the average of the maximum monthly demand currents for the previous 12 months or it may have to be estimated. All power generation equipment applications are limited to these values of current distortion regardless of the actual short circuit ratio I_{sc}/I_L. The tables of individual harmonic component limits apply to the odd harmonic components and even harmonic components are limited to 25% of the limits in the tables due to this it is neglected. Current distortion which results in a dc offset is not allowed.

Total Demand Distortion (TDD) [12, 24] is defined as:

$$\mathrm{TDD} = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_L} X100\% \tag{3.33}$$

Where:

I_n= magnitude of individual harmonic components (rms amps).

n = harmonic order.

I_L= maximum demand load current (rms amps).

$$I_L = \frac{P}{\sqrt{3} * Pf * KV}, \tag{3.34}$$

$$I_{sc} = \frac{V_n}{\sqrt{3} * V_T}, \tag{3.35}$$

$$\text{Short circuit ratio} = \frac{I_{sc}}{I_L}. \tag{3.36}$$

Whereas:

V_n - Nominal voltage with the secondary side of transformer open

I_{sc} - Short circuit current of the transformer

%Z - Percentage transformer impedance

P - Load demand

Pf - Power factor

If the harmonic producing loads consist of power converters with pulse number (q) higher than six, the limits indicated in the table are increased by a factor equal to $\sqrt{\frac{q}{6}}$ provided that the magnitudes of the non-characteristic harmonics are less than 25% of the limits specified in the table 3.5.

Table 3.5: harmonic voltage limits, IEEE standard 519-1992 or recommended voltage distortion limits for general systems.

Utility Voltage bus	Maximum individual harmonic Component (%)	Maximum THD (%)
Less than 69KV	3	5
115KV to 161 KV	1.5	2.5
Above 161 KV	1	1.5

This table 3.6 shows the voltage distortion level and RMS value of each phase taken from the transformer data of the national cement share company; which is measured on individual phases. The average full load measurement shows that the THDv is 3.212%, 3.25% and 3.266% for each phase respectively ,which is beyond the standard limits as dedicated on the table 3.5 for 132KV is 1.5% for Maximum individual harmonic Component and 2.5 % for maximum THD;As per IEEE standard the voltage distortion should be below or less than 1.5% for individual harmonic components and less than 2.5% for total harmonic distortion. In this table implies there is a significant voltage distortion which is a big effect on the motors and factory.

The voltage unbalance limit at the terminal of the motors in the industry should be below 1% as per IEEE standard at full load and less than 3% at no load condition. The unbalance greater than 1% makes motor operation difficult in which the motors are over heated and forced to function below their rated power as shown in table 3.6 above which is 1.11%. Again the measurement taken at the terminal of the motors indicates the voltage unbalance is beyond the standard to some extent which is greater than one and the average measured supply frequency is 49.85 Hz which is in the range of acceptable limit.

Table 3.6: voltage data from transformer supplying at full load in NCSC

No	Freq.(Hz)	RMS(V)			THD (%)			V(unbalance)%
		V_1	V_2	V_3	V_1	V_2	V_3	
1	50.12	220	216	217	3.15	3.25	3.25	1.17
2	49.91	199	200	199.6	3.25	3.33	3.25	0.93
3	50	205	208	207	3.25	3.15	3.24	1.14
4	50.1	215	210	211	3.26	3.25	3.26	1.41
5	49.1	210	212	210	3.15	3.27	3.33	0.89
A_{vr}	49.85	209.8	209.2	208.92	3.212	3.25	3.266	1.11

Table 3.7: the average RMS current, unbalance current and THD_I, taken from the transformer at full load of the NCSC.

No.	RMS			THD (%)			I (unbalance)
	I_1	I_2	I_3	I_1	I_2	I_3	%
1	168	171	165	30	32	29	1.79
2	170	172	167	30.6	33	29.3	1.38
3	169	172	168	33	35	32	1.38
4	170.5	173	169	31	33	30	1.27
5	170.5	173	169	31.1	33	30	1.27
Avr.	169.6	172.2	167.6	31.14	33.2	30.06	1.41

This table 3.7 shows the RMS current, THD_I per phase and unbalances Current between the phases for different readings. The reading in the table shows average values of the parameters at the bottom of the table 3.7. The average current unbalance value is 1.41% which is less than the limited value of the given standard IEEE is 10%. But the THD_I measured shows there is high value of distortion as shown in the table 3.7.This table shows the individual current harmonic components for each phase: 1, 2, and 3 with their distortion level in percentage are 31.14%, 33.2%, and 30.06% respectively.

The causes of this THD_I are due to high use of non-linear load equipment such as computer power supplies, electronic ballasts, compact fluorescent lamps and variable speed drives etc, which create high current flow with harmonic frequency components. The common cause of this disturbance is switching on of the heavy appliances like motor or refrigerator or Air conditioner which require large start up power. Other reasons can be failure on the power lines and transformers. Harmonic problems are almost always introduced by the consumers' equipment and installation practices. The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated to avoid overheating of busbars, circuit breakers, neutral conductors, transformer windings or generator alternators. But when voltage sags occur, the local utility usually is blamed. However, many voltage sag events are caused by equipment within the plant. Power quality problems occur on both sides of the electric meter. It is sometimes difficult to determine the source of voltage sags or other power quality problems. Even experienced power quality experts do not always agree. Voltage sags that occur on the utility side of the power meter can either be human created or natural events. The most common human-created events are switching operations. The most common natural events include: Lightning, Wind, and Trees falling onto power lines, Construction workers digging into buried cables, Squirrels and rodent.

CHAPTER FOUR

SYSESTEM DESIGN AND DESCRIPTION

4.1. Three Phase Model of the AC Voltage Controller using SVPWM

The Matlab Simulink modeling is used to determine the improvement of power factor and THD are obtained in this thesis to present the Ac voltage controller by using the SVPWM techniques through simulation. Designing by using SVPWM techniques of the thesis has been implemented by using MATLAB R2013a Simulink software for simulate the result and the new model used here is SVPWM techniques used instead of AVR controller. To come up with this the following block diagrams are discussed below.

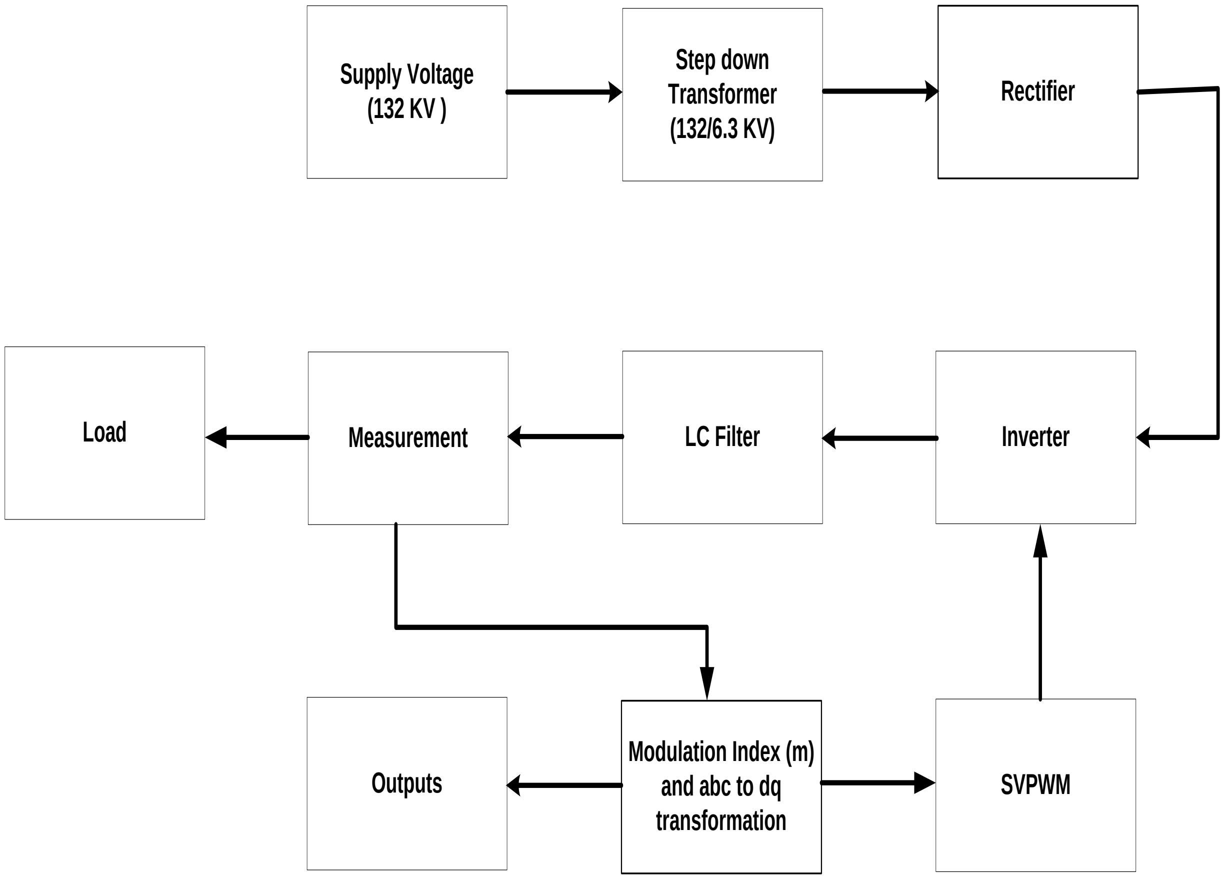


Figure 4.1: The block diagram of designed SVPWM.

According to the above block diagram the 132 KV voltage source given to the step dawn transformer, which followed by rectifier and voltage source inverter which uses SVPWM techniques to get the desired output. The overall completed Voltage source inverter is fed from rectifier and SVPWM. The AC voltage of induction motor is controlled by using SVPWM controller techniques through the steps of modulation index and transformations. The compilation design of the paper is discussed as follow by using MATLAB R2013a software as tools.

4.2. MATLAB implementation of Three Phase AC Voltage Controller using SVPWM

The modeling of AC voltage controller using the SVPWM technique is in order to generate the appropriate output voltage at the end of the factory. Using these techniques implements the power qualities like voltage sag and THD and as well as power factor. The following diagram shows the MATLAB implementation of three-phase Ac voltage controller which is discussed each one by one.

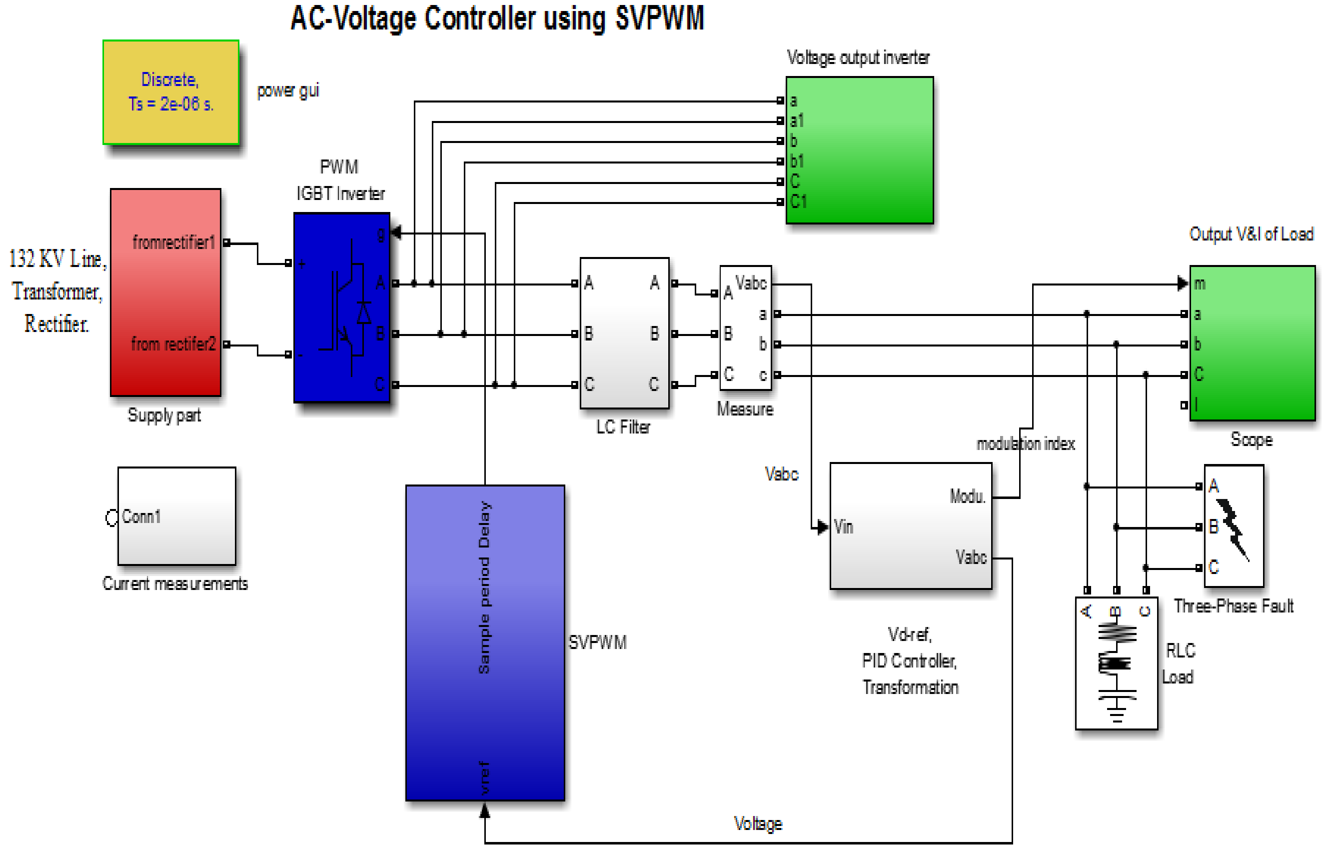


Figure 4.2: Three phase AC voltage controller using SVPWM

A simplified block flow diagram for the implementation of the SVPWM algorithm is shown in Figure 4.1 and 4.2. The procedure for implementing a space vector PWM can be summarized as follows:

i. Calculate the angle α and reference voltage vector (V_{ref}) based on the input voltage components.

ii. Calculate the modulation index (m) and determine if it is in the over-modulation region.

iii. Find the sector in which (V_{ref}) lies and the adjacent space vectors of V_k and V_{k+1} based on the sector angle α.

iv. Find the time intervals T_0, T_1 and T_2 based on T_z and the angle α.

v. Determine the modulation times for the different switching states.

4.3. Rectifier

Universal bridge rectifier block can be discretized to be used in a discrete time step simulation specified by the discrete system block.in this case, the internal communication between the power switches and the diodes in the converter legs. Apart from the dc component, this pulsating dc voltage will have unwanted ac components like the components of its supply frequency along with its harmonics (together called ripples)[20]. The ripples will be minimum for 3-phase rectifier circuits. Such supply is not useful for driving complex electronic circuits in general due to their harmonics. The universal bridge block in an ac –ac converter conducting of a rectifier feeding an IGBT inverter through a dc link .the inverter is PWM to produce a three phase variable voltage and frequency sinusoidal voltage to the load.in this paper the modulation frequency is 50 Hz.

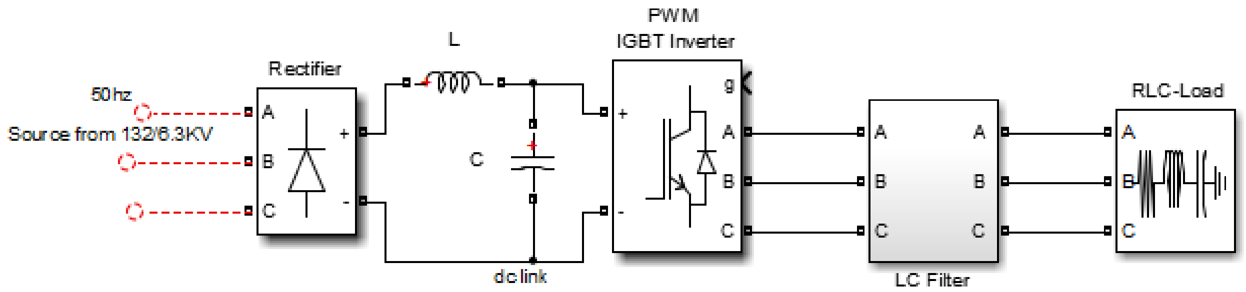


Figure 4.3: the universal bridge rectifier's blocks with IGBT inverter.

According to the figure 4.3 the universal bridge block rectifier feeding an IGBT inverter through the dc link at the parameters of C=5 mf and L=0.2 mH which is the same values used to AVR of the national cement share company.

4.4. Voltage Source Inverter (VSI)

Inverters are static power converters that produce an AC output waveform from a DC power supply. If a DC input is a voltage source, then the inverter is called a Voltage Source Inverter (VSI). Similarly in case of a Current Source Inverter (CSI), the input to the circuit is a current source. The VSI circuit has a capability of controlling AC output voltage, whereas the CSI directly controls AC output current. Power inverters are devices which can convert electrical energy of DC form into that of AC. Inverters can come in many different varieties, differing in price, power, efficiency and purpose. VSI input voltage is maintained constant and the amplitude of output voltage does not depend on the load. However, the waveform of load current as well as its magnitude depends upon the nature of the load impedance as sued in this paper at NCSC as shown in figure 4.2 and 4.3. VSI produces an output voltage and current to required ranges and frequencies. This inverter uses The IGBT Transistors for its switching purpose. Due to the main advantages of using the Insulated gate bipolar transistor over other types of transistor devices are its high voltage capability, low ON-resistance, ease of drive, relatively fast switching speeds and combined with zero gate drive current makes it a good choice for moderate speed, high voltage application in SVPWM, variable speed control, switching mode power supplies or solar powered DC-AC inverters. Insulated-gate bipolar transistor (IGBT) is voltage controlled power transistor that is used while voltage requirement increases and it also offers better speed than the others like power bipolar junction transistor (BJT) and metallic oxide semiconductor field effect transistor(MOSFET).
The voltage source inverter that use SVPWM switching techniques have a DC input voltage from the rectifier as shown in figure 4.1.and 4.2 that is usually constant in

magnitude. The inverter job is to take this DC input from rectifier and to give AC output, where the magnitude and frequency can be controlled and gives or transfers to modulation index. There is techniques of space vector Pulse Width Modulation (SVPWM).The efficiency parameters of an inverter such as switching losses and harmonic reduction are principally depended on the modulation strategies used to control the inverter.
In this design the Space vector Pulse Width Modulation (SVPWM) technique has been used for controlling the inverter as it can be directly controlled the inverter output voltage and output frequency according to the vector functions [22]. Space vector pulse width modulation (SVPWM) is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the ON and OFF of the power switches. The SVPWM inverter has been the main choice in power electronic for decades, because of its circuit simplicity and rugged control scheme. Space vector Pulse Width Modulation switching technique is commonly used in industrial applications or solar electric vehicle applications in popular now a day. The parameters of VSI specifications are the same to the AVR used in NCSC see table 4.1 which is used for Portland pozzolana cement.
Table 4.1: Voltage source inverter specifications

No.	Rating	value	
1	Inverter kVA	10kVA	
2	DC bus voltage	600V	
3	Output line voltage	400V rms	
4	Output Current	15A rms	
5	Switching Frequency	20KHz (max)	
6	$VCES$ (IGBT rating)	1200V	
7	IC (IGBT rating)	25A @ 100°C	

4.5. LC filter

An inductor (L=2mH) filter increases the ripple factor with the increase in load current R load. A capacitor(C=5 mF) filter has an inversely proportional ripple factor with respect to load resistance. The parameters or value of L-C are taken from the NCSC which AVR has using. Economically, both inductor filter and capacitor filter are not suitable for high end purpose L-C inductor input or L-section filter consists of an inductor ‘ L’ connected in series with a half or full wave rectifier and a capacitor ’C’ across the load. This arrangement is also called a choke input filter or L-section filters because its shape resembles and inverted L-shape. To increase the smoothing action using the filter circuit, just one L-C circuit will be required [30, 31].

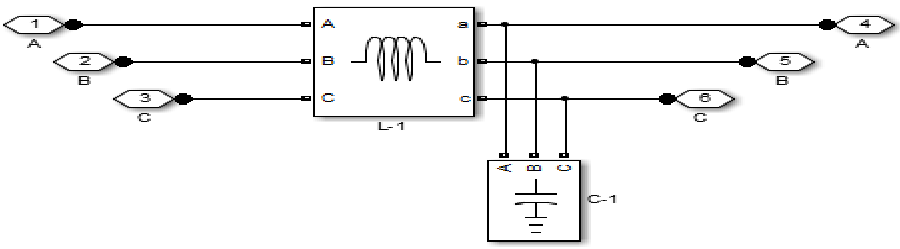


Figure 4.4: 2nd order LC filter for 3 phase system

According to the figure 4.3 harmonic attenuation can be achieved by several methods such as by resonating of the loads, by an LC filter, by pulse width modulation, by sine wave synthesis, by selected harmonic reduction and by three phase inverters. Apart from these in PWM technique, if the carrier frequency is increased, the harmonics components are reduced. A high carrier ratio improves waveform quality by raising the order of the principle harmonics. RC and LC filters are the most used passive filters. LC is the 2nd order filter which is used in the SVPWM techniques. After LC filter a measurement of voltage and current is used and after to modulation index and load part.
Advantages of Passive Filter over Active Filter:

- ✓ Less costly than active filter.
- ✓ Passive filters can be used for small loads as well as large loads in a power system.

4.6. Modulation index

Modulation Index (m) is controls the harmonic content of the output voltage waveform. The magnitude of fundamental component of output voltage is proportional to m, but m can never be more than unity. Thus the output voltage is controlled by varying m.
For m less than one i.e. m<1; largest harmonics amplitudes in the output voltage are associated with harmonics of higher order ($f_c/f+1$),($f_c/f-1$) or (2N-1), where N is the number of pulse per half cycle. Thus, by increasing the number of pulses per half cycle, the order of dominant harmonic frequency can be raised, which can be filtered out easily. It is observed from above that as N is increased, the order of significant harmonic increases and the filtering requirements are accordingly minimized.
For m greater than one i.e. m>1; lower order harmonics appear, pulse width are no longer a sinusoidal function. This PWM signal can then be used to control switches connected to a high-voltage bus, which will replicate this signal at the appropriate voltage. Put through an LC filter, this SVPWM signal will clean up into a close approximation of a sine wave. Though this technique produces a much cleaner source of AC power than either the square or modified sine waves, the frequency analysis shows that the primary harmonic is still truncated, and there is a relatively high amount of higher level harmonics in the signal.
The fundamental component of the voltage waveform is from a Fourier analysis, the fundamental voltage magnitude is given by (4.1) [25].

$$V_{max\_sixstep} = \frac{3}{4}\left[\int_0^{\pi/3} \frac{V_{dc}}{3}\sin\theta d\theta + \int_{\pi/3}^{\pi/2} \frac{2V_{dc}}{3}\sin\theta d\theta\right] = \frac{2V_{dc}}{\pi} \qquad (4.1)$$

The ratio between the reference vector V_{ref} and the fundamental peak value of the square phase voltage wave ($2V_{dc}/\pi$) are called the modulation index. The mode of operation is determined by the modulation index (m). In this linear region, the m can be expressed as:

$$m = \frac{V_{ref}}{V_{max\_sixstep}} \qquad (4.2)$$

The maximum modulation index(m) is obtained when V_{ref} equals the radius of the inscribed circle as in figure 3.9 from chapter three [23].

$$V_{ref(max)} = \frac{2}{3}V_{ref}\cos{\pi/6} \text{ ; Therefore, } m_{max} = \frac{\frac{2}{3}V_{dc}\cos{\pi/6}}{\frac{2}{\pi}V_{dc}} = 0.907 \qquad (4.3)$$

4.7. PID Controller using in SVPWM to control V_{ref} voltage

PID controller is proportional–integral–derivative controller. The PID controller is simple and easy to implement. It is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady-state error due to a step function to zero [22]. The PID controller transfer function is (4.4) [27]:

$$C(S) = K_p + \frac{K_i}{s} + K_d s \text{ and } e = error = SP - PV \tag{4.4}$$

Where,

SP: Set Point

PV: Process Variable

t: Time or instantaneous time and s is laplace transform of time.

K_p :Proportion gain.

K_i :Integration gain.

K_d: Derivative gain.

PID stands for the Proportional, Integral, and Derivative terms that sum to create the controller output signal as follows:

Time domain formula: $UC(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d(\tau) + K_d \frac{d}{dt} e(t)$,

Frequency domain formula: $UC(s) = \left[K_p + \frac{K_i}{s} + K_d s\right] E(s)$

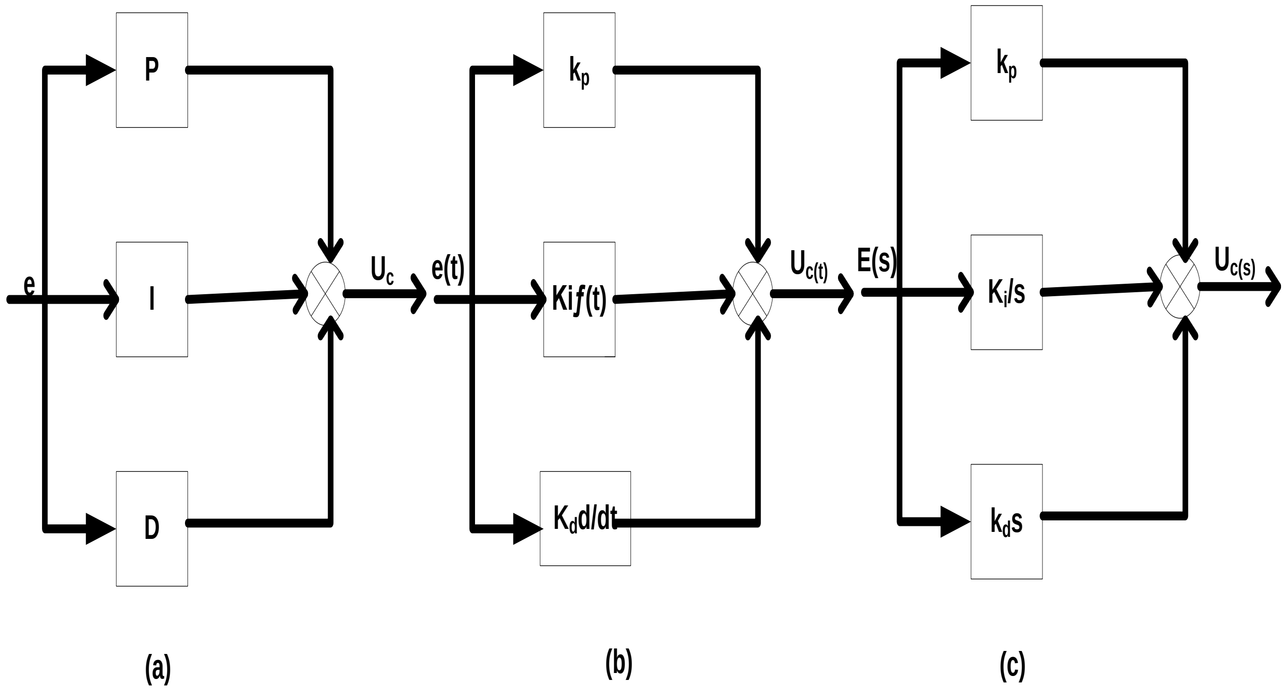


Figure 4.5: Block Diagram of the PID controller, (a) symbolic form, (b) time domain form, (c) Frequency domain form.

According to the figure 4.5 the pi controller is used to control the $V_d V_q$ inverter and dqo to abc transformation as well as the modulation index also controlled under unity.

4.7.1. Tuning of a PID Controller

This part of setting up a PID controller is to tune or choose numerical values for the PID coefficients. Many industrial process companies have in-house manuals that provide guidelines for the tuning of PID controllers for particular process plant units. Thus for simple processes it is often possible to provide rules and empirical formulae for the PID controller tuning procedure [22]. The PID controller tuning methods are classified into two main categories

- ✓ Closed loop methods
- ✓ Open loop methods

Closed loop tuning techniques refer to methods that tune the controller during automatic state in which the plant is operating in closed loop. The open loop techniques refer to methods that tune the controller when it is in manual state and the plant operates in open loop. Some of these closed loop tuning techniques base on the pro forma routines of the classical Ziegler–Nichols (Ziegler & Nichols 1942) methods and their numerous extensions of the associated rules. The Ziegler–Nichols methods use an on-line process experiment followed by the use of rules to calculate the numerical values of the PID coefficients. New versions of the Ziegler–Nichols (ZN) procedures were introduced, notably the Astrom and hagglund relay experiment (Astrom and hagglund, 1985).
SVPWM technique's or methods reveled to be an extensive development for PID controller tuning and optimization of performances used in SVPWM. In this thesis PID algorithm has been discussed to tune and optimize to synchronize with SVPWM parameters.

4.7.2. The Ziegler-Nichols (ZN) Tuning Method

This closed loop ZN method is a trial and error tuning method based on sustained oscillations. This method that is probably the most known and the most widely used method for tuning of PID controllers is also known as online or continuous cycling tuning method. The P gain is increased until it reaches the ultimate gain ,K_u, at which the output of the loop starts to oscillate. Ku and the oscillation period Pu are used to set the gains as shown in table below. Having the ultimate gain and frequency (Ku and Pu) and using the Table 4.1, setting the values of K_p, K_i and K_d according to the formulas.
Table 4.2: K_p, K_i and K_d values using Ziegler–Nichols method [22] Controller parameters of Closed-loop ZN Tuning Rule.

Ziegler-Nichols tuning Method (ZN)			
Controller type	**Tuning parameters**		
	K_p	K_i	K_d
P	$\frac{1}{2.0}K_u$	-	-
PI	$\frac{1}{2.2}K_u$	$1.2\frac{K_u}{K_p}$	-
PID	$\frac{1}{1.7}K_u$	$2\frac{K_u}{K_p}$	$\frac{K_u * K_p}{8}$

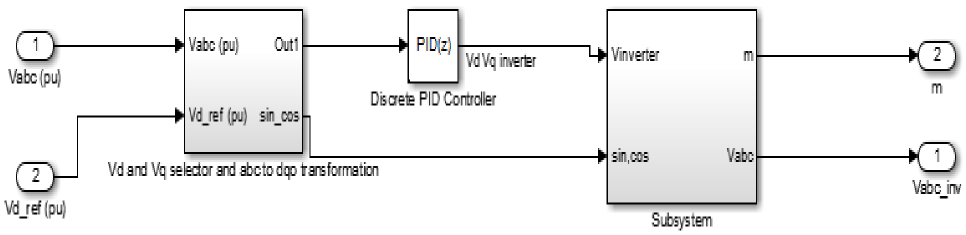


Figure 4.6: The matlab block diagrams of the PI controller.

According to figure 4.6 this matlab block that is modeled to control the modulation index under unity and the transformation of the voltages from abc to dqo or vice versa as well as the V_{ref} or voltage reference is controlled by using this PID controller.

4.8. Space Vector Pulse Width Modulation

The space vector PWM (SVM) method is an advanced, computation-intensive PWM method and is possibly the best method among the all PWM techniques for variable-frequency drive application. Because of its superior performance characteristics, it has been finding wide spread application in recent years. Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM) [1]. It is used for the creation of alternating current (AC) waveforms; most commonly to drive 3 phase AC powered motors at varying speeds from DC using multiple class-D amplifiers. There are SVPWM that result in quality requirements. One active area of development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these of block diagram.

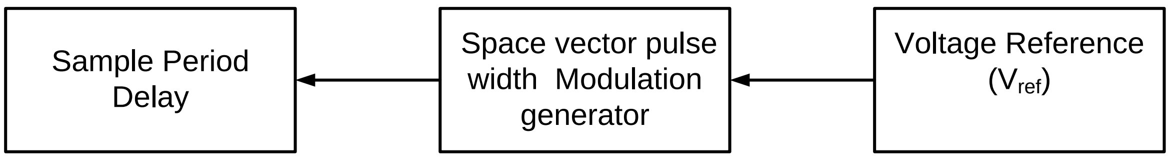


Figure 4.7: The subblock diagram of SVPWM in matlab.

Sample period Delay is in figure 4.7 provides an output port for a subsystem of a space vector pulse width modulation generator. The output when disabled and initial output parameters only apply to conditionally executed subsystems of inverter. When a conditionally executed subsystem is disabled, the output is either held at its last value or set to the initial output.it is a discrete time operator. The block accepts one input and generates one output. This output in a vector form. Which it makes the space vector modulation.

Space vector pulse width modulation generator is discrete the switching time and carrier or triangular voltage and controlled voltage which is controlled by fundamental frequency. This controlled voltage is given to the inverter though the sample period delay.in this paper the number of voltage vector and magnitudes are determined.as shown in figure 4.8 the SVPWM generator is to approximate the reference voltage vector instantaneously by combining the swishing states corresponding to the basic space vectors.

More precisely, for every PWM period, the reference voltage vector is averaged by using its adjacent vectors voltages for certain duration of time and null vector also there at origin and end.

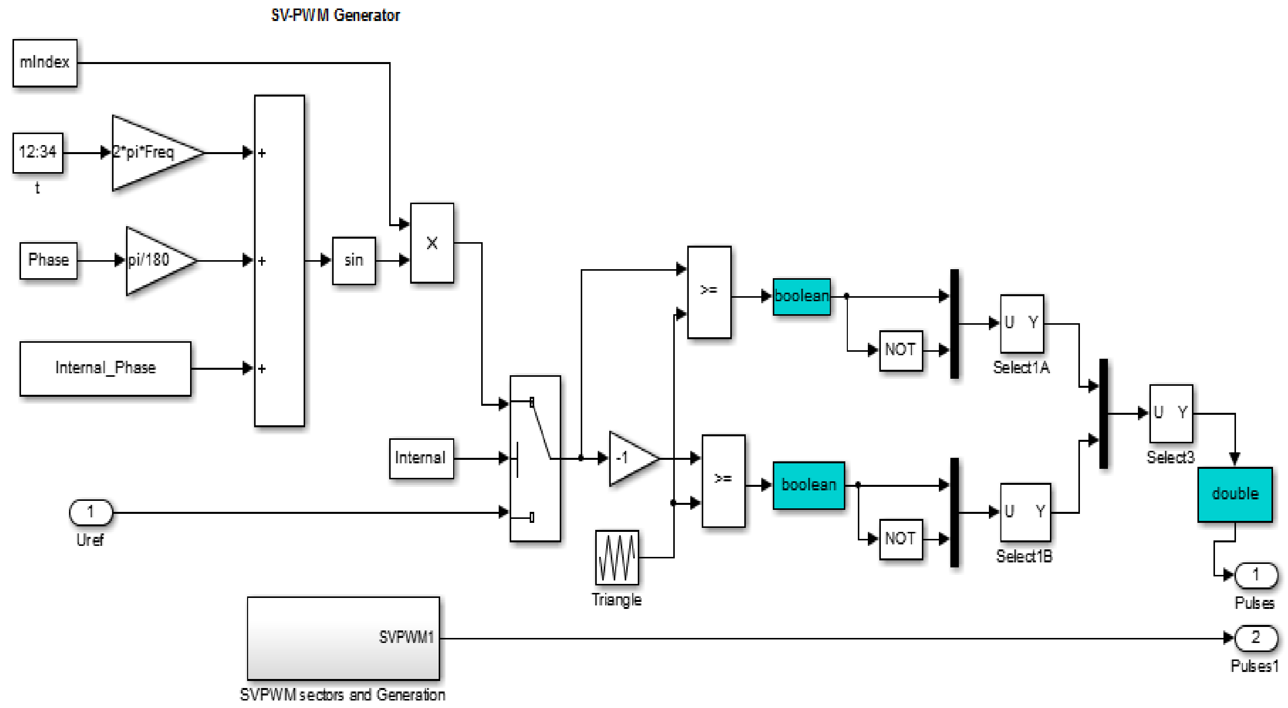


Figure 4.8: Sub block diagram of SVPWM generator triangular and control voltage.

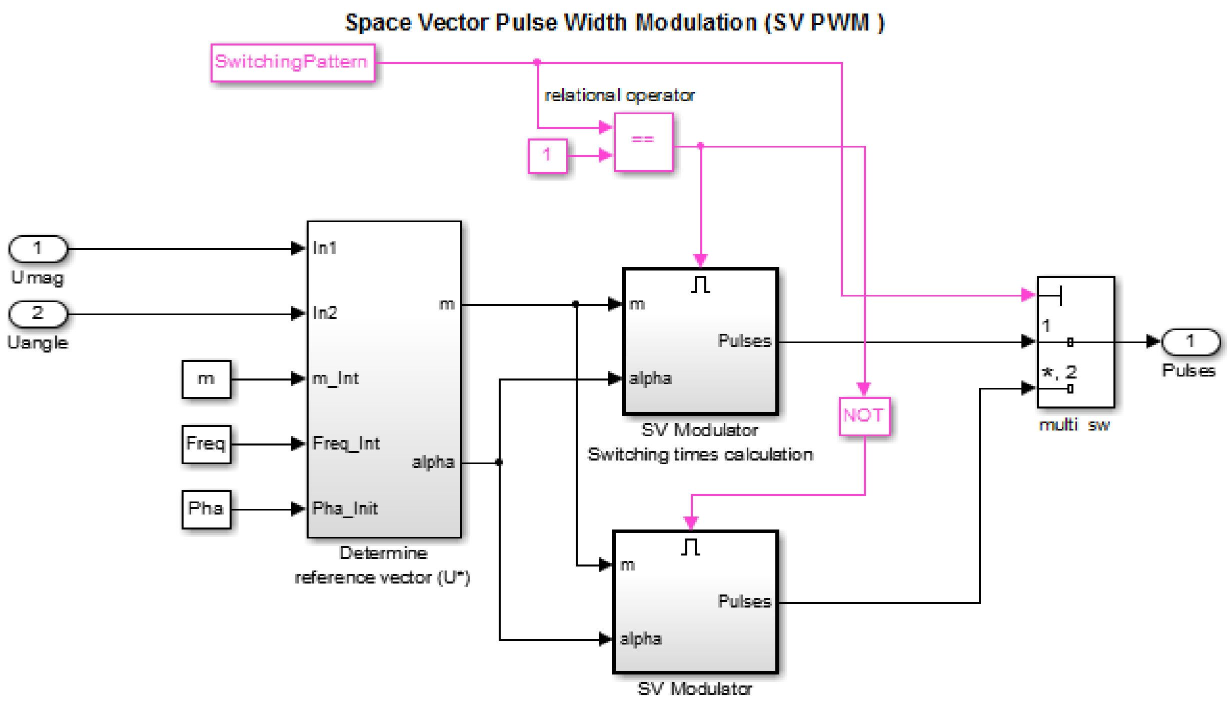


Figure 4.9: Sub block diagram of SVPWM generator of switching signal generation.

According to the figure 4.9 , To implement space vector modulation a reference signal V_{ref} is sampled with a frequency f_s (T_s =1/f_s). The reference signal may be generated from three separate phase references using the transform accordingly each calculated switching sectors. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Switching loss is approximately proportional to the magnitude of the current being switched and it would be advantageous to avoid switching the inverter leg with the highest instantaneous current.

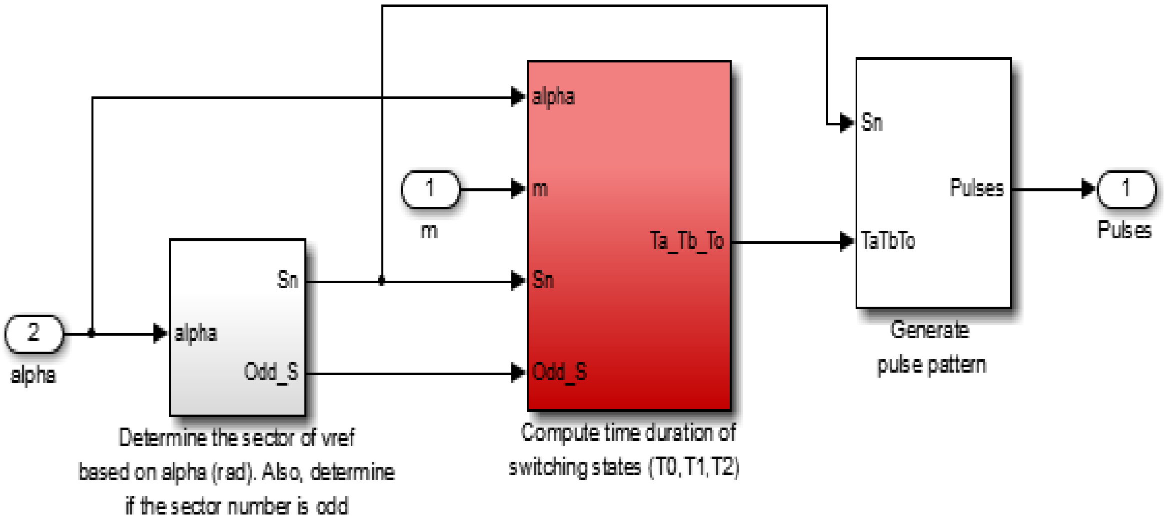


Figure 4.10: Subblock diagram SVM switching sector and time calculations.

According figure 4.10, it determines the Null vector is assigned for odd sectors 1, 3, 5 and null vector [0 0 0] is assigned for sectors 2, 4, 6.The no-switching interval occurs in the 60 degrees next after the peak of the phase voltage. Generally, the current is leading the phase voltage and most probably the peak of the current fundamental sits in the next 60 degrees after the peak of voltage. This method of sector is reduces the switching. The counter-clockwise and clockwise sequences were used alternatively in the generation of pulses.

4.9. Voltage Sag

Voltage sags defined as short duration reductions in RMS voltage, which is one of the power quality problems in NCSC. Sags are mainly caused by short circuit faults in the power system [26] and discussed in chapter five. Voltage sag data are aggregated for 10 minute interval at each location in general [15].

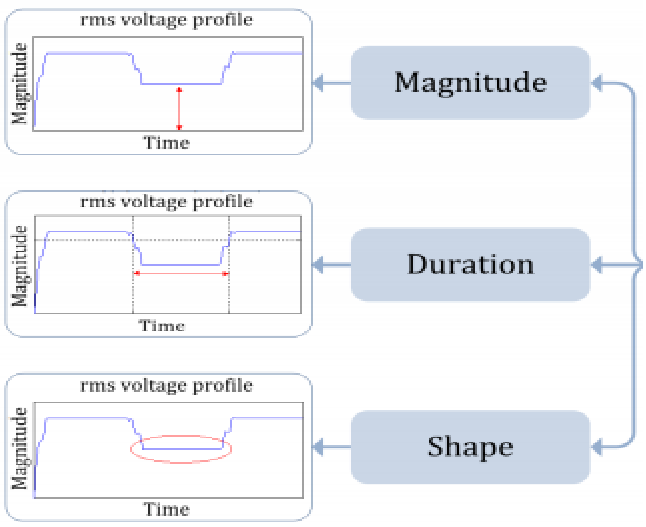


Figure 4.11: Characteristics of voltage sag.

According to figure 4.11, the voltage profile shape is another characteristic taken into consideration. Non-rectangular sags can be studied by modeling and simulating the start of large induction motors in power systems. Sag duration corresponds to the period of time during which the protective equipment allows fault current to flow.

If one or two phases are greater than 1.0 per unit (because of neutral shift), they will be reset to 1.0p.u then Sags will be qualified. Qualifying sag has at least one phase equal to or below 0.75p.u. That is, the sags with maximum voltage 0.75 per unit but above those values are not counted. The lost energy in a sag event is E calculated from is (4.5) [22].

$$E = (1 - V_{pu})^{3.14} * t \tag{4.5}$$

Where V_{pu} is per unit voltage during the sag event and t is the time sag duration.

E is the energy loss in sag event.

An example for only one phase voltage is used in this table 4.2.

Table 4.3: One phase voltage sag of energy loss in NCSC.

Duration time(ms)	V1(pu)	A=$(1 - V_{pu})^{3.14}$	E=A*t
0.37	0.88	0.001284	0.475
0.11	0.68	0.028	3.07
0.42	0.83	0.17	3.83

From this table 4.2: number of qualified voltage sags is 3.

Average Voltage Sag Energy Index: 1/3 (0.88+0.68+0.83) =0.79 pu and

Total energy loss (E) =0.475+3.07+3.83=7.375 pu.

Average energy loss (E_{avr}) =E/3=2.46 pu.

For three-phase calculation, lost energy for all three phases will be added the three individual phases.

CHAPTER FIVE

SIMULATION RESULTS AND DISCUSSION

5.1. Introduction

The simulation results are discussed in this chapter; Simulations has been done for one AC voltage controller. Both current and voltage harmonics have been simulated and discussed.
Dire Dawa National Cement Share Company takes power from high voltage feeder which is 132 KV line. This voltage is stepped down to 6.3KV by one transformer. The power quality data of AVR have been analyzed and are compared with SVPWM and different international standards in chapter three and in this chapter by tabular form. In this chapter simulation result studies with different mitigation techniques and analysis of these techniques are also presented graphically.
The main aim of any modulation technique is to obtain variable output having maximum fundamental component with minimum harmonics. The objective of Pulse Width Modulation techniques is enhancement of fundamental output voltage and reduction of harmonic content in Three Phase Voltage Source Inverters. In this paper SVPWM techniques are compared in terms of Total Harmonic Distortion (THD) with AVR. Simulink Models has been developed for Space vector PWM (SVPWM) technique and switching Patterns. Simulation work is carried in MATLAB13a Simulink.

5.2. Voltage Sag Calculation

Voltage sag is one of the types of power quality problem which is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level in the factory. They normally last from 3 cycle to the maximum 1 (one) minute in the company. Voltage sags are the most significant power quality (PQ) problem facing industrial customers today in National cement share company which can be caused either internal or externally, and they can be a significant problem for the companies like NCSC as well. This thesis work does suggest a solution to voltage sag at the factory level since the problem originate at utility level as well. The solution should be using of SVPWM that effective voltage regulation systems should be used to avoid voltage sag.
Voltage sags are usually characterized by voltage magnitude and duration Voltage sag data are aggregated for 10 minute interval at each location of the three phase. Sags has discussed in table form as shown in table 5.1. Qualifying sag has generally the magnitude of voltage sag is between 0.1p.u and 0.9p.u. Table 5.1; is the data of each three phase voltage values in per unit as calculated in appendix B, is total sag energy is 50.142pu and average sag energy index is 5.0142pu at sag event 10.

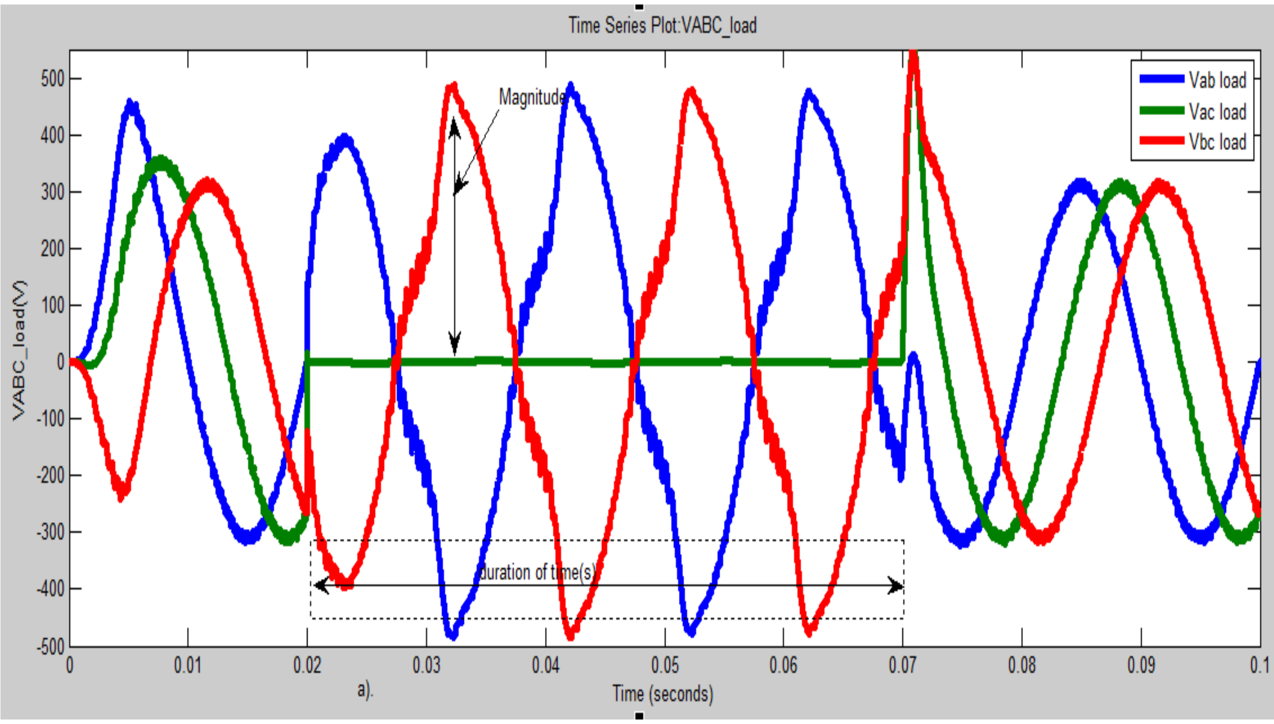
Table 5.1: Measured voltage sag data of NCSC.

Duration time(second)	V_1(pu)	V_2(pu)	V_3(pu)
0.37	0.88	0.64	0.69
0.11	0.68	0.65	0.70
0.42	0.83	0.81	0.81
0.083	0.81	0.82	0.78
0.10	0.77	0.84	0.79
0.083	0.95	0.77	0.70
0.033	0.85	0.98	0.80
0.099	0.90	0.70	0.60
0.1	0.68	0.49	0.57
0.067	0.97	0.86	0.84

Examples of Data for only one phase to calculate the voltage sag. For three phase calculation, lost energy for all three phase has been added, and become the energy lost for one phase is approximately 7.9pu. And average voltage sag energy is approximately 2.6 as shown in table 5.2.

Table 5.2: the energy loss and average voltage sag energy at NCSC for one phase.

voltage V(p.u)	Time t(ms)	(1-V(p.u))	[(1-V(pu))^(3.14)]*t	average voltage sag energy index/3	No. of sag
0.8	65	0.2	0.42		3
0.6	50.4	0.4	2.84		
0.5	40.5	0.5	4.6		
Total Energy loss(pu)			7.9	2.6	



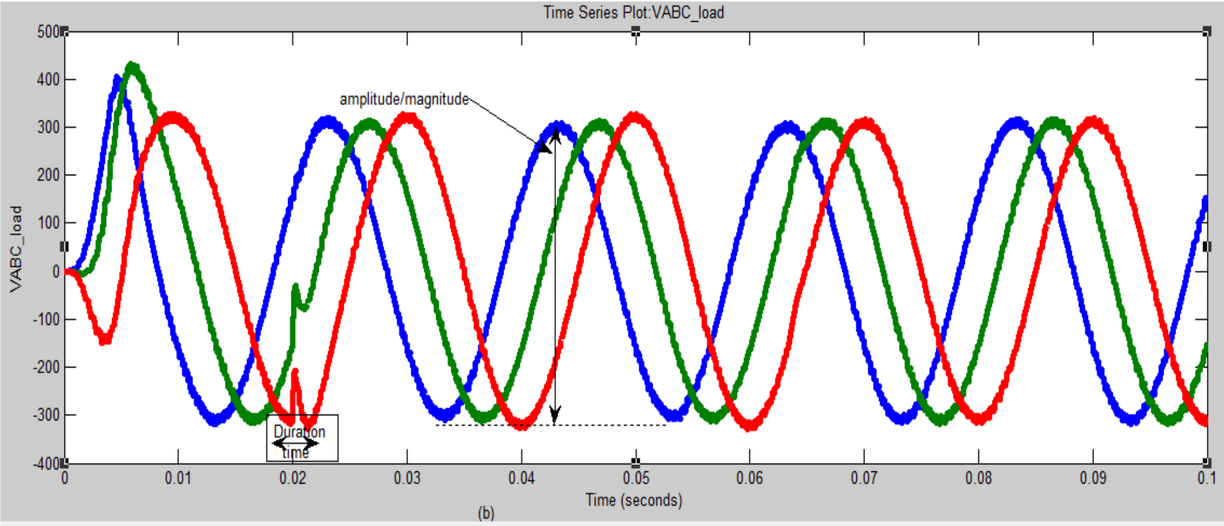


Figure 5.1: Simulation of voltage sag on the load (three-phase fault) a).Phase to phase fault. b).phase to ground fault.

Building models of electrical protection devices on Matlab/Simulink is necessary for simulations, because this tool does include those models of output. A SVPWM technique of power system has been simulated with voltage sag reduction in Figure 5.1a) and b); because this is the most widely used technique. Figure 5.1 shows the voltage sag on the load, which presents non-rectangular voltage sag of 0.674 pu and 50 ms (time that the motor takes to reach its rated speed). The voltage sags due to power system faults simulated are compared with the ones presented in table 5.1 and 5.2. In those papers, the voltage sags caused by faults in phase to phase and phase to ground are studied, including the effect of sag on power system protections and loads.

Sag duration corresponds to the period of time during which the protective equipment allows fault current to flow. There is a SVPWM technique using in the power system and each one has a minimum fault clearing time. But a delay for protection coordination or duration is there in AVR. In the case of temporary faults, some of the protective devices have a reclose function to restore service within a short time figure 5.1 b) and voltage sag in SVPWM technique faults are cleared faster than AVR controller system faults.

5.3. Total Harmonic Distortion Mitigation

Harmonics are unwanted higher frequencies which superimposed on the fundamental waveform creating a distorted wave pattern form. The data presented in SVPWM techniques, the harmonic distortion measured on the transformers are within standards as shown in table 5.3. But the harmonic distortion data on the transformer by using AVRs are more than the SVPWM technique as shown in table 3.6 and 3.7 and in chapter three. The THD of voltage and Current exist in the Dire Dawa NCSC is more distorted when comparing with the SVPWM techniques.

Table 5.3: THD of voltage standard and measured values

Value	Standard value of max. THD for 115 to 161 KV	Measured values of THD while using AVR controller	Modeled values of THD
THD%	THD_v%	THD_v%	THD_v%
A	2.5	3.212	1.73
B	2.5	3.25	2.06
C	2.5	3.266	1.60

5.4. Output Voltage inverter

The expected output of the total harmonic distortion of the inverter voltage simulated value for each phase as shown in figure 5.2 to 5.4 below. SVPWM is a popular choice in the inverter controls of the voltage in this thesis.

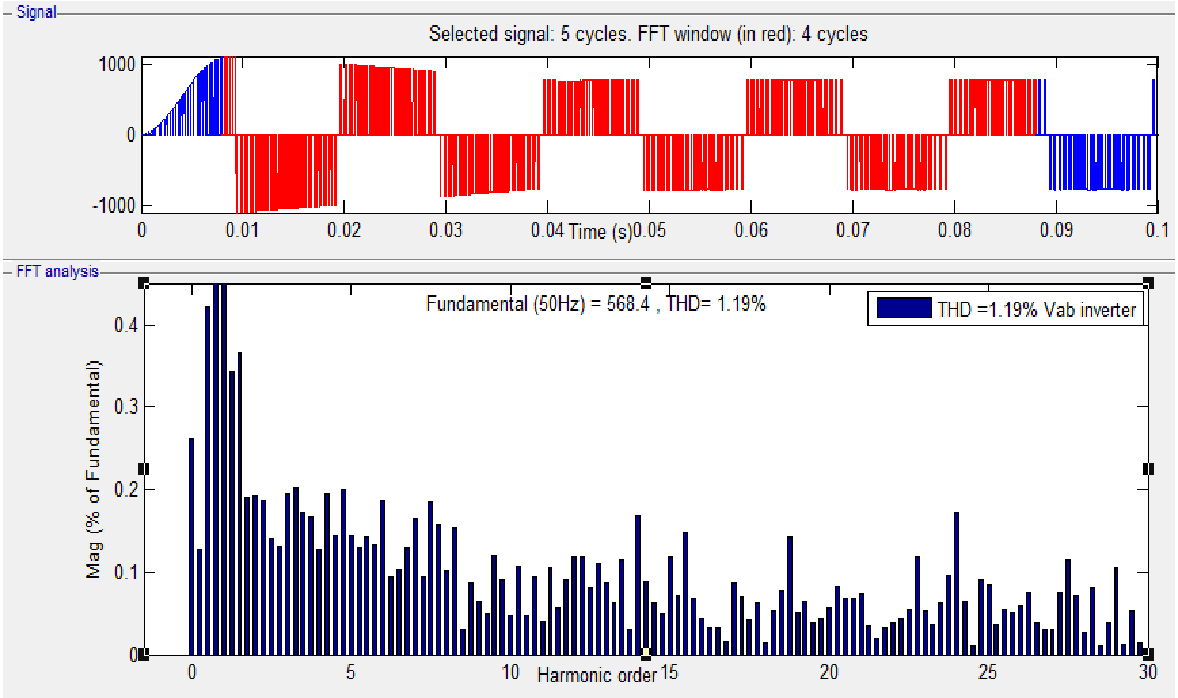


Figure 5.2: THD=1.19% of inverter voltage (V_{ab}-inverter) While using SVPWM.

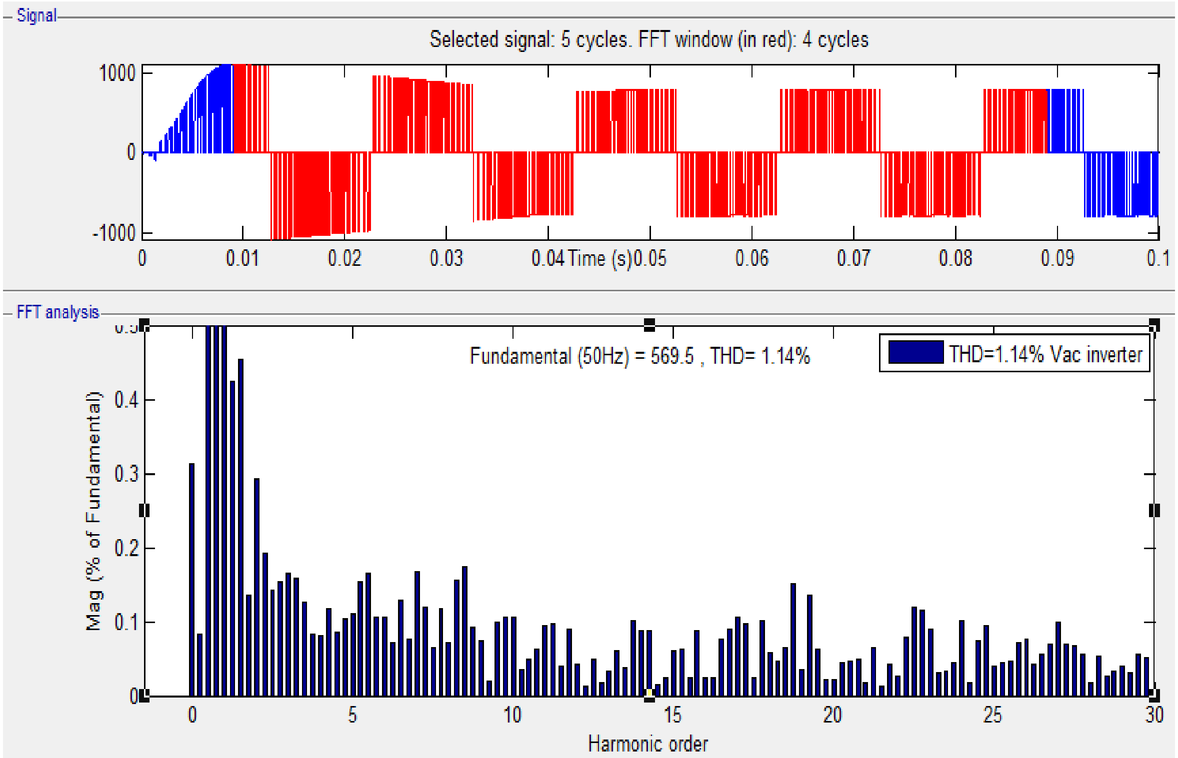


Figure 5.3: THD=1.14% of Inverter Voltage (V_{ac}-inverter) while using SVPWM.

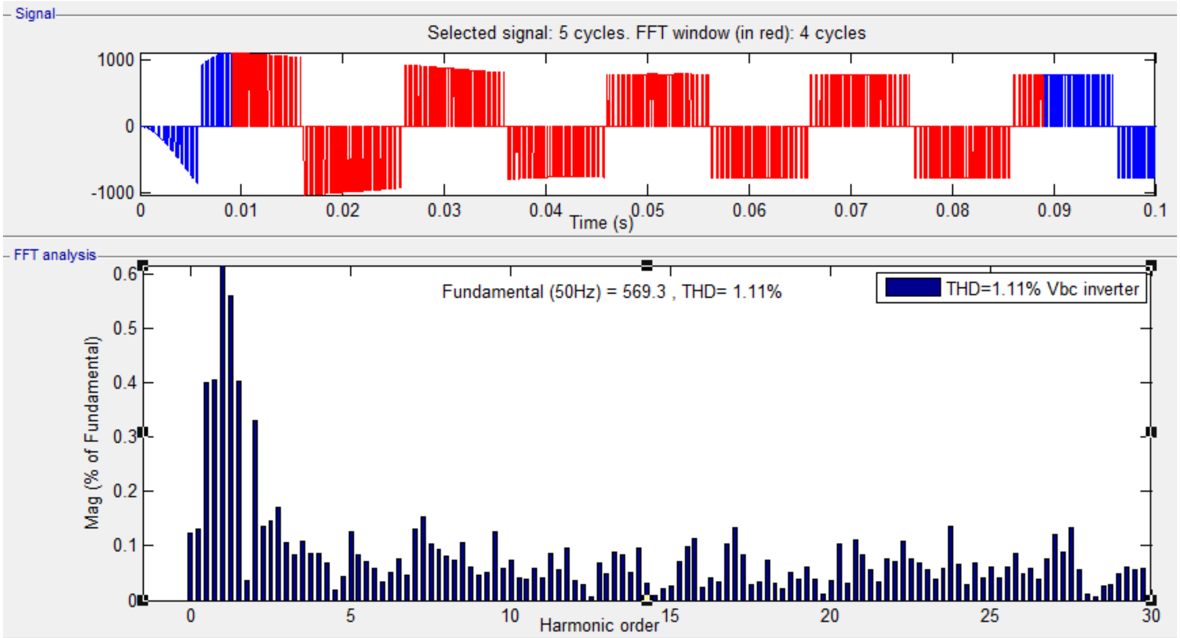


Figure 5.4: THD=1.11% of Inverter Voltage (V_{bc}.inverter) while using SVPWM.

Total harmonic distortion is an important criterion for power quality improvement. For the basis of presented harmonics in a power line THD is being calculated. This figure created by the help of MATLAB, power gui, FFTAnalysis Result, during an inverter condition THD of phase side voltage presented in this figure. From this presented figure 5.2 to 5.4 we can see that voltage source inverter using SVPWM technique is much better than AVR because the harmonics which is generated in the distribution line eliminated by the help of PI controller system and the load voltage is approximately sinusoidal.

5.5. Sampling time vs gating time

The figure 5.5 is the gating time of the SVPWM directly using the time allocated to states given for (tga, tgb,tgc). The definition of the switching gate time sequence would result to be implemented in matlab software as shown in (appendix A). It is more advantageous to define a function called "Switching reference function" of ON and OFF gating time with the same meaning as the reference used in SVPWM of sector. It represents the duty ratio of each inverter leg or the conduction time normalized to the sampling period of time for a given switch.

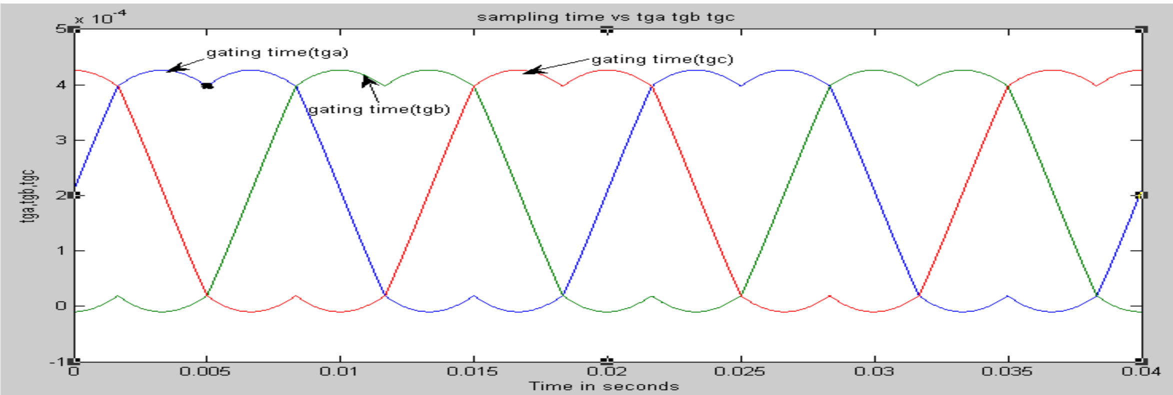


Figure 5.5: sampling time vs gating time

5.6. Sampling time vs switching sectors

At the Null vector [1 1 1] is assigned for sectors 1, 3, 5 and null vector [0 0 0] is assigned for sectors 2, 4, 6.The no-switching interval occurs in the 60 degrees next after the peak of the phase voltage. Generally, the current is leading the phase voltage and most probably the peak of the current fundamental sits in the next 60 degrees after the peak of voltage. This method of sector is reduces the switching loss and the mitigated scheme was designed as follows in figure 5.6. Assuming the reference vector located in sector I, the first sampling point used the sequence V_1-V_2-V_7, which goes counter clockwise along the vertices of the sector, and then the next sampling point used V_2-V_1-V_0, which goes clockwise. The counter-clockwise and clockwise sequences were used alternatively. The dwelling times or the spending of each sequence were happening during the changing of the sequences at the sampling frequency.

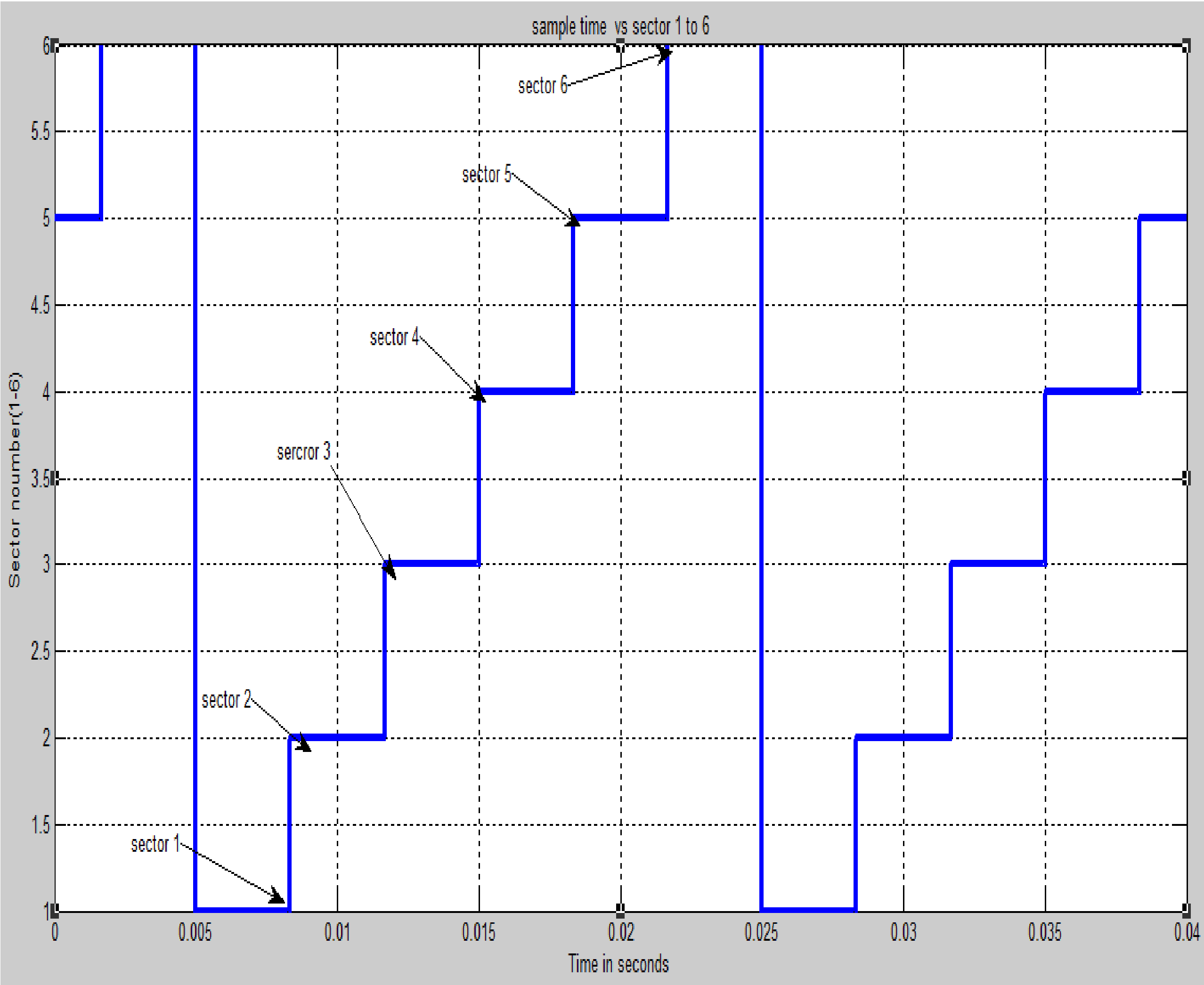


Figure 5.6: sampling time vs switching sectors

5.7. Output of load Voltage

The expected output load voltage is simulated at figure 5.7-5.9.When SVPWM control technique is used in the power electronic system; it mostly operates in the under modulation region as discussed in chapter three. The output load voltage magnitude of the SVPWM is between 380V and 400V.

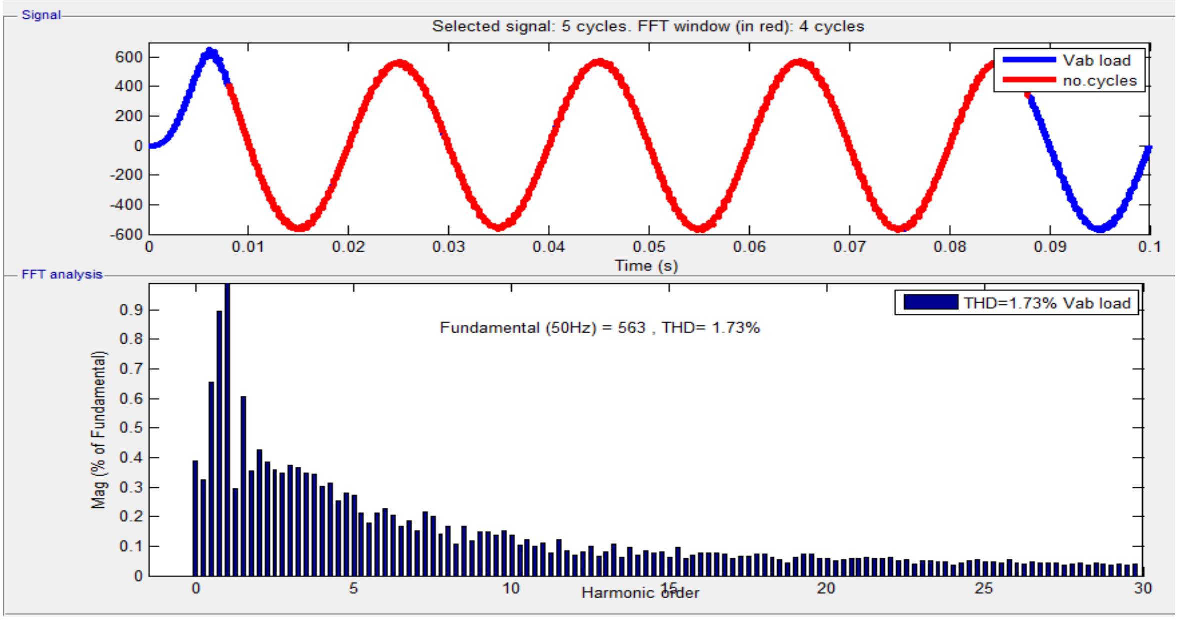


Figure 5.7: THD=1.73% of load voltage (V_{ab}.Load) while using SVPWM.

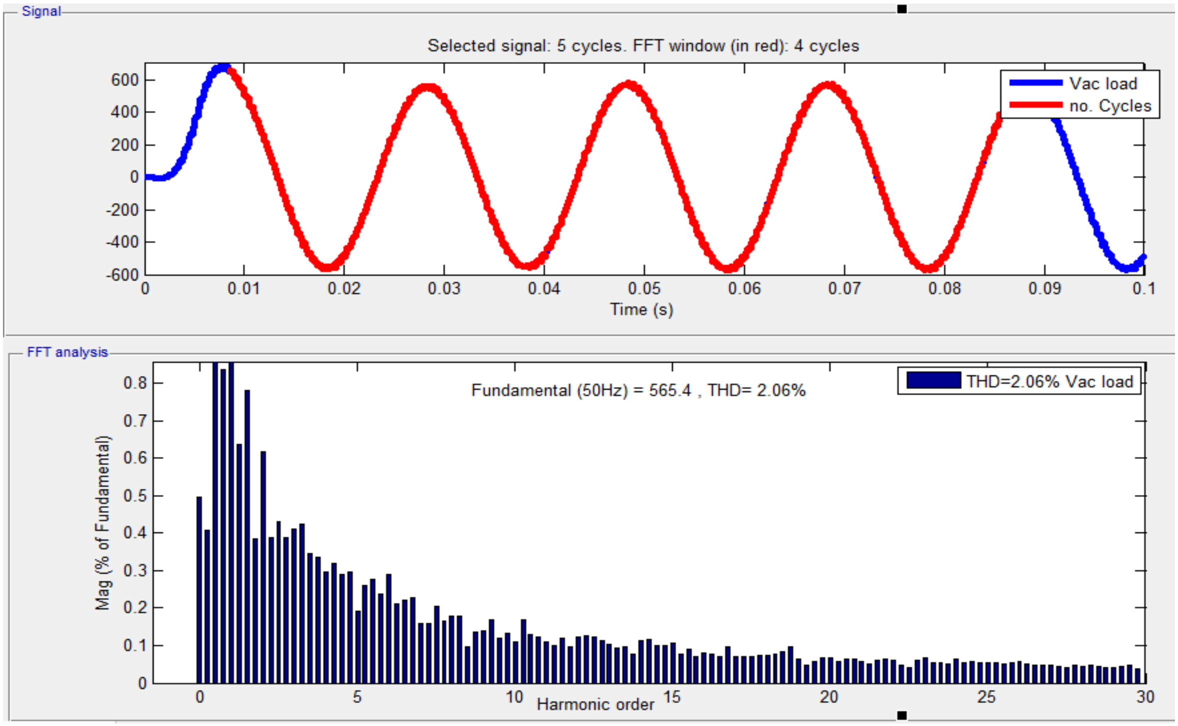


Figure 5.8: THD=2.06% of Load Voltage (V_{ac}.Load) while using SVPWM.

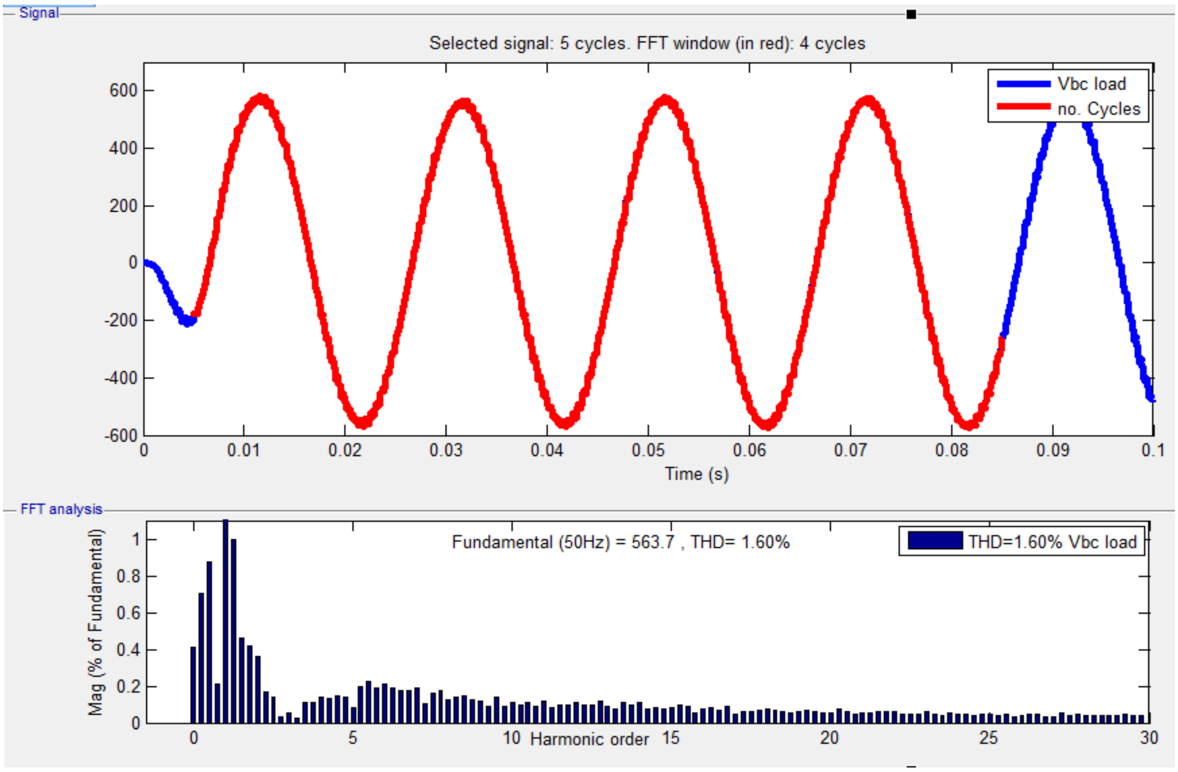


Figure 5.9: THD=1.60% of Load Voltage (V_{bc}-Load) while using SVPWM.

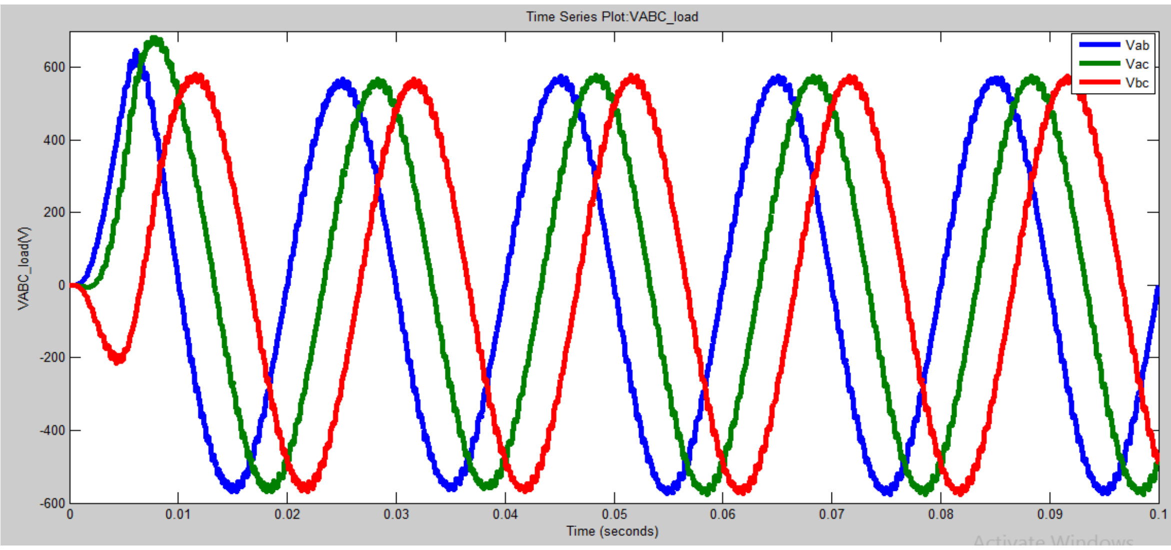


Figure 5.10: Three phase Load Voltage while using SVPWM.

As 3-phase system, the output load voltage of all phase should be shown in figure 5.10 for comparison of the loads sinusoidal wave. But according to the figure 5.7 to 5.9 is the expected output load voltage using the modeled AC voltage controller by using of the SVPWM techniques. From this simulated output the type of load used is RLC load. The above conditions are generally met the Smallest instantaneous deviation from its reference value, maximum utilization of the available dc-bus voltages, lowest ripple in the load or motor current, and minimum switching loss in the inverter legs or sectors.

5.8. Output Load Current

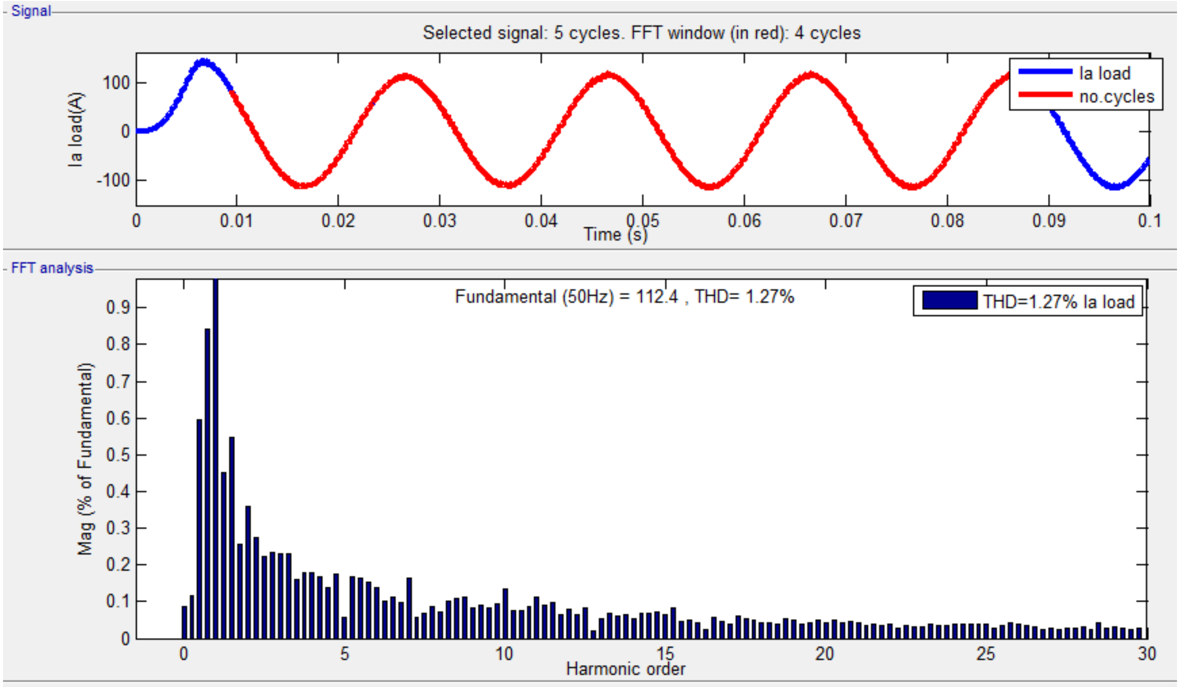


Figure 5.11: THD=1.27% of Load Current ($I_{a\text{-}Load}$) while using SVPWM.

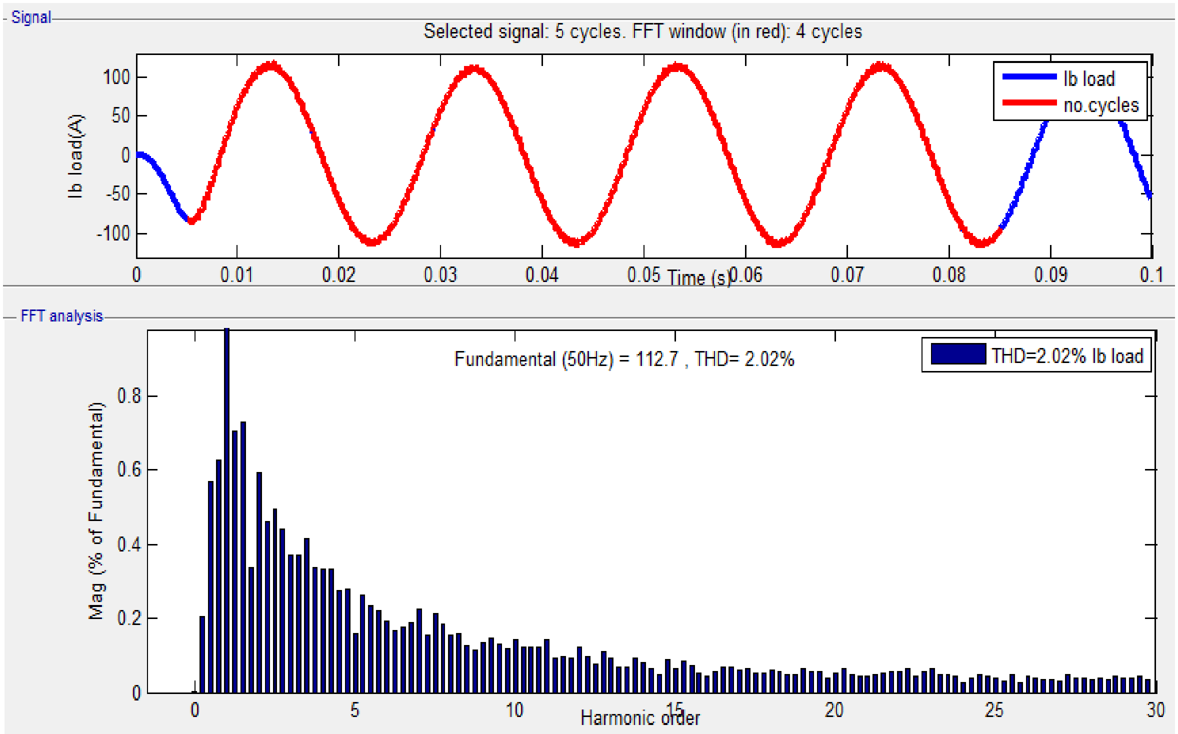


Figure 5.12: THD=2.02% of Load Current ($I_{b\text{-}Load}$) while using SVPWM.

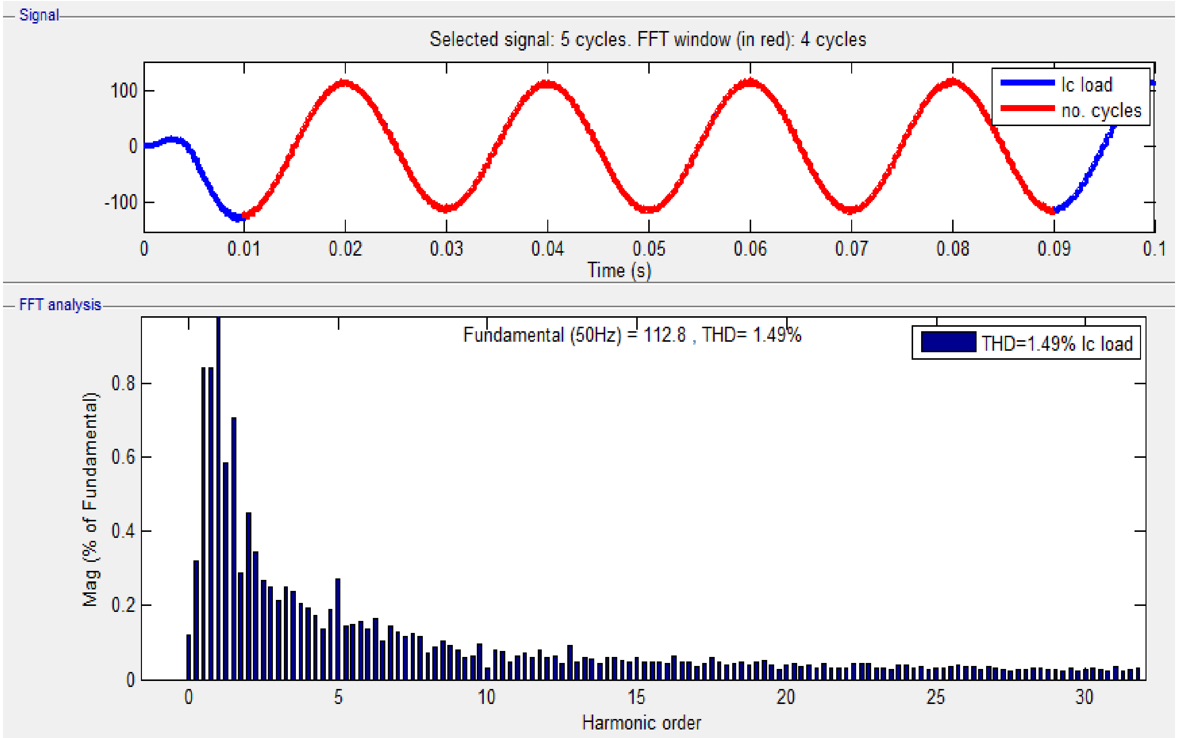


Figure 5.13: THD=1.49% of Load Current ($I_{c\text{-}Load}$) while using SVPWM.

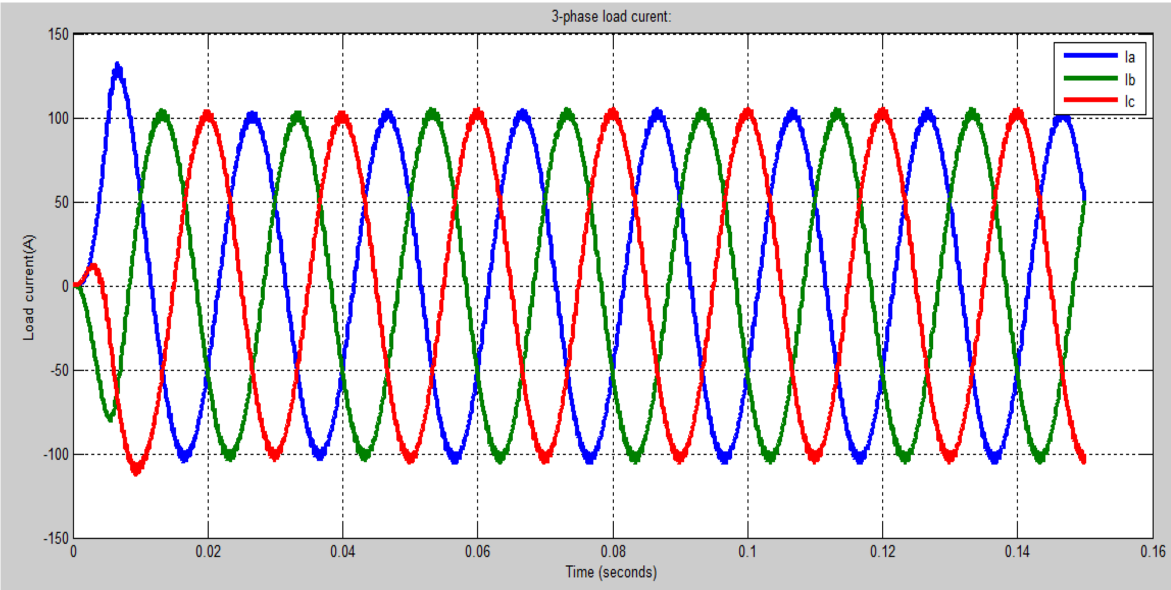


Figure 5.14: All three phase Load Current while using SVPWM.

As 3-phase system, the output load current of all phase should be shown in figure 5.14 for comparison of the current loads in sinusoidal wave form. But according to the figure 5.11 to 5.13 is the expected output load current using the modeled AC voltage controller by using of the SVPWM techniques. From this simulated output the type of load used is RLC load. The above outputs of load current are generally met lowest ripple in the load or motor current.

The Comparison of the Existing values of the system and the modeled values of THD in the Dire Dawa National Cement Share Company (NCSC).

Table 5.4: Comparison of existing THD voltage values of the system with the modeled values.

THD	Existing Value in %	After Model %
THD_{Ia}	31.14	1.27
THD_{Ib}	33.2	2.02
THD_{Ic}	30.06	1.49
THD_{Vab_Load}	3.212	1.73
THD_{Vac_Load}	3.25	2.06
THD_{Vbc_Load}	3.266	1.60

5.9. Summary of voltage and current unbalances

The table 5.5 and 5.6 the summary of voltage and current unbalances on the dire dawa national cement share company in percentage (V %) and (I %) for using AVR and SVPWM techniques of voltage and current respectively.

Table 5.5: Summary voltage and current unbalances for the transformers at full loads using AVR controller.

Items	Voltage unbalances V (%) using AVR.	Current unbalance I (%) using AVR.
In Average values	1.11	1.41
IEEE standards	Less than 1	Less than 10
Summary of conclusion	Beyond the standard	In range of standard

Table 5.6: Summary voltage and current unbalances for the transformers at full loads using SVPWM techniques.

Items	Voltage unbalances V (%) using the SVPWM techniques.	Current unbalance I (%) using SVPWM
In Average values	0.814	1.124
IEEE standards	Less than 1	Less than 10
Summary of conclusion	In range of standard	In range of standard

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Space vector modulation technique has become the most popular and important PWM technique for three phase voltage source inverters for the control of AC voltage induction motors. This thesis work is sufficiently describe assessment of power quality problems starting with review of literature, previous research works and collected and analysis of data. In most the thesis emphases on recent and more practical industrial applications of AC voltage controller using of SVPWM by controlling voltage source inverter. Measurements have been conducted to design AC Voltage controller using SVPWM technique at Dire Dawa NCSC. Based on the data, various analyses have been performed to identify the values or levels of the THD problems. Then respective solutions have been presented. In this paper, AVR and SVPWM techniques have been investigated and compared. During the investigations, the realization of total harmonic distortion and voltage sag in SVPWM techniques. For this purpose the performed extensive simulations of these techniques using MATLAB tools. It has been observed that SVPWM has showed superior performances due to less THD and less voltage sag because SVPWM utilizes advance computational switching technique to reduce THD. It also reduces switching times because of the changing of any one switching state which results in one single phase voltage change every time. Furthermore, at high switching frequencies SVPWM gives better results as compared to AVR. Thus, based on all obtained results, concluded that SVPWM technique provides greater overall performance as compared to AVR. From the analysis model of AVR, it is seen that current THD in the range of 30.06% to 33.2% and voltage THD in the range of 3.212% to 3.27% were measured from the system. But using the designed mitigation techniques it is seen that current THD in the range of 1.27% to 2.02% and voltage THD in the range of 1.60% to 2.06% were obtained from modeled Matlab Simulink. In this paper, the method for harmonic reduction in SVPWM-AC voltage controller has been presented and Smaller THD values are obtained when compared with the AVR. As a consequence, power quality improvement is realized, by improving the THD using AC voltage controllers using SVPWM technique. The THD and voltage sags in SVPWM method are decreased proportionally corresponding to the AVR. The performance of the machine will be improved when it is fed with SVPWM techniques.

6.2. Recommendation

Based on the result of this thesis work, it is strongly recommended that the following recommendations are drawn

- ✓ The Ethiopian electric utility should work a lot on the whole distribution power system, from generation to customer to reduce power quality problems and especial attention should be given to power problems like THD and Voltage Sag which has been a day to day problem for the end users.
- ✓ Generally Industries like NCSC in Ethiopia need to assess practically and theoretically the power quality status of their supply system and sensitivity of their

equipment to the power quality problems with coordination to University Lectures are amended.

- ✓ Hence the THD value of current and voltage has the negative effects on the performance of the machine; the author recommends NCSC Factory to look the standard THD value of the currents and voltage during buying. So that the company can free from extra billing for the Ethiopian Electric Utility.

REFERENCES

[1] P. M. Balasubramaniam, "Power Quality Issues, Solutions and Standards," Journal of Applied Science and Engineering, Vol.18, No. 4, pp. 371-380, 2015.

[2] Bollen, M., "Understanding Power Quality Problems Voltage Sags and Interruptions,"IEEE Press Series on Power Engineering John Wiley and Sons, Piscataway, USA, 2000.

[3] Raja Kumar, "Review on Power Quality Issues," Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498, Vol.2, No. 1, 2012.

[4] Manish Sahajwani and Sushma Patel, "A Review on Modern Pulse Width Modulation Techniques Based Inverters," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 5, Issue 9, September 2016.

[5] Bose, B. K., "Modern Power Electronics and AC Drives," Prentice-Hall, Inc. New Jersey, USA, pp.700-709, 2002.

[6] Balci, M.E., Hocaoglu, M.H, "Effects of Source Voltage Harmonic Distortion on Power Factor Compensation in Triac Controlled AC Chopper Circuits," IEEE PEDS, 11191- 2005.

[7] Biran A. and Breiner M, "MATLAB for Engineers," Addison-Wesley Publishing Company, Cambridge-United Kingdom, pp.625-668, 1995.

[8] Kazmierkowski, M.P.Krishnan, and R.Blaabjerc, "Control in Power Electronics," Academic-Press, Inc. California-USA, pp.510-518, 2002.

[9] V.K.Proakis and J.G, "Digital Signal Processing Using Matlab," Bookware Companion Series, Canada, pp.400-418, 2000.

[10] Shinyama T.,Ueda A.and Torii A.,"AC Choppers Using Four Switches," IEEE,1056:1060, 2002.

[11] N. Mohan, T. Undel and, W. Robbins, "Power Electronics: Converters Applications and Design," Wiley Text Books, Third Edition, ISBN: 0471226939, 2002

[12] Prof. Ravindra Joshi, "IEEE 519 Recommended practices and requirements for harmonics control in electrical power systems," Technical Report, IEEE Industrial Applications Society/Power Engineering Society, 1993.

[13] Lettl, J, "Duality of PWM rectifiers," Proceedings of Electronic Devices and Systems Conference, Brno, 2003.

[14] R Paku and R Marschalku, “Matlab/simulink/Sim power systems model for a PWM AC-DC converter with line conditioning capabilities”, Vol.51, No.2, 2010.

[15] D. Lee, T. Habetler, “A voltage sag supporter utilizing a PWM-switched autotransformer,” IEEE Transactions on Power Electronics, 22(2): 626–635, 2007.

[16] G.M. Hashem and M.K. Darwish, “Generalized symmetrical angle PWM technique for AC voltage controller,” Power Engineering Conference, UPEC2004, Vol. 2, pp.898- 901, 2004.

[17] H. W. van der Broeck, H. C. Skudelny, and G. Stanke, “Analysis and realization of a pulse width modulator based on voltage space vectors,” IEEE Trans. Ind. Applicat., vol. 24, pp. 142–150, Jan. /Feb. 1988.

[18] Alexander Kusko, Sc.D., and Marc T. Thompson, Ph.D., “Power Quality in Electrical Systems,” McGraw-Hill Companies, 2015.

[19] Reger C. Dugan and Mark F. McGranaghan, “Electrical power quality”, second edition, 2011.

[20] Thomas M. Blooming, and Daniel J.Carnovale, “CAPACITOR APPLICATION ISSUES,” Senior Members, IEEE Eaton Corporation, 2012.

[21] R. Cordero and J.O.P. Pinto, “Relationship between SPWM and SVPWM for Under-modulation and Over-modulation Modes Based on Modified Carrier Signal,”2015.

[22] B. Wu. John Wiley and Sons, “High-Power Converters and AC Drives,” IEEE Press, Inc., 20016.

[23] E. Hendawi, F. Khater, and A. Shaltout, “Analysis, Simulation and Implementation of Space Vector Pulse Width Modulation Inverter,” International Conference on Application of Electrical Engineering, pp. 124-131, 2015.

[24] A.A.Girgis and C.M.fallon, “fault location techniques for radial and loop transmission systems using digital fault recorded data,”IEEE Transactions on Power Delivery, vol.7, no 4, pp. 1936-1945, 2014.

[25] Shady A., El. Kashlan and Hussein E.and Desouki Saied, “power quality assessment via coordinated voltage control in distributed power generation,” International Journal of Electrical and Power Engineering, vol.3, no.6, pp.289-295, 2009.

[26] Aasha Chauhan and Dr. Ravindra Pratap Singh, “a study paper based on space vector pulse width modulation technique for power quality improvement” International Journal of Science Technology & Management, Volume No.04, Special Issue No.01, February 2015.

[27] P. K. Banerjee and Kaamran Raahemifar, "AC-AC Voltage Regulation By Switch Mode PWM Voltage Controller With Improved Performance," International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-018, Vol. 2 Issue 9, September 2013.

[28] Waheed Ahmed and Syed M Usman Ali, "Comparative study of SVPWM (space vector pulse width modulation) & SPWM (sinusoidal pulse width modulation) based three phase voltage source inverters for variable speed drive," IOP Conference Series: Materials Science and Engineering, IOP Conf. Ser. Mater. Sci. Eng. 51 012027, 2013.

[29] Anugu Saritha, Abhiram, and Dr. K. Sumanth, "Space Vector Pulse Width Modulation for two level inverter" international journal of professional engineering studies, Vol.1 /Issue 3/ May 2016.

[30] Bhakti I, Chaughule Amit, L.Nehete and Rupali Shinde,"Reduction in Harmonic Distortion of the System Using Active Power Filter in Matlab Simulink," International Journal of Computational Engineering Research Vol.3,Issue, 6,June, 2013.

[31] C. Pacis, M. Martinez and V. Tecson,"Modelling and Simulation of Active Power Filters for Harmonic Compensation, Voltage Sags and Swells Mitigation and Power Factor Correction," Proceedings of the World Congress on Engineering and Computer Vol II, San Francisco, USA ,Science October 20, 2010.

[32] Phuong Hue Tran, "Matlab/Simulink implementation and analysis of Three Pulse-Width-Modulation (PWM) techniques", Electrical Engineering Boise State University, May 2012.

[33] Pack Wong, "Harmonic distortions & solutions," ABB group pp.5-22, April 12, 2010.

Appendix A

```
%Ac Voltage controller using SVPWM technique
clear all
clc
% Three phase SVPWM using generalized multiphase space vector approach
ma0= 0.907;     % maximum modulation index
ma=ma0;         % desired ma value
Vdc=563;        % dc link voltage
Vsr=ma*Vdc;   % space vector variation with ma
f0=50;            %frequency
% V/f stretegy for three phase Induction machine.
if ma<=ma0
fmod=f0*ma/ma0;
else
fmod=f0;
end
no_sample=48;                    % number of samples
Ts=(1/fmod)/no_sample;       % sampling time period
Vm=2/3*Vsr;                     % peak of phase voltage
alp=2*pi/3;                       % phase diff 120 degree
ts=0:Ts/100:2/fmod;            % step time
Va=Vm*sin(2*pi*fmod*ts); % phase voltage
Vb=Vm*sin(2*pi*fmod*ts-alp);
Vc=Vm*sin(2*pi*fmod*ts-2*alp);
L=length(ts);
for i=1:1:L
% Three phase to two phase transformation
%(Clark transformation method it use to transform 3ph to 2ph)
Vds(i)=(Va(i)+Vb(i)*cos(alp)+ Vc(i)*cos(2*alp) );
Vqs(i)=(Vb(i)*sin(alp)+ Vc(i)*sin(2*alp) );
% sector1 to 6 identifications
tht(i)=atan2(Vqs(i),Vds(i));
if tht(i) >= 0
```

```
theta(i)=tht(i);
else
theta(i)=2*pi+tht(i);
end
if theta(i)>=0 && theta(i)<alp/2
Sn(i)=1;
elseif theta(i)>=alp/2 && theta(i)<alp
Sn(i)=2;
elseif theta(i)>=alp && theta(i)<3/2*alp
Sn(i)=3;
elseif theta(i)>=3/2*alp && theta(i)<2*alp
Sn(i)=4;
elseif theta(i)>=2*alp && theta(i)<5/2*alp
Sn(i)=5;
else Sn(i)=6;
end
```

% selection of switching vector for each sector

```
if Sn(i)==1
v1=[1 ;0 ;0];  %4;
v2=[1 ;1 ;0];  %6;
v0=[1 ;1 ;1];
elseif Sn(i)==2
v1=[1; 1; 0];  %6;
v2=[0; 1; 0];  %2;
v0=[1; 1; 1];
elseif Sn(i)==3
v1=[0; 1; 0];  %2;
v2=[0; 1; 1];  %3;
v0=[1; 1; 1];
elseif Sn(i)==4
v1=[0; 1; 1];  %3;
v2=[0; 0; 1];  %1
v0=[1; 1; 1];
elseif Sn(i)==5
```

```
v1=[0; 0; 1];   %1;
v2=[1; 0; 1];   %5;
v0=[1; 1; 1];
else
v1=[1; 0; 1];  %5;
v2=[1; 0; 0];  %4;
v0=[1; 1; 1];  %0;
end
u=Sn(i);
```

% using voltage section balance calculation of active timing vector.

```
An_inv=(Ts/(sin(pi/3)*Vdc))*[sin(u*pi/3) -cos(u*pi/3) ; -sin((u-1)*pi/3) cos((u-1)*pi/3) ];
Vref=[Vds(i); Vqs(i)];
tn=An_inv*Vref;
t0by2=(Ts-tn(1)-tn(2))/2;
t120=[tn(1);tn(2); t0by2];
V120=[v1 v2 v0];
% calculation for tga gating time period for each leg
tgx(:,i) = (V120)*(t120);
tga(i)=tgx(1,i);
tgb(i)=tgx(2,i);
tgc(i)=tgx(3,i);
end
```

% Output of sampling time for switching sector.

```
figure
plot(ts,Sn);
hold on
title ('ts vs Sn');
xlabel ('Time in seconds');
ylabel ('Sector noumber');
% output of gating time
figure
plot(ts,tga,ts,tgb,ts,tgc);
hold on
title('ts vs tga tgb tgc');
xlabel('Time in seconds');
ylabel('tga,tgb,tgc')
% End of programming the codes.
```

Appendix B

Voltage sag duration time and loss energy sag at Dire Dawa National Cement Share Company (NCSC).

Duration time(s)	V1(pu)	V2(pu)	V3(pu)	E1	E2	E3	E(pu)	E(pu*ms)
0.117	0.88	0.88	0.74	2E-04	0.00015025	0.0017	0.0020035	2.0035
0.115	0.84	0.85	0.86	4E-04	0.000297594	0.00024	0.0009017	0.9017
0.434	0.76	0.75	0.75	0.005	0.005584977	0.00558	0.016083	16.083
0.083	0.97	0.85	0.8	1E-06	0.000214785	0.00053	0.0007462	0.7462
0.1	0.77	0.84	0.79	1E-03	0.000316911	0.00074	0.0020517	2.0517
0.083	0.95	0.77	0.7	7E-06	0.00082206	0.00189	0.0027223	2.7223
0.033	0.85	0.98	0.81	9E-05	1.53E-07	0.00018	0.0002649	0.2649
0.039	0.97	0.7	0.6	6E-07	0.000889663	0.0022	0.0030858	3.0858
0.1	0.68	0.49	0.57	0.003	0.012071753	0.00706	0.0219301	21.93
0.067	0.97	0.86	0.84	1E-06	0.00013961	0.00021	0.000353	0.353
Total E(Energy loss in pu and pu*ms) respectively							0.0501421	50.142