**TRIBHUVAN UNIVERSITY**

**INSTITUTE OF ENGINEERING**

**PASHCHIMANCHAL CAMPUS**

# ELECTRIC POWER CONVERSION USING MATRIX CONVERTER

**Subject Code: EE755**

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A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR'S DEGREE IN ELECTRICAL ENGINEERING

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DEPARTMENT OF ELECTRICAL ENGINEERING

POKHARA, NEPAL


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## CERTIFICATE OF APPROVAL

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project entitled "**Electric Power Conversion using Matrix Converter**" submitted by Birendra Kumar Shah, Nikee Thakur, Rahul Kumar Jha, Sumina Neupane and Utsab Paudel in partial fulfilment of the requirements for the bachelor degree in Electrical engineering.

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## ABSTRACT

Power conversion from certain AC voltage into an AC voltage with desired magnitude and desired frequency is attracting more attention in case of utility grid connected loads. For this, Matrix Converter is an appropriate solution for single stage AC-AC conversion for fulfilling the requirement of the output voltage with desired magnitude and frequency and provides bidirectional power flow. Matrix converter consists of nonlinear elements or semiconductors. During this power conversion process, the current harmonics distortion in the utility power supply is produced from the matrix converter. Hence, this project introduces shunt active power filter to compensate total harmonics distortion efficiently so that the harmonic pollution in the power system will be reduced, and power quality will be increased. In this project we have considered any non-linear load. Similarly, Direct Matrix Converter is used for power conversion which is to be operated by using Pulse Width Modulation that has an algorithm of Space Vector Algorithm.
The developed compensating current will be calculated by using P-Q theory that uses Clarke's transformation which transforms three phase voltage or current into alpha and beta reference frames.

The proposed approach of removing harmonics from Matrix Converter's output by using Series Active Power Filter based on instantaneous reactive power theory is to be tested and evaluated by using MATLAB/Simulink. Similarly, the harmonics from output obtained from the load is removed using Shunt Active Power Filter which is further evaluated by using MATLAB/Simulink model.

The suggested method consists of two components: the first portion corrects problems with the input power quality of matrix converters, and the second part corrects issues with the output power quality of MCs. The matrix converter is categorized as either a current-source load or a voltage-source load, depending on the harmonic source.


**Key Words:** Matrix Converter, Power Conversion, Harmonics, Active Power Filter, MATLAB

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| MC | Matrix converter |
| SAPF | Shunt Active Power Filter |
| SVPWM | Space Vector Pulse Width Modulation |
| SVM | Space Vector Modulation |
| PWM | Pulse Width Modulation |
| APF | Active Power Filter |
| AC | Alternating Current |
| DC | Direct Current |
| PV | Photo Voltaic |
| PCC | Point of Common Coupling |
| kVA | Kilo Volt Ampere |
| kW | Kilo Watt |
| THD | Total Harmonic Distortion |

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

In industrial applications, ac to ac conversion is achieved using direct ac-ac converters, dc linked indirect converters and matrix converters. The purpose of AC to AC convertor is for conversion of AC waveform having particular frequency and voltage magnitude to another waveform with another frequency and magnitude. The conversion is required especially for speed control of machines.

Matrix converters (MC) have been extensively employed in industrial applications such as aircraft systems, wind turbine generation systems, induction machines, photovoltaic (PV) systems and motor drive systems. The MC converts the fixed voltage to voltage with variable amplitude and frequency[1].

MCs are preferred for compact design eliminating need for large energy storage components and dc-link circuits so providing single stage power conversion. MCs provide output regulation with variable frequency control and can have high power density with more reliable operation.

The MCs are potentially reversible to obtain variables amplitude and frequency of sinusoidal output voltages in order to adjust the power factor and the input harmonic distortion. MCs do not include passive elements for energy storage so they are also called ALL- SILICON. These converters are in the trend of research especially for applications where space, weight and reliability are very important parameters. The direct matrix converter is used so that it is able to directly connect m-phase power alternative source to n-phase load, via an m * n dimensions matrix array of bidirectional switch.

There are 27 possible states of combination which can be classified into three groups as

Group 1: The first 18 states allow in creating output voltages and inputting current with fixed direction and variable amplitude vectors. These states are called “active configurations".

Group 2: Three states of the matrix converter generate the zero vector voltage and current. They are also called “configurations freewheel”. MCs are also useful when it comes to a complete sampling cycle.

Group 3: Last six combinations of MCs generates voltage and current rotating vector with constant amplitude.

The proposed techniques basically contains two parts where the first part compensates matrix converter’s input power quality problems while the second part compensates matrix converter’s output power quality problems. The matrix converter is considered to have two types of load i.e. Current-Source Type of Harmonic Sources, Voltage-Source Type of Harmonic Sources [2]. The enhanced control system is proposed to further eliminate harmonics with higher accuracy. The control system design of the shunt active power filter for matrix converter which cancels the harmonics present in supply current. Shunt active filters compensate current harmonics of nonlinear loads in order to perform reactive power compensation and to balance the imbalance currents. A shunt active filter also senses the load current and injects a current into the system to compensate current harmonics or reactive load. Here, a shunt filter compensates the current harmonics of matrix converter here the shunt active filter acts as a current source. The sum of its current and load current is the total current that flows through the source. Therefore, controlling the output current of the active filter can control the source current.

Power electronic converters are a common and typical source of harmonic currents. The distortion of the current waveform, that is, the generation of harmonics, results from the switching operation. Because the harmonic current contents and characteristics are less dependent upon the AC side, this type of harmonic source behaves like a current source. Therefore, they are called current-source type of harmonic source (or harmonic current source) and represented as a current source. A shunt active filter is to be placed in parallel with a load (matrix converter) to detect the harmonic current of the load and to inject a harmonic current with the same amplitude of that of the load into the AC system.

Another type of common harmonic source in matrix converter output is production of harmonics voltage and current waveforms. Although the current is highly distorted, its harmonic amplitude is greatly affected by the impedance of the AC side. Therefore, the matrix converter output behaves like a voltage source harmonic. The basic principle of series active filters compensating for a harmonic voltage source. A series active filter eliminates the voltage harmonics produced by the matrix converter. When the load is sensitive and critical, a series converter regulates the line voltage for the load. It cancels out any line voltage distortions such as voltage harmonics, sag, swell, and voltage unbalance. It is also capable of eliminating any voltage harmonics with a frequency within the bandwidth of the control scheme.

There are three types of harmonic detection algorithms used to find the active filter's current reference.

They are as follows:

1. Measuring and utilizing the load harmonic current to be corrected as a reference instruction.

2. Measuring the source harmonic current and adjusting the filter to reduce it.

3. Monitoring harmonic voltage at the active filter's point of common coupling (PCC) and adjusting the filter to reduce voltage distortion.

Active filters provide a nearly sinusoidal supply current by monitoring harmonic currents and then injecting them with a 180° phase shift back into the power system. Thus, the output waveform is the harmonic power, which is recognized as solely comprising current harmonics [3].

**1.2 Problem Statement**

During the conversion it is important to consider that there must not be limitation in output frequency range and voltage conversion must be as high as possible. The power factor also must be kept into consideration such that the converter operates at unity power factor or as close to unity as possible. There also should not be too many conversion stages. The use of passive elements should be analyzed such that the passive components must not be large or bulky such that overall cost is large and system becomes unreliable. If the converter uses active components then the production of harmonics is inevitable and there must be certain measures for harmonic elimination so the adverse effects of harmonics in the system will be prevented.

The load served by the converter must be practically applicable and the converter must be accountable for efficient supply and conversion of the power to the load. The use of non-linear load and harmonics also due to the load should be also taken into account and such that the system must contain effective measures for the harmonic elimination due to both the converter and the load. Hence, there is the requirement for converter protection form overvoltage, overcurrent and short circuits.

The use of matrix converter in the project will hope to achieve efficient and reliable power conversion with use of active shunt filter for removal of harmonics that arises due to the switching action of the converter and use of non-linear load.

Since SVM is responsible for generating pulse width modulated signals to control the switches of MC which then produces the required modulated voltage to drive the load at desired speed and torque. Similarly main objective of SVM is to generate the switching sequence that correspond to the reference voltage vector for every PWM period to achieve a continuously rotating space vector. Hence, MCs are being operated using Space Vector Algorithm.

We could have used rectifier along with filter and inverter instead of Matrix converter but the process would not be a single stage power transform with excess of power loss and there will be a low power factor. But in case of Matrix converter the pf is always maintained unity or nearly unity with reliable power transform.

A bidirectional switch is used to control current but blocking voltage in both direction is not commercially available.

## 1.3 OBJECTIVES

The objectives of the project are as follows:

To provide energy flow and utilize a controlled switch for automatic conversion of power from AC to AC with the MCs.

To study effect of Harmonics produced from Matrix Converter.

SVM technique is used as a controller.

Controller produced harmonics are eliminated using a filter design.

## 1.4 SCOPES AND LIMITATIONS

### 1.4.1 SCOPES

Electrical Power Conversion has several applications within. Major applications are discussed below:

Matrix converter is used as a single stage AC-AC power converter for interfacing the energy conversion to a grid as a distributed load system.

PWM is used to control the speed of electric motor, the brightness of light in ultrasonic cleaning applications and many more.

Active Power Filter can be used to filter out both lower and higher order of harmonics in power system, which is significantly below the switching frequency.

Some of the specific applications are discusses below:

The direct converters are able to create sinusoidal waveforms on output side, which is necessary for good working condition of drive systems.

Shunt active power filter for power quality improvement for nonlinear DC load.

### 1.4.2 LIMITATIONS

There are some limitations mentioned below:

Use of MCs for small range of voltage becomes quite expensive.

Thus obtained output from MCs results in huge harmonic distortion.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Review of Papers

The paper by Lee Empringham, Liliana de Lillo, Patrick W Wheeler and Jon C Clare explained the concept of matrix converter, features, advantages, disadvantages and emergency/ failure modes which required various protection schemes []. Two target applications were used to explain limitation of existing protection strategies. The first was 25 KVA Matrix converter Permanent magnet synchronous machine based aircraft actuator and second 100 KVA Permanent magnet synchronous machine drive. The robust arrangement fitted to the two target application was discussed and results were presented for continuous operation under different failure modes. This article was studied for initialization of matrix converter and the application and various protection schemes for the converter[4].

Petr Chlebis and Petr Simonik compared the main output and input characteristic parameters of direct and indirect converters[5]. The comparison criterions included quality of waveform and output current and converter circuit complexity, commutation and control strategy were also evaluated and concluded that the different types of matrix converters had comparable characteristics. The article was studied for the analysis of different converters and feasibility of the specific converter for the project.

Kalyan Govindarajan and Divakhar Anbazhagan presented working of matrix converter what utilized Direct Space Vector Modulation technique []. The dynamic model had been developed in direct-quadrature axis for compatibility of the model with the grid during static conditions. The dynamic model of the MC had also been presented in this paper for faster implementation of the matrix converter and the comparison between the two models had been carried out by simulations in MATLAB[6]. The study of this paper was one for establishing effective working of the matrix converter with the specified modulation technique as well as comparison of the two mentioned models.

The paper by P. Subha Karuvelam and M. Rajaram was concerned with use of Matrix converter to drive the three phase BLDC motor and eliminates bulky DC link energy storage element[7]. Brushless DC motors are widely used in industrial areas and are driven either by indirect AC to AC converters or direct AC to AC converters. For the generation of switching pulses for the matrix converter a control technique was designed. The paper analyzed for the application of the matrix converter for control of Brushless DC Motor.

Rashid Alammari, Zeeshan Aleem, Atif Iqbal and Simon Winberg investigated and compared Matrix converter topology for ac-ac power conversion with conventional ac-dc-ac topologies []. The MC is formed of controllable active devices and without any sizeable passive components. The converter can be used to directly control the loads and is highly effective in controlling the power factor and providing sinusoidal input and output currents[8]. The paper provided comprehensive review of MC and discussed the main topology variations which included single-phase conventional and isolated matrix converters, three phase direct and indirect matrix converters, impedance source matrix converter, multiphase matrix converter and multilevel matrix converters. The article was extensively studied for the comparison and analysis of various converters and their effective implementation on the proposed model.

The paper by K.Selvakumar, R.Pulanisamy, Arul Rayappan Stalin, P.Gopi, P.Ponselvin, K.Saravanan illustrated the simulation of Three phase matrix converter using space vector modulation. Variable AC was generated using matrix converter having bidirectional switches. Conventional PWM caused common mode current and lead to bearing failure in load drive. These problems were solved using SVM and the effect of harmonic fluctuation in AC was reduced as well as the stress on power switch was reduced[9].

## 2.2 Review of Matrix Converter

Matrix converters allow the implementation of single stage AC to AC power conversion with inherent bidirectional power flow and avoidance of typical DC-link capacitor causes the converter to have potential of achieving higher power density and more reliable operation and less maintenance as opposing to conventional two stage conventional AC to AC converter or AC to AC converter with DC link.

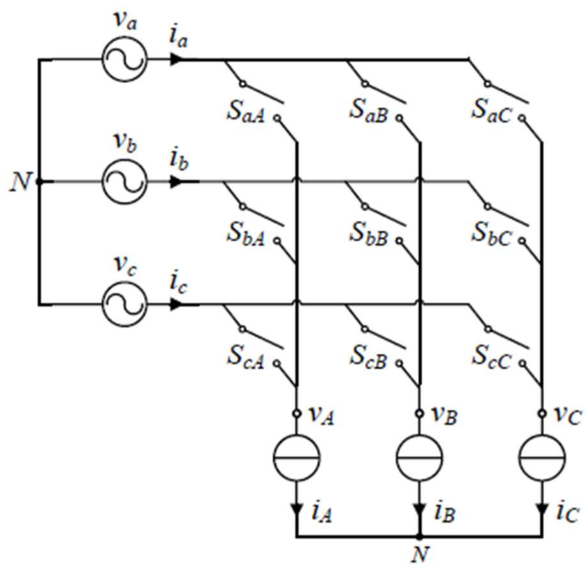


**Figure 2.1 General Matrix Topology**

This is the reason matrix converters have been receiving significant attention from academic sector but have not been fully implemented on large industrial scale. The article review Direct Matrix Converter and Indirect Matrix Converter along with respective actual and most important modulation methods [10]. Simulation method was provided to validate the theoretical analysis and for getting deep insight about the implementation of direct space vector modulation method and generation of respective pattern for pulse width modulation. Extreme care was given in study of the modulation technique in the article which was used to implement direct space vector modulation for pulse width modulation for the matrix converters.

### 2.2 Review of Space Vector Modulation

The paper presented working of matrix converter what utilized Space Vector Modulation technique. The dynamic model had been developed in direct-quadrature axis for compatibility of the model with the grid during static conditions. The dynamic model of the MC had also been presented in this paper for faster implementation of the matrix converter and the comparison between the two models had been carried out by simulations in MATLAB. The study of this paper was one for establishing effective working of the matrix converter with the specified modulation technique as well as comparison of the two mentioned models[6].

Carrier-based and SVM modulation procedures are two types of pulse width modulation (PWM) techniques for MCs. Using the offset voltage and altering the carrier's slope, the input power factor in the carrier-based modulation may be controlled. The SVM is a more widely used technique, and it has the ability to maximize input voltage in order to decrease the number of commutations, to manage the input power factor, and to offer superior power quality. The SVM combines the neighboring two vectors and zero state vectors to provide the required reference based on the space vector representation. The modulation problem of MCs can be generalized using SVM.SVMs for MCs come in direct and indirect forms. Better comprehension of the modulation's functioning and implementation is provided via direct SVM[11].

Variable speed drives have seen a significant growth in use in industrial and commercial buildings over the past few years. As a result, ac-ac conversion, which changes a three-phase input into a three-phase load, is necessary to obtain variable frequency, amplitude, and phase for a variety of applications. The ac to ac converters take electricity from the input source and send it in the desired voltage and frequency to the three phase output. Several power converter circuits are now available to improve the systems' characteristics, efficacy, and consistency. The highest voltage transformation ratio of direct AC-AC pulse-width-modulated converters was studied by the author. Unrelated to the control approach, an intrinsic limit was discovered. A suitable novel converter control technique was proposed in order to attain maximum output capacity with some intriguing characteristics. Finally, the possibility of developing a matrix converter control plan utilizing feedback methods was discussed, and a feedback-based modulation strategy for the converter was also described[12].

Space vector modulation (SVM) method is used to achieve the required displacement angle between input voltage and input current of matrix converter. The direction of the space vector is always in various axis and the size of it changes over time, with a pulse sinusoidal time phase difference of 120°. Three voltage space vectors prove that the summing synthesizer space vector is a rotating space vector. SVPWM provides a constant switching frequency and therefore the switching frequency SVPWM provides a constant switching frequency and therefore the switching frequency can be adjusted easily[13]. SVPWM method is based on the continuous depiction of input and output voltage and currents. In the SVM method, only 21 of the 27 potential switching states are employed. The 18 switching pattern, which defines the space vector for both the input side and the output side as shown below in sector representation.

### 2.2.1 Sector Representation

Three phase (a-b-c frame) system is transformed into α-β stationary frame by using Clarke transformation which is represented by an equivalent voltage magnitude Vref and angle α. Using this eight voltage vectors, a regular hexagon is formed in plane which consists of six sectors spanning 60 degree each. $V_{ref}$ rotates with the speed of angular velocity w (2πf).

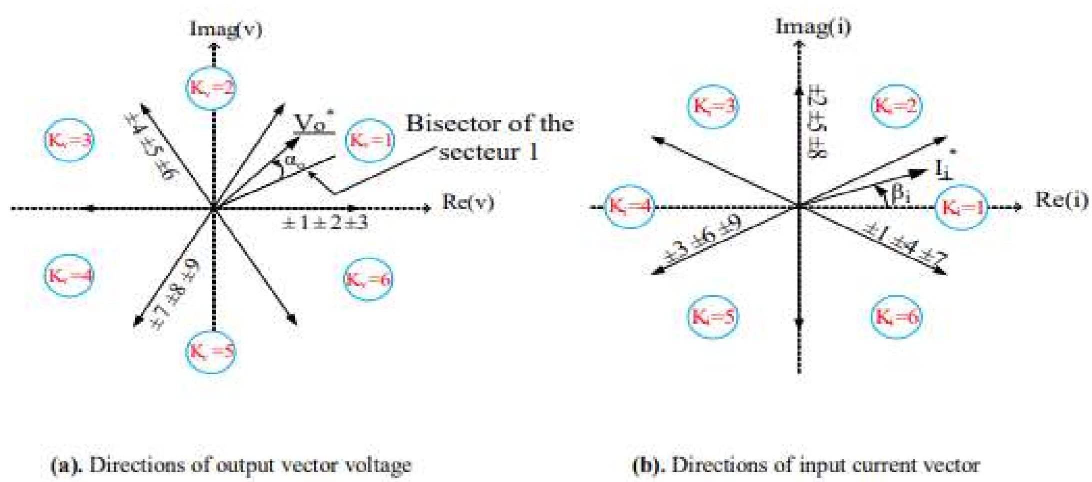


Figure 2.2 Sector Representation of SVPWM

SVM is realized by picking four stationary vectors that are applied during adequate time intervals inside $T_s$.. It'll be assumed that both $\vec{V_o}$ and $\vec{i_i}$ are lying in sector 1 without the loss of generality. It consists of a set of vectors that are defined as instantaneous space vectors of input and output voltage as well as current with low switching loss. In the direct space vector modulation, constant voltage and current have to be proved.

### 2.2.2 Clarke Transformation

The Clarke transform converts the time domain components of a three-phase system (in abc frame) to two components in an orthogonal stationary frame (αβ)[14].

Mathematically,

$$\begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 0 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix}$$

$$V_{ref} = \sqrt{V_\alpha^2 + V_\beta^2}$$

$$\alpha = \tan^{-1}\frac{V_\beta}{V\alpha}$$

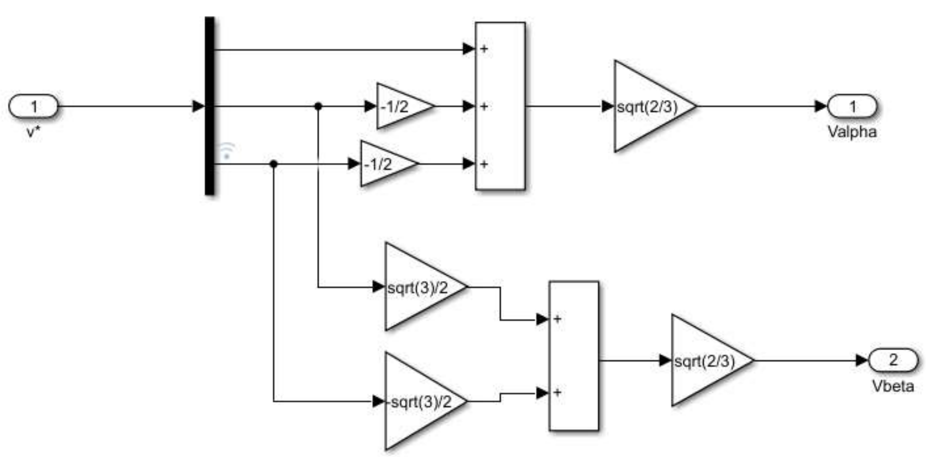


Figure 2.3 Simulink Model of Clarke Transform

### 2.2.3 Park Transformation

This component transforms the αβ to dq transformation. This transformation rotates the 2 stationaries axes αβ synchronously with a reference frequency. Thus obtained reference frequency is passed through the phase input ωt.

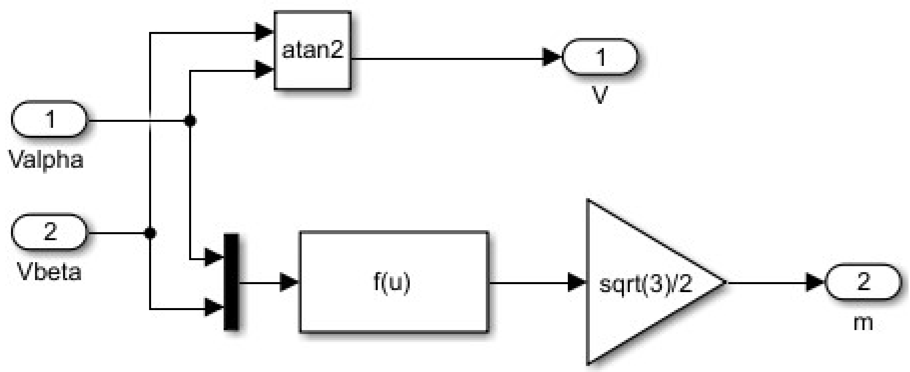


Figure 2.4 Simulink Model of Alpha-Beta Transformation

### 2.2.4 Vector Switching Time and Switching Action

The instantaneous output voltage space vector is:

$\overrightarrow{V_o} = \frac{2}{3}(V_{AB} + aV_{BC} + a^2V_{CA}) = V_o e^{j\alpha_o}$ Where $a = e^{j\frac{2\pi}{3}}$, $V_o, \alpha_o$ are amplitude and angle of $\overrightarrow{V_o}$.

Instantaneous input current space vector is

$\vec{i_i} = \frac{2}{3}(i_a + ai_b + a^2 i_c) = i_i e^{j\beta_i}$ where $i_i$ and $\beta_i$ are amplitude and angle of $\vec{i_i}$ .

Voltage space vector of input is

$\overrightarrow{V_i} = \frac{2}{3}(V_a + aV_b + a^2V_c) = V_i e^{j\alpha_i}$ where $V_i$ and $\alpha_i$ are amplitude and angle of $\overrightarrow{V_i}$

.

Table 2.1 Switching Configuration and Vector used in Matrix Converter

| **No** | **A B C** | $\|V_o\|$ | $\angle V_o$ | $\|I_i\|$ | $\angle I_i$ |
|---|---|---|---|---|---|
| 1+ | a b c | $2/\sqrt{3}\ V_{ab}$ | $\pi/6$ | $2/\sqrt{3}\ i_A$ | $-\pi/6$ |
| 1- | b a a | $2/\sqrt{3}\ V_{ab}$ | $-5\pi/6$ | $2/\sqrt{3}\ i_A$ | $5\pi/6$ |
| 2+ | b c c | $2/\sqrt{3}\ V_{bc}$ | $\pi/6$ | $2/\sqrt{3}\ i_A$ | $\pi/2$ |
| 2- | c b b | $2/\sqrt{3}\ V_{bc}$ | $-5\pi/6$ | $2/\sqrt{3}\ i_A$ | $-\pi/2$ |
| 3+ | c a a | $2/\sqrt{3}\ V_{ca}$ | $\pi/6$ | $2/\sqrt{3}\ i_A$ | $-5\pi/6$ |
| 3- | a c c | $2/\sqrt{3}\ V_{ca}$ | $-5\pi/6$ | $2/\sqrt{3}\ i_A$ | $\pi/6$ |
| 4+ | b a b | $2/\sqrt{3}\ V_{ab}$ | $5\pi/6$ | $2/\sqrt{3}\ i_B$ | $-\pi/6$ |
| 4- | a b a | $2/\sqrt{3}\ V_{ab}$ | $-\pi/6$ | $2/\sqrt{3}\ i_B$ | $5\pi/6$ |
| 5+ | c b c | $2/\sqrt{3}\ V_{bc}$ | $5\pi/6$ | $2/\sqrt{3}\ i_B$ | $\pi/2$ |
| 5- | b c b | $2/\sqrt{3}\ V_{bc}$ | $-\pi/6$ | $2/\sqrt{3}\ i_B$ | $-\pi/2$ |
| 6+ | a c a | $2/\sqrt{3}\ V_{ca}$ | $5\pi/6$ | $2/\sqrt{3}\ i_B$ | $-5\pi/6$ |
| 6- | c a c | $2/\sqrt{3}\ V_{ca}$ | $-\pi/6$ | $2/\sqrt{3}\ i_B$ | $\pi/6$ |
| 7+ | b b a | $2/\sqrt{3}\ V_{ab}$ | $-\pi/2$ | $2/\sqrt{3}\ i_C$ | $-\pi/6$ |
| 7- | a a b | $2/\sqrt{3}\ V_{ab}$ | $\pi/2$ | $2/\sqrt{3}\ i_C$ | $5\pi/6$ |
| 8+ | c c b | $2/\sqrt{3}\ V_{bc}$ | $-\pi/2$ | $2/\sqrt{3}\ i_C$ | $\pi/2$ |
| 8- | b b c | $2/\sqrt{3}\ V_{bc}$ | $\pi/2$ | $2/\sqrt{3}\ i_C$ | $-\pi/2$ |
| 9+ | a a c | $2/\sqrt{3}\ V_{ca}$ | $-\pi/2$ | $2/\sqrt{3}\ i_C$ | $-5\pi/6$ |
| 9- | c c a | $2/\sqrt{3}\ V_{ca}$ | $\pi/2$ | $2/\sqrt{3}\ i_C$ | $\pi/6$ |
| $0_a$ | a a a | 0 | - | 0 | - |
| $0_b$ | b b b | 0 | - | 0 | - |
| $0_c$ | c c c | 0 | - | 0 | - |

The switching sequence able to synthesize components of $V_0$ and $i_i$

$$\overrightarrow{V_{o^1}} = \pm 7, \pm 8, \pm 9$$

$$\overrightarrow{V_{o2}} = \pm 1, \pm 2, \pm 3$$

$$\overrightarrow{i_{i^1}} = \pm 3, \pm 6, \pm 9$$

$$\overrightarrow{i_{i^2}} = \pm 1, \pm 4, \pm 7$$

To generate $v_0$ and $i_i$ at same time common switching states are 7,9,1,3 are used. Only one of the switching arrangements with same number and opposite signs are applied, the ones with higher voltage values are obtained. The four switching arrangements for each combination of output voltage sector (nv) and input current (ni) can be determined.

$V_0$ and $i_i$ are synthesized by time averaging of each four stationary vectors during the switching sequence.$V_0$ and $i_i$ are generated by applying stationary vectors according to proper duty cycles. They are determined using phase of output voltage reference and phase of input current vector reference as

$$\delta^{I} = \frac{2}{\sqrt{3}} q \frac{\cos(\overrightarrow{\alpha_o} - \pi/3)\cos(\overrightarrow{\beta_i} - \pi/3)}{\cos\phi_i}$$

$$\delta^{III} = \frac{2}{\sqrt{3}} q \frac{\cos(\overrightarrow{\alpha_o} + \pi/3)\cos(\overrightarrow{\beta_i} - \pi/3)}{\cos\phi_i}$$

$$\delta^{IV} = \frac{2}{\sqrt{3}} q \frac{\cos(\overrightarrow{\alpha_o} - \pi/3)\cos(\overrightarrow{\beta_i} + \pi/3)}{\cos\phi_i}$$ Where, $q = \frac{|\overrightarrow{V_o}|}{\sqrt{3}|\overrightarrow{V_i}|}$ is voltage transfer ratio.

The angles determined respective to bisecting line according to output voltage and input current sectors.

$$-\frac{\pi}{6} < \overrightarrow{\alpha_o} < \frac{\pi}{6} \quad , \quad -\frac{\pi}{6} < \overrightarrow{\beta_i} < \frac{\pi}{6}$$

The duty cycles of zero vectors are calculated in order to complete switching period

$$\delta^{oa} + \delta^{ob} + \delta^{oc} = 1 - (\delta^{I} + \delta^{II} + \delta^{III} + \delta^{IV})$$

And, $\delta^{oa}, \delta^{ob}, \delta^{oc} \geq 0$

$$\delta^{I}, \delta^{II}, \delta^{III}, \delta^{IV} \geq 0$$

Considering balanced supply voltage and output voltages, maximum voltage transfer ratio is

$$q \le \frac{\sqrt{3}}{2} | \cos \phi_i |$$

## 2.3 Review of Filter

Matrix converter has got several advantages, but it generates high- order harmonics. If Conventional harmonics mitigation like series passive and shunt active filter are used, they have some drawbacks. These passive filters are not stable in supply frequency variations. Since the output obtained from matrix converter is variable voltage and variable frequency supply; passive filters easily creates the resonance in the matrix converter output. So, active filtering technique method is proposed to overcome these problems[15]. The major advantage of filtering technology is to minimize the inductance value. Passive filters without inductors cannot obtain a high Q factor (low damping), but with inductor, it is very expensive at low frequencies. So, this proposed system is applicable where low harmonics and high accurate power regulations are required.

### 2.3.1 Shunt active power filter

Figure below shows the proposed compensation for a matrix converter with a shunt active filter, source, and load when the filter is used to compensate for the current harmonics produced by the matrix converter .A shunt filter is used to compensate for the current harmonics of the matrix converter; here the shunt active filter acts as a current source. By controlling the output current of the active filter can control the source current. Shunt active filters are used to compensate for current harmonics of nonlinear loads to perform reactive power compensation and to balance the imbalance currents.

$Z_s$ is the source (line) impedance, $I_L$ is the equivalent harmonic current source, $Z_L$ is the equivalent impedance on the input side of matrix converter which may include passive filters and power factor correction capacitors, and G is the equivalent transfer function of the active filter including the detection circuit of harmonics and the delay of the control circuit.

In the following analysis, all equations are represented per unit. From Figure , the following equations are obtained .Load side instantaneous real and imaginary power components are calculated by using source currents and phase neutral voltages given.

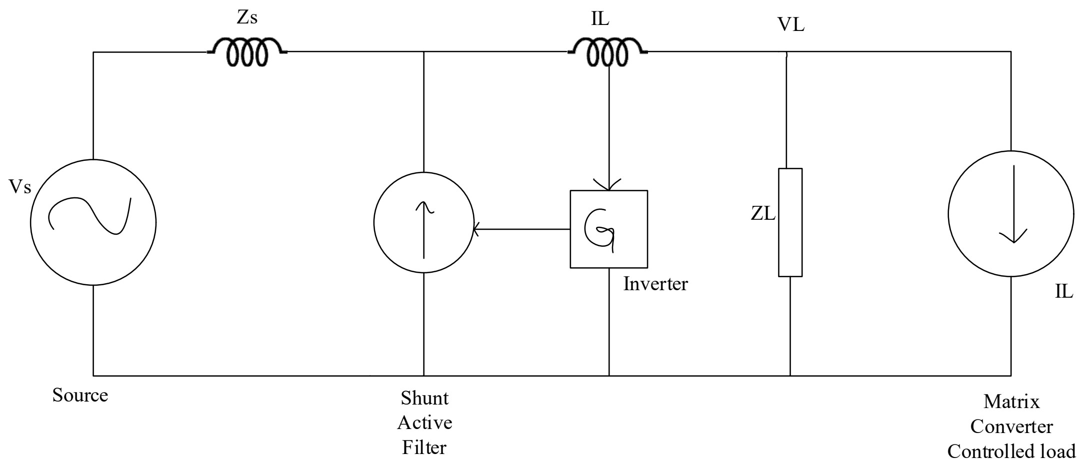


Figure 2.5 Principle of Shunt Active Filter for Matrix

The mathematical expression for operation of shunt active power filter is given by:

$$I_c = GI_L$$

$$I_s = \frac{Z_L}{Z_s + (Z_L/1 - G)} . I_{LO} + \frac{V_S}{Z_s + (Z_L/1 - G)}$$

$$I_L = \frac{\frac{Z_L}{1} - G}{Z_s + (Z_L/1 - G)} . I_{LO} + \frac{V_S}{Z_s + (Z_L/1 - G)}$$

$$\left|\frac{Z_L}{1 - G}\right|_h > |Z_S|_h$$

$$I_c = I_{Lh}$$

$$I_{Lh} = I_{LO} \quad + \frac{V_{Sh}}{Z_L}$$

$$\begin{bmatrix} p_o \\ p \\ q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} v_o & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\alpha & v_\beta \end{bmatrix} \begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix}$$

$$p_o = v_o . i_o \quad p = \bar{p} + \tilde{p} \qquad q = \bar{q} + \tilde{q}$$

$$\begin{bmatrix} i^*{}_{s\alpha} \\ i^*{}_{s\beta} \end{bmatrix} = \frac{1}{v^2{}_\alpha + v^2{}_\beta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} + p_0 + \overline{p_{loss}} \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} v_o \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$

$$\begin{bmatrix} i_o \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix}$$

$$\begin{bmatrix} i^*{}_{sa} \\ i^*{}_{sb} \\ i^*{}_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*{}_{s0} \\ i^*{}_{s\alpha} \\ i^*{}_{s\beta} \end{bmatrix}$$

### 2.3.2 Series Active Power Filter

Series Active Power Filter consists of a series connected inverter with a DC source, a filter circuit, and a control system. The inverter generates a current that is in phase with the load current and equal in magnitude but opposite in direction.

This current cancels out the harmonic current generated by the load, resulting in a sinusoidal current waveform. The filter circuit is used to filter out the harmonics generated by the load, and the control system is used to generate the reference current for the inverter. The control system compares the load current with the reference current and generates the control signal for the inverter.

Series Active Power Filter has several advantages over other harmonic mitigation techniques, such as passive filters and shunt active filters. It does not require large reactive components like passive filters, which reduces the size and cost of the system. It also does not generate additional harmonic distortion like shunt active filters, which improves the overall power quality of the system.

Series Active Power Filter has found various applications in industrial, commercial, and residential settings, such as in data centers, power plants, and electric vehicle charging stations. It has become an essential tool in maintaining power quality in modern electrical systems[16].

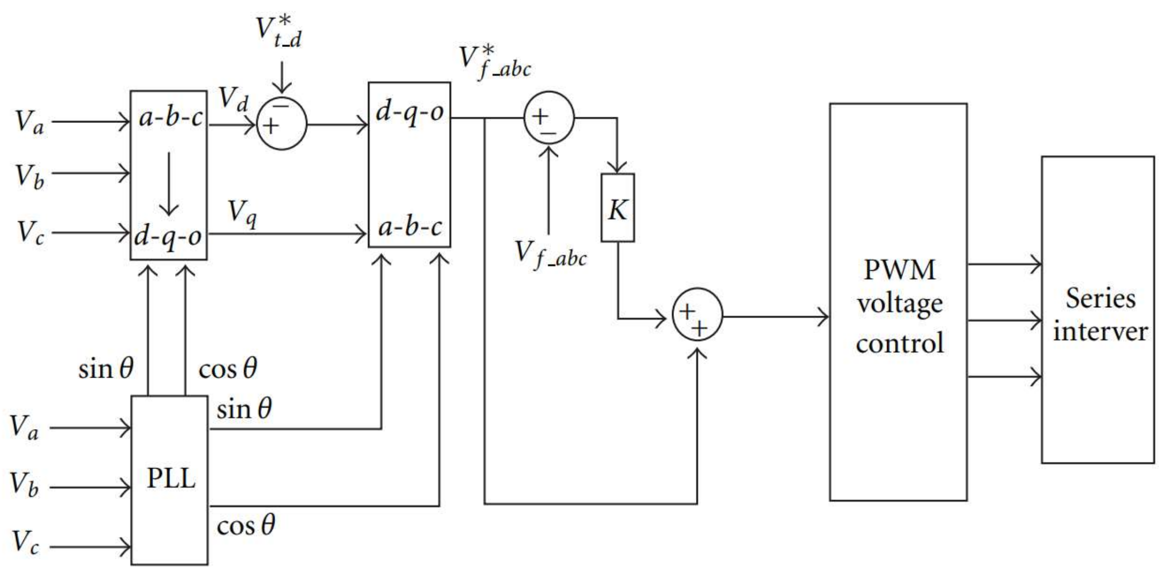


Figure 2.6 Principle of Series Active Filter for Matrix Converter

The mathematical expression for operation of series active power filter is given by:

$$V_f = V_{ref} - V_s + V_h = V_s(1 - \frac{1}{k}) + V_h$$

$$CS = I_{rms} * V_{rms}.$$

$$Vrms = \{(v_1^2 + \Sigma_h^2)\} = Vs[\left(1 - \frac{1}{k}\right)^2 + (THDv)^2]^{\frac{1}{2}}$$

$$CS_{series} = v_s I_l * \cos\Theta \sqrt{(\frac{1}{K} - 1)^2 + THDv^2}$$

$THD_v = \sqrt{\frac{\sum Vh^2}{Vs}}$ is the Total Harmonic Distortion of the source voltage and defined as the power factor of the load, and $I_L$ is the fundamental component of the load current.

# CHAPTER THREE: METHODOLOGY

## 3.1 Selection of Appropriate Procedure and Components

MC is a type of direct ac-ac converter and thus eliminates the need of energy storage elements. It uses an array of bi-directional fully controlled switches as the main power elements. This allows connection of all input lines to all output lines. It does not use the dc-link circuit which can drastically reduce the size of MC system. It replaces the multiple power conversion by a single power conversion stage. For protection of Matrix Converter from surges overvoltage and short circuit, clamp circuit is used. One or two capacitor is connected to all input and all output lines through two diode bridges. Varistors can also be used. However, clamp circuit is more efficient and economical. Active Power Filters are widely used for Harmonic mitigation as well as Reactive power compensation, Voltage Regulation, Voltage flicker compensation, supply current balancing and so on. One of the widely used APF is Shunt Active Power Filter, which is controlled to generate required compensating currents.

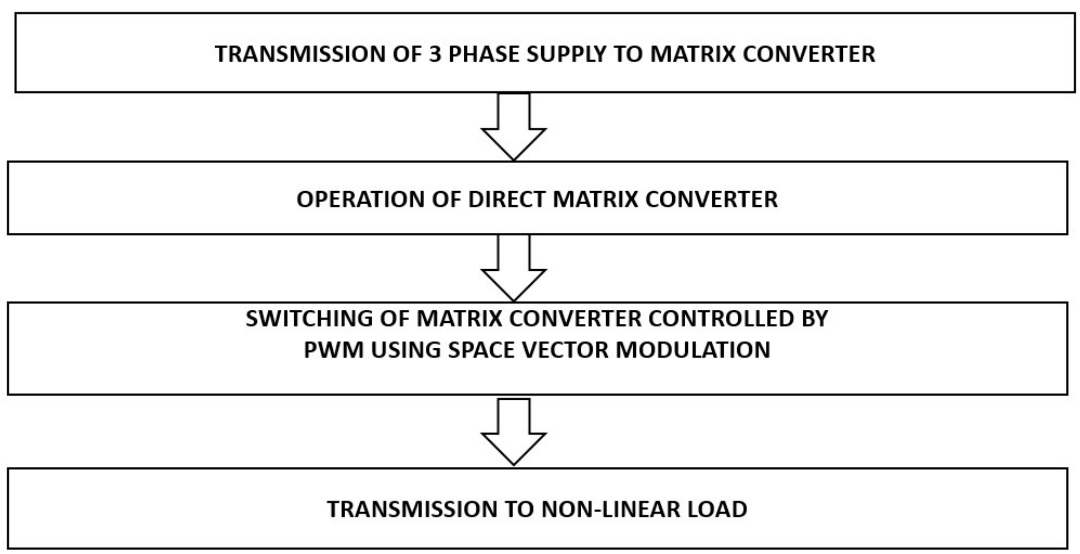


Figure 3.1 Method of variable power transmission

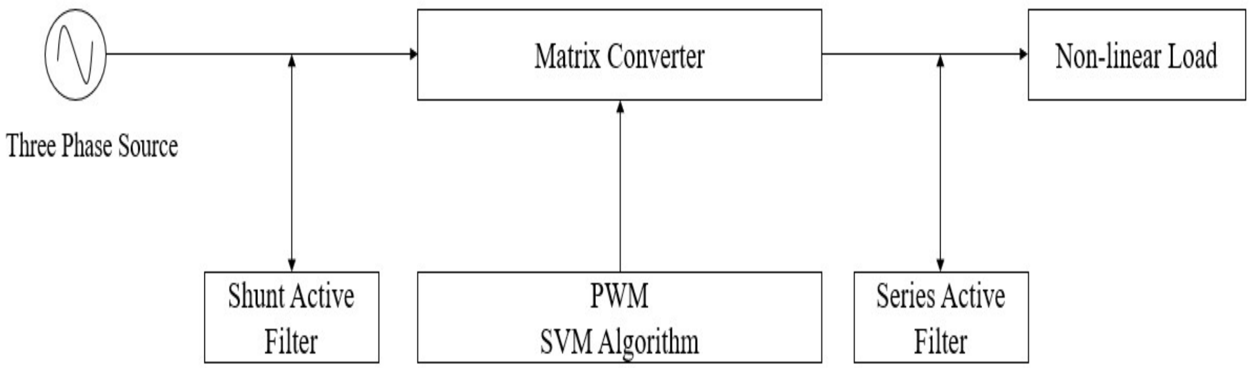


Figure 3.2 Overall Block Diagram of the Model

In order to control the switching action of MC, SVPWM technique is used. PWM works under the SVM algorithm. Three- phase supply is given to the SVPWM and thus obtained modulated signal is then supplied to the MC. The variable voltage and frequency is obtained along with the harmonics. In order to reduce the obtained harmonics Series Active Power Filter is used. The use of non-linear load also induces harmonics into the system which is eliminated using Shunt active Power Filter. Thus, obtained variable voltage and frequency free from harmonics is provided to drive the nonlinear load.

The figure below shows the overall Simulink model of the Matrix Converter that has being operated with Space Vector Modulation Technique along with both Shunt and Series Active Power Filter for removal of current as well as voltage harmonics.

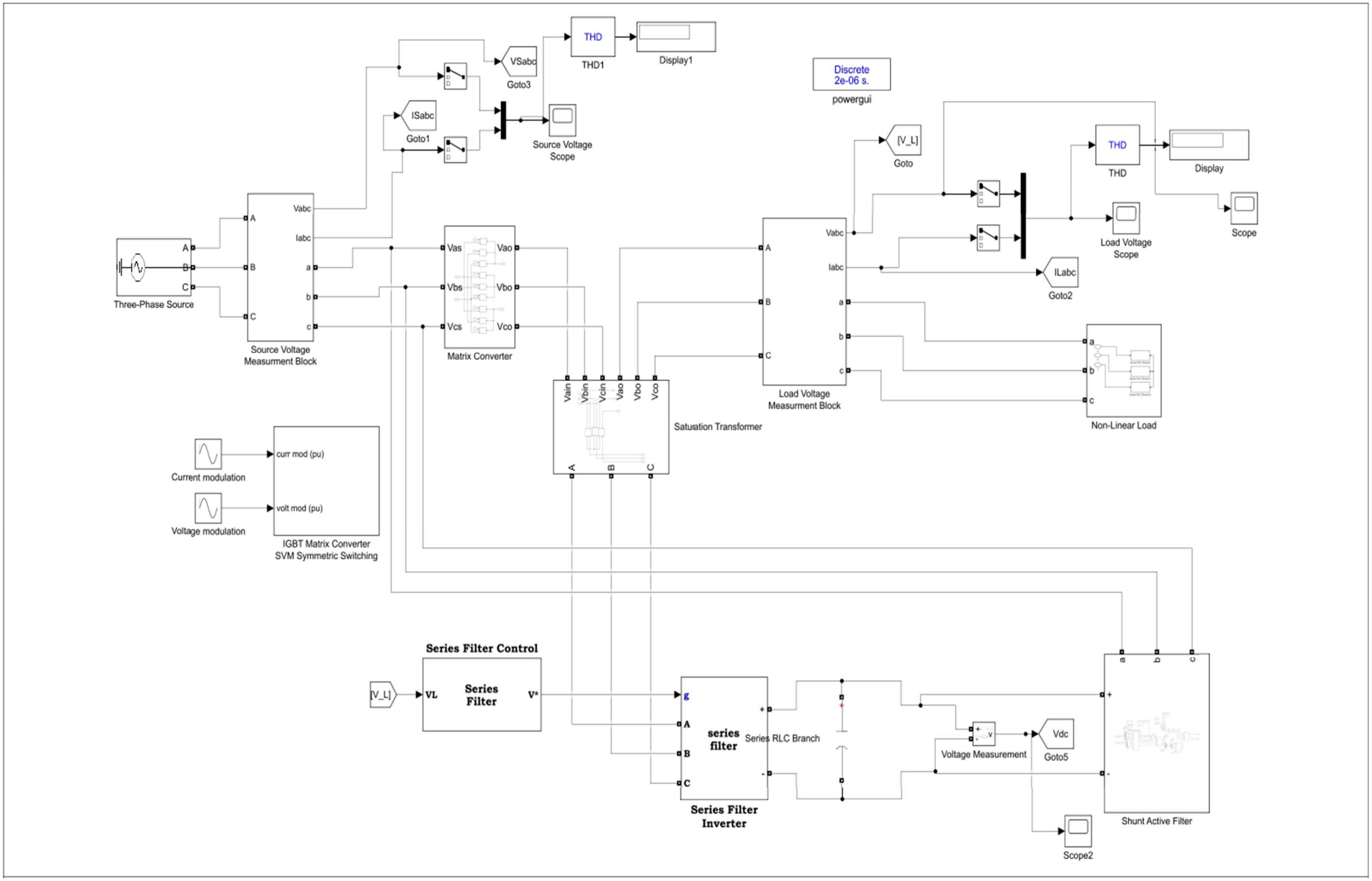


Figure 3.3 Overall Simulink Model of System

### 3.1.1 Simulation for Matrix Converter

The figure shows overall Simulink model of the system. It consists of a three-phase source along with matrix converter and non-linear load along with series and shunt active filters. The series filter is connected towards the source side and shunt active filter is connected towards the load side of matrix converter. The supply was given 400V, 50 Hz three phase.

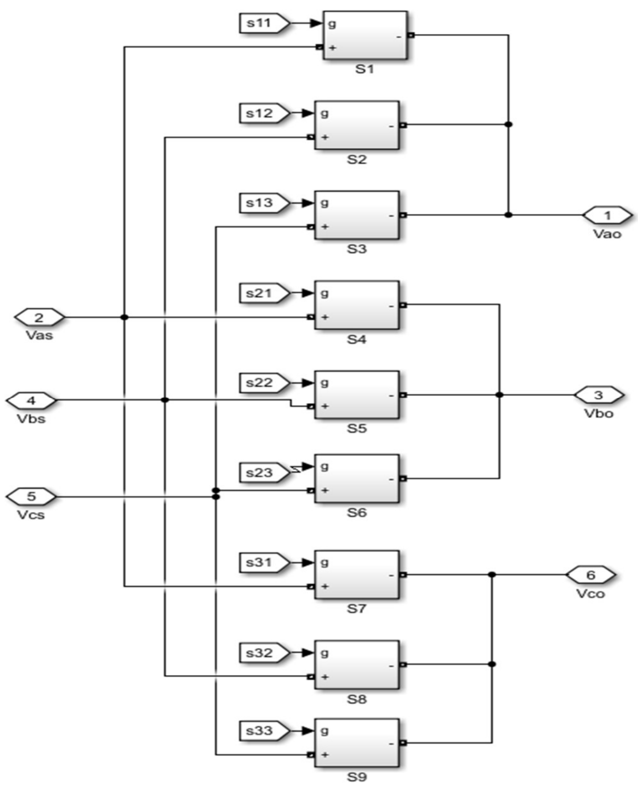


Figure 3.4 Simulink Model Of Matrix Converter

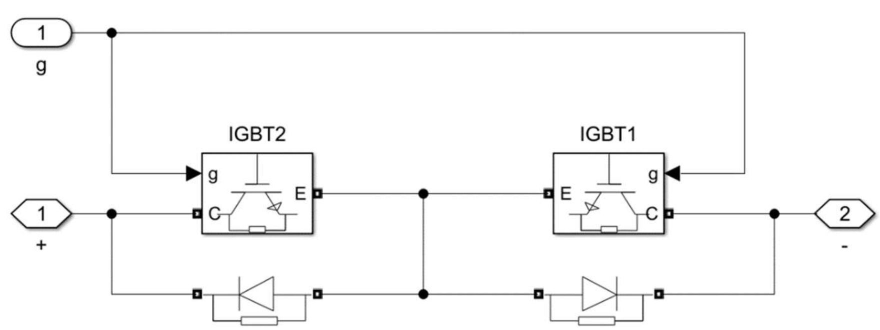


Figure 3.5 Simulink Model of Matrix Converter Switch

### 3.2 Selection of Appropriate Algorithm

In order to feed the nonlinear load, we present the model in an indispensable way to design control systems more efficient, and its control algorithm is Space Vector Modulation (SVM).Then, we perform simulation tests for the whole converter using MATLAB/Simulink. Similarly the Control Algorithm is one of the subsystems of the APF control system. The task of control algorithm is evaluation of reference signals on the grounds of information about voltages and currents at the point of common coupling (PCC).Thus the appropriate algorithm was finalized.

The following block diagram shows the operation of SVPWM,

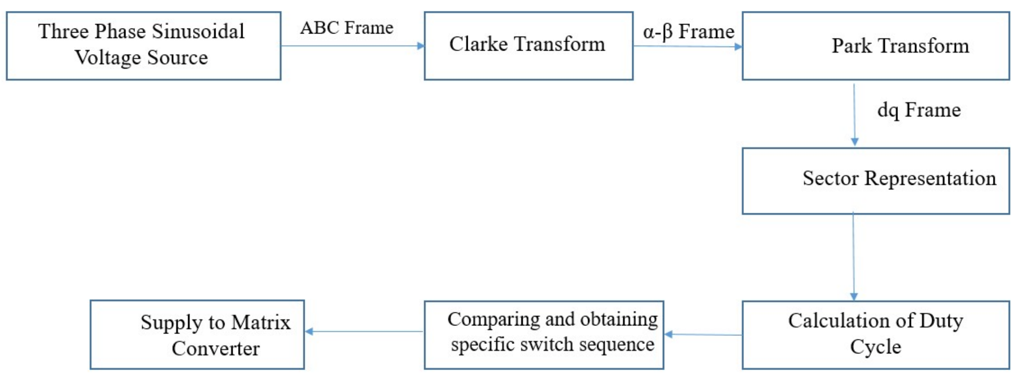


Figure 3.6 Block Diagram of SVPWM

#### 3.2.1 SIMULATION OF SVPWM

Space vector modulation (SVM) method is used to achieve the required displacement angle between input voltage and input current of matrix converter. The direction of the space vector is always in various axis and the size of it changes over time, with a pulse sinusoidally time phase difference of 120°. Three voltage space vectors prove that the summing synthesizer space vector is a rotating space vector. SVPWM provides a constant switching frequency and therefore the switching frequency SVPWM provides a constant switching frequency and therefore the switching frequency can be adjusted easily. It consists of a set of vectors that are defined as instantaneous space vectors of input and output voltage as well as current with low switching loss. In the direct space vector modulation, constant voltage and current have to be proved.

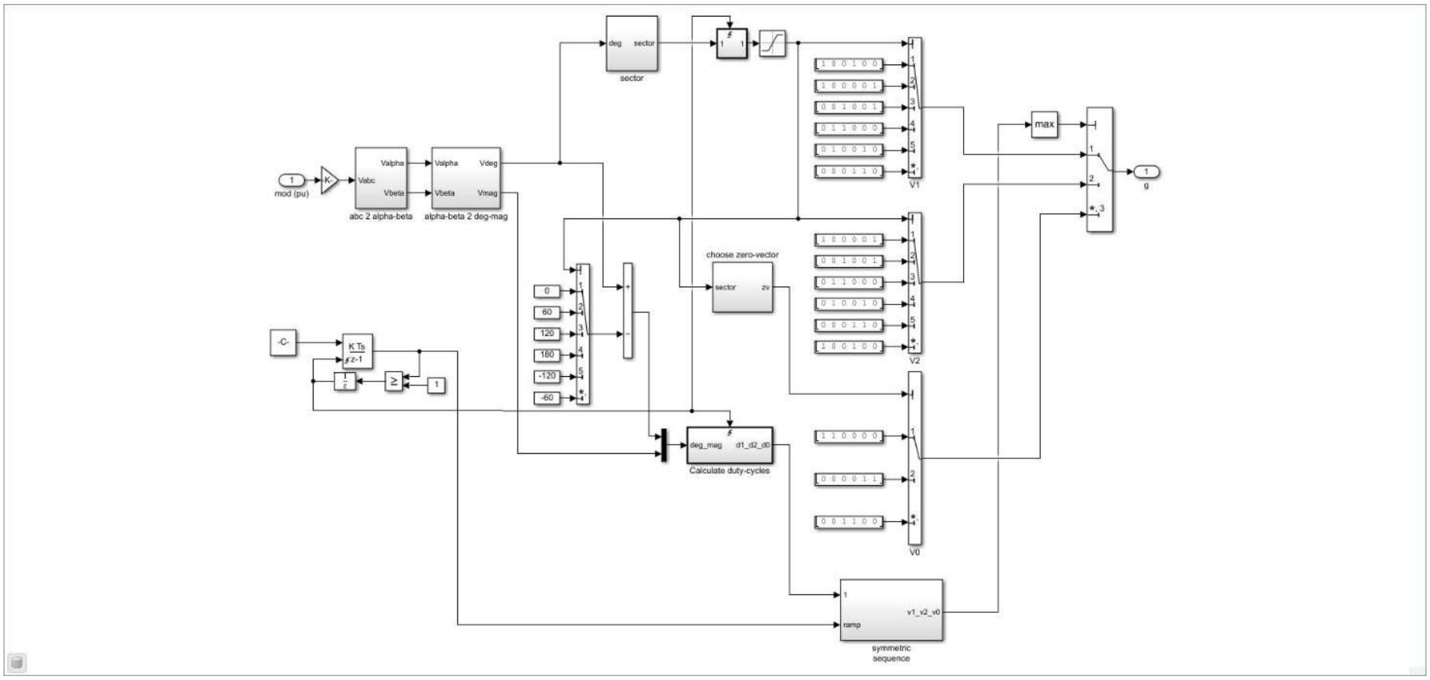


Figure 3.7 Current Modulation

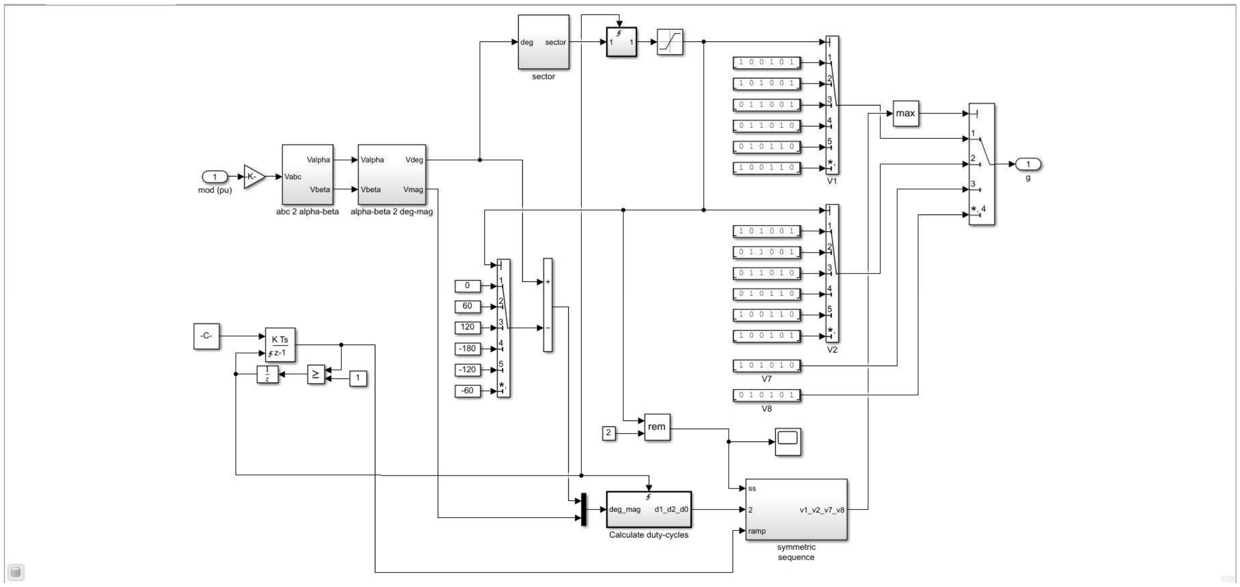


Figure 3.8 Voltage Modulation

### 3.3 Input System of Model

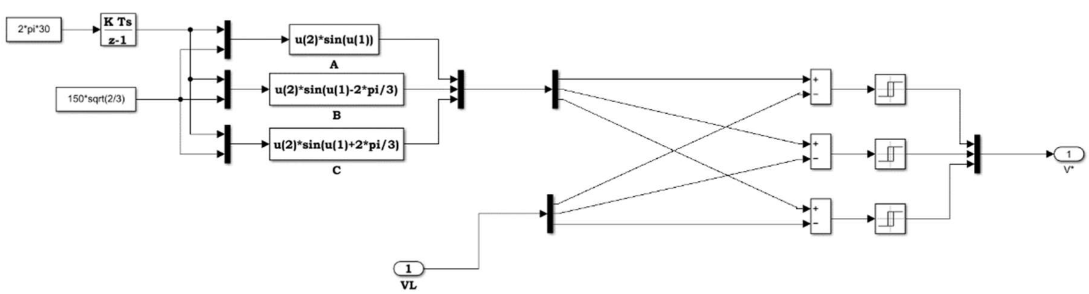


Figure 3.9 Input System of the Model

In the input block, two parameters are given, frequency and voltage. Then the system output will be as according to the given values. Here, example of 150V and 30 Hz was used.

### 3.4 Simulation of Active Power Filters

Here, Shunt Active Power Filter from figure given below shows the simulation for matrix converter, cancels out the harmonics in the supply current as well as from the load.

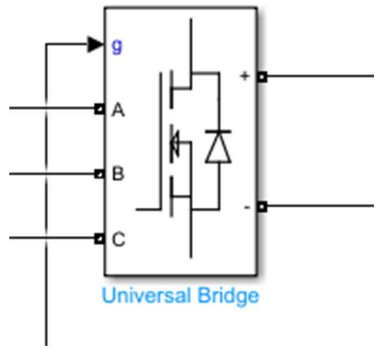


Figure 3.10 Universal Bridge of SAPF

When the load is sensitive and critical, a series converter is used to regulate line voltage for the load. The second function of the series converter of UPQC, which is considered in very-high-power applications, is defined to protect the power system against the voltage distortions originating from the load.

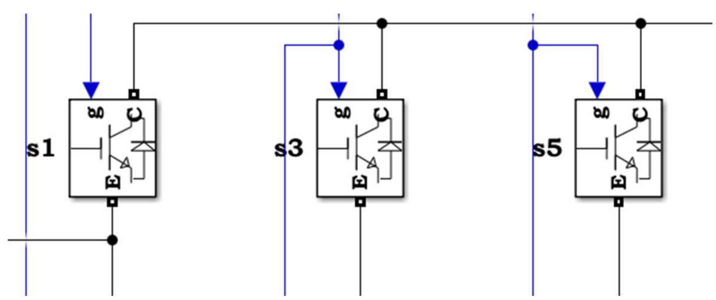


Figure 3.11 Universal Bridge of SAPF

Both the figure shows the universal bridge of both Shunt as well as Series Active Power Filter. The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box

# CHAPTER FOUR: RESULT AND DISCUSSIONS

## 4.1 Outcomes for Modelling of SVPWM

New switching strategy is introduced based on the maximum compensated angle and for the controllable input power factor of matrix converter. It is also responsible for generating PWM signal to control switches of MCs which then produces the required modulated voltage to drive the non-linear load.

Main objective of SVM is to generate a switching sequence that corresponds to the reference voltage vector, for every PWM period to achieve a continuously rotating space vector.

## 4.2 Outcomes for Modelling Of Matrix Converter

The control is tested with an ideal nine-switch three phases to three phase matrix converter feeding a Non Linear Load. For this purpose, digital simulations are carried out using MATLAB / Simulink software.

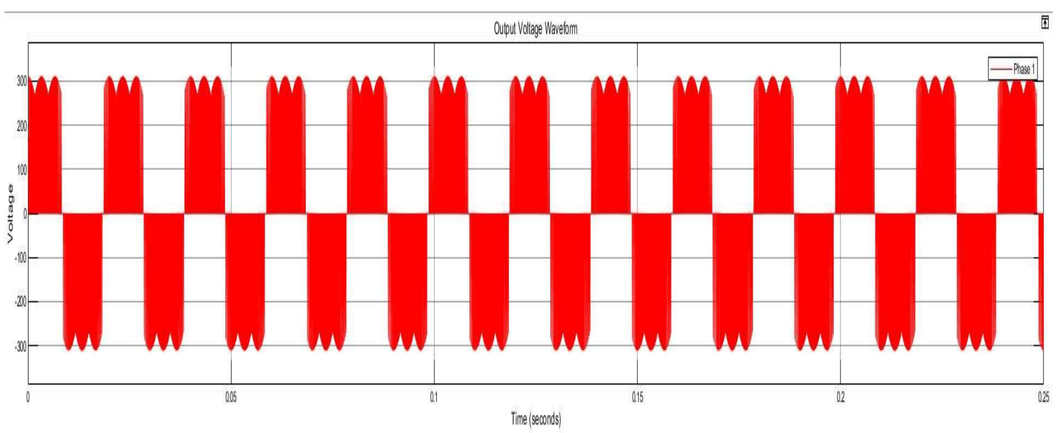


Figure 4.1 Output Voltage Waveform for Matrix Converter

The THD of 60% was obtained.

After application of filter the following waveforms are obtained.

## 4.3 Waveform of Voltage and Current Injected By Filters

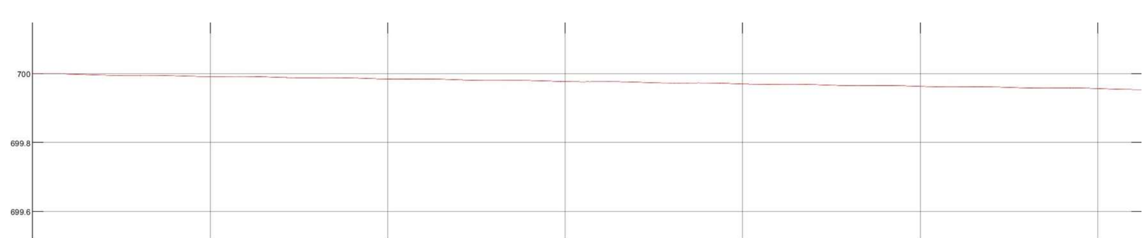

Figure 4.2 Waveform of Current injected Shunt Filter

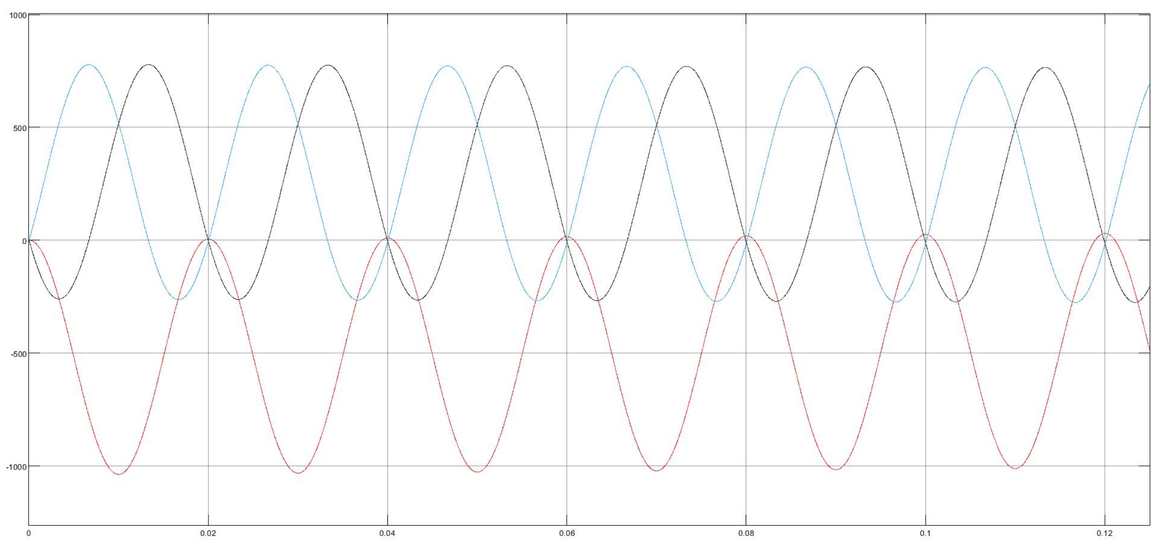


Figure 4.3 Waveform of Voltage injected by Series Filter

## 4.4 Outcomes of Matrix Converter with Filters

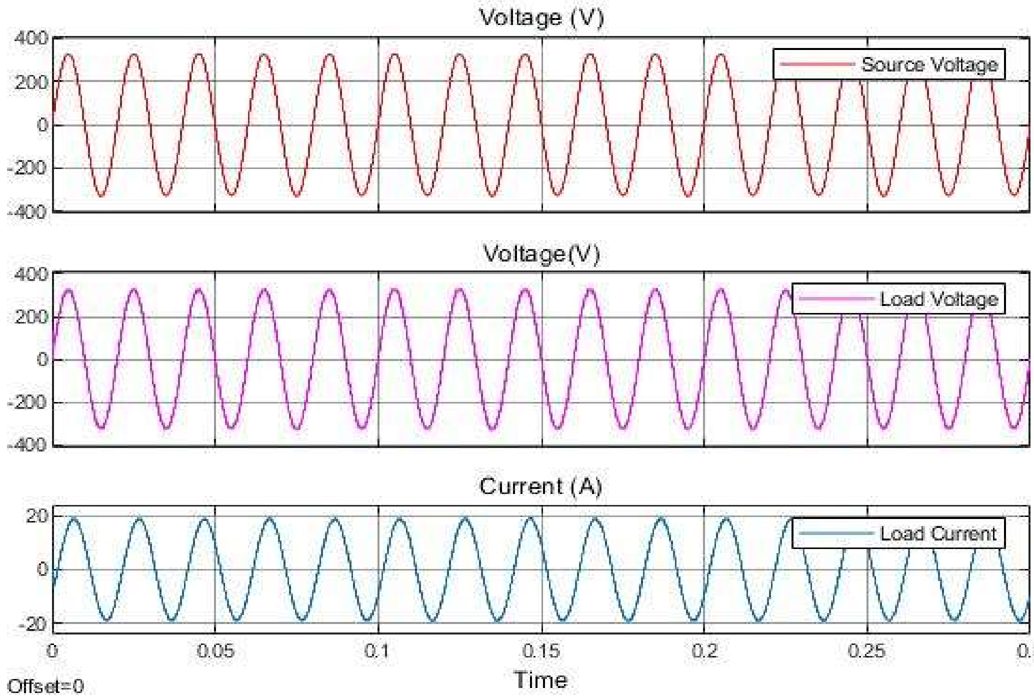


Figure 4.4 Waveform With Series and Shunt Filter for 50 Hz,400 V Output

Figure 1 shows the per phase input voltage, load voltage, and load current. The input voltage applied to the matrix converter is 400 V, 50 Hz. The output of the matrix converter is obtained at same voltage and frequency as shown in figure 1. The total harmonic distortion found in the load voltage, and load current are 1.3 %, and 1.2% respectively.

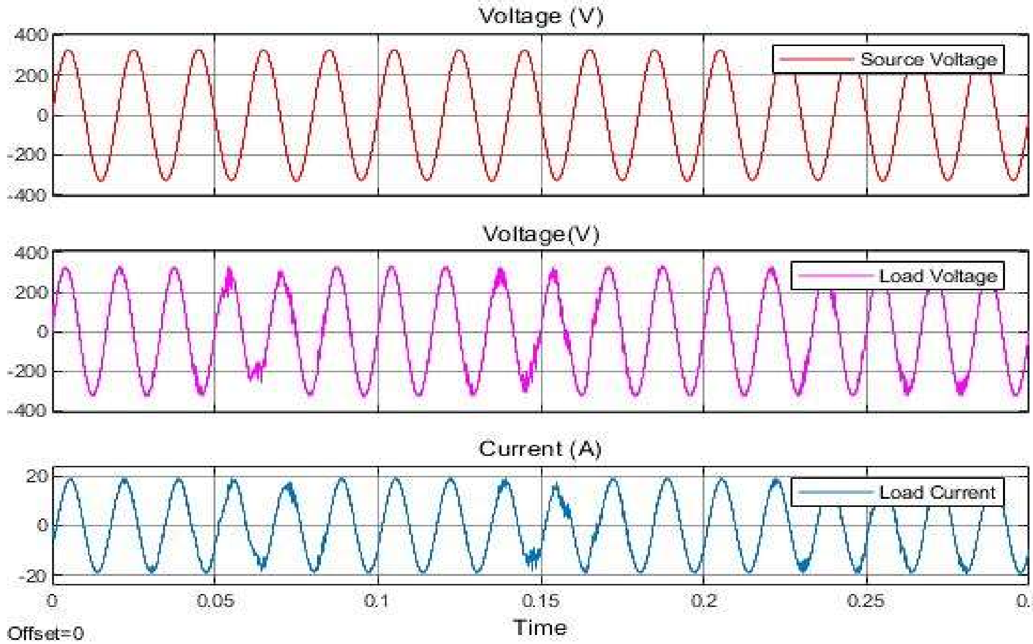


Figure 4.5 With Series and Shunt Active Filter Output for 60Hz, 400V Output

Figure 2 shows the per phase input voltage, load voltage, and load current. The input voltage applied to the matrix converter is 400 V, 50 Hz. The output of the matrix converter is obtained at same voltage but frequency is changed to 60 Hz. The waveform is as shown in figure 2. The total harmonics found in voltage, and current wave form are 3.2 %, and 2 % respectively.

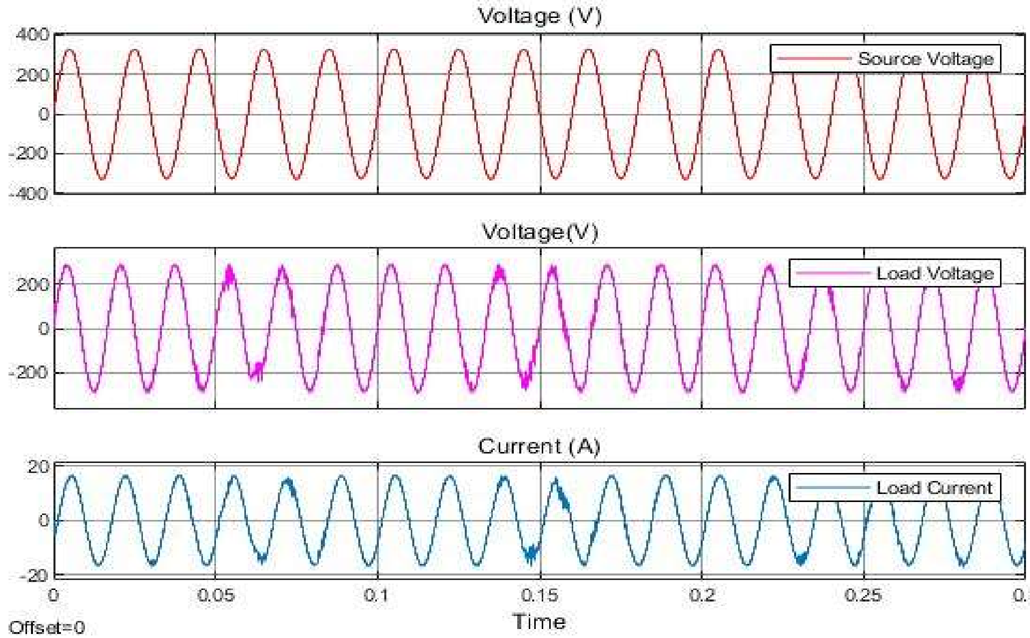


Figure 4.6 With Series and Shunt Active Filter for 60Hz,350 V Output

Figure 3 shows the per phase input voltage, load voltage, and load current. The input voltage applied to the matrix converter is 400 V, 50 Hz. The output of the matrix converter is obtained at 350 V and frequency is changed to 60 Hz. The waveform is as shown in figure 3. The total harmonics found in voltage, and current wave form are 2.66 %, and 1.28 % Respectively.

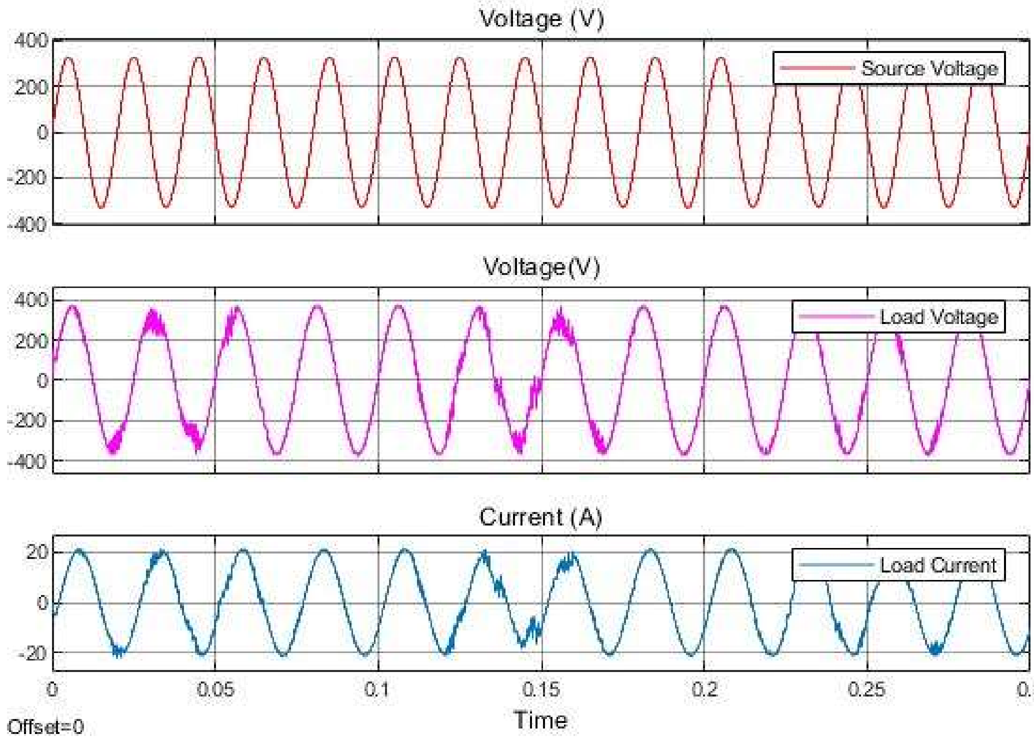


Figure 4.7 With Series and Shunt Active Filter Waveform at 40Hz, 400 V Output

Figure 4 shows the per phase input voltage, load voltage, and load current. The input voltage applied to the matrix converter is 400 V, 50 Hz. The output of the matrix converter is obtained at same voltage and frequency is changed to 40 Hz. The waveform is as shown in figure 4. The total harmonics found in voltage, and current wave form are 1.3 %, and 1.5 % respectively.

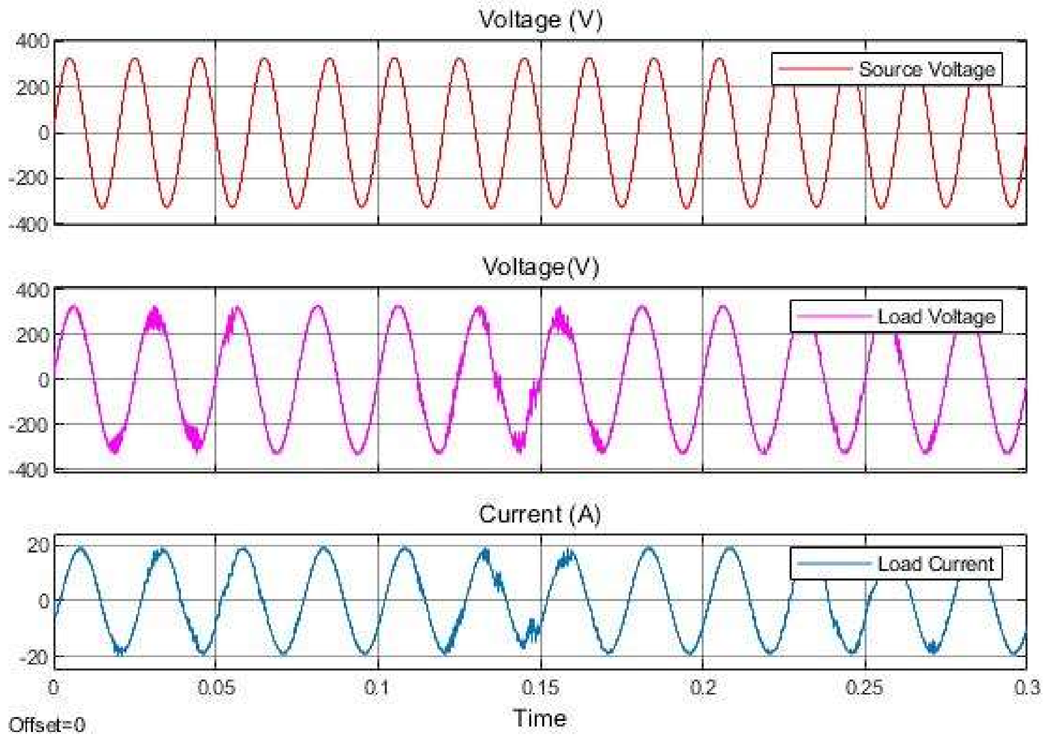


Figure 4.8 With Series and Shunt Active Filter Waveform for 40 Hz, 450 V Output

Figure 5 shows the per phase input voltage, load voltage, and load current. The input voltage applied to the matrix converter is 400 V, 50 Hz. The output of the matrix converter is obtained at 450 V and frequency is changed to 60 Hz. The waveform is as shown in figure 5. The total harmonics found in voltage, and current wave form are 1.2 %, and 1.6 % Respectively.

From the result obtained as shown in figure 1,2,3,4, and 5. It is concluded that, the matrix converter with active series and shunt filter, can be used for achieving desired frequency and voltage. With proper capacity of the filters, it is applicable in controlling the load having varying frequency, and voltage. Thus, matrix converter with series active filter find the application in control induction motor.

Similarly, the other obtained voltages, frequency and respective THD are tabulated as:

Table 4.1 Obtained Voltages, Frequency and THD

| Voltage | Frequency | THD |
|---|---|---|
| 150 | 30 | 4.3% |
| 150 | 45 | 3.6% |
| 200 | 45 | 2.8% |
| 315 | 60 | 1.8% |
| 600 | 50 | 1.4% |
| 750 | 30 | 1.3% |
| 800 | 45 | 1.3% |
| 875 | 60 | 1.3% |
| 900 | 55 | 1.3% |
| 1000 | 40 | 1.3% |

THD of 3.9% was obtained in the former case and 4.1% in the later case.

# CHAPTER FIVE: CONCLUSION

In conclusion, the use of matrix converters for power conversion applications can be analyzed and modeled using mathematical equations. The matrix converter topology allows for direct AC-to-AC power conversion and can be described by a set of nonlinear equations that govern the input and output voltages and currents.

Various mathematical models have been developed to study the behavior of matrix converters under different operating conditions. These models include space vector and state-space models, which provide a comprehensive analysis of the converter's dynamic behavior and steady-state performance. Pulse width modulation (PWM) techniques are commonly used to control the output voltage and current waveforms of matrix converters.

The mathematical equations for PWM control strategies can be derived based on the converter's nonlinear equations, and advanced control techniques such as predictive control and sliding mode control can also be implemented to improve the converter's performance.

Overall, the use of mathematical equations is essential in understanding and analyzing the behavior of matrix converters for power conversion applications. Mathematical models and control strategies can help optimize the converter's performance and ensure stable and efficient operation.

Finally, the matrix converter is a potential power conversion technology because of its capacity to do bidirectional power conversion without the usage of bulky DC-link capacitors or inductors. The matrix converter can convert alternating current to alternating current with variable frequency and voltage, making it useful for a variety of applications such as motor drives, renewable energy systems, and power supply. The matrix converter topology eliminates the need for bulky and expensive DC-link capacitors and allows for direct AC-to-AC power conversion.

Furthermore, the matrix converter has various advantages over traditional converters, such as higher efficiency, lower harmonic distortion, and better power factor adjustment. It's also smaller and lighter, making it ideal for usage in compact systems. However, due to the complicated control algorithms necessary to manage the input and output voltages and frequencies, the construction of a matrix converter might be difficult. In this report, we have discussed the working principle of the matrix converter and its various topologies. We have also highlighted the advantages and disadvantages of using a matrix converter for power conversion. Furthermore, we have discussed some applications of the matrix converter, including renewable energy systems, electric vehicles, and industrial automation. Overall, the matrix converter is an innovative technology that has the potential to revolutionize the way we convert and control electrical power. As the demand for efficient and sustainable energy solutions continues to grow, the matrix converter is likely to become an increasingly popular choice for power conversion in various industries.

Overall, matrix converters offer several benefits over traditional converters, but their complex control algorithms and high component cost must be considered in the design and implementation of power conversion systems.

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# APPENDIX