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Comparative analysis of Conventional Converter and SVPWM based Matrix Converter

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Abstract : **In recent years, matrix converters have become increasingly attractive for these applications because they fulfil all the requirements, having the potential to replace the conventionally used rectifier_dc link_inverter structures. The matrix converter is an array of controlled semiconductor switches that connects directly the three-phase source to the three-phase load. It utilizes bidirectional controlled switch to achieve automatic conversion of power from AC to AC. In the last few years, an increase in research work has been observed, bringing this topology closer to the industrial application.There are several modulation techniques for matrix converter out of each Space Vector Pulse Width Modulation(SVPWM) is considered. It is an algorithm for the control of pulse width modulation width modulation (PWM). Indirect matrix converter is implemented because of its simplicity in switching scheme and advantages over Direct matrix converter. Three phase matrix converter is studied and implemented using MATLAB/SIMULINK. Finally the results are compared with conventional dc-link back to back converter. From the results, it can be concluded that THD level of line voltages, phase voltages is reduced in case of Indirect matrix converter when compared to conventional dc-link back to back converter.**

Keywords* —Conventional dc link back to back converter, Direct Matrix Converter, MATLAB/SIMULINK, *Indirect Matrix Converter, SVPWM, THD.

I. INTRODUCTION

Power electronic converters are used for a wide power range and in various applications to get controllable power output. The number of such systems is large and still growing. The need for power converters will keep increase in future. The electric power conversion is from ac (alternating current) to dc (direct current), from dc to ac, from dc to dc and from ac to ac. The ac to ac conversion is widely used in industrial adjustable-speed drives, since around 80% of them are AC drives[1],[2]. The available AC-AC converter structures can be divided into two schemes such as direct and indirect. The indirect topology[3] of the power converter of the regenerative drives uses two identical bridges in the rectifier and inverter stage, connected through a dc-link bus with a small capacitor connected across it, and is usually known as a Voltage back-to-back converter .Indirect Matrix Converter is mostly preferred over Direct Matric Converter because of easy implementation, more secure computation and possibility of constructing Ac-Ac converters with multiple three-phase outputs[4]-[7]. Matrix Converter (MC) is a variable voltage, variable frequency power converter. Compared to the other AC-AC converter topologies, the MC has many significant features that converter may be operated to give sinusoidal line currents, for sinusoidal currents, the dc-link voltage must be higher than the peak main voltage, the dc-link voltage is regulated by controlling the power flow to the ac grid and finally, the inverter operates on the boosted dc-link, making it possible to increase the output power of a connected machine over its rated power.The advantages are near sinusoidal input and output waveforms, unity input displacement factor, bidirectional power flow, natural four quadrant operation, potential for compact design because of the absence of dc link capacitors and the input power factor can be fully controlled. However, MC has some disadvantage. The voltage transfer ratio is limited to 0.866, to obtain sinusoidal output waveforms. It requires more semiconductor devices compared to conventional AC–AC indirect converter. Moreover, MC is sensitive to disturbances of the input voltage system. The Space Vector Modulation (SVM) control technique is used for controlling IMC. SVM technique [8]-[13] is more popular than all other conventional technique because of more dc bus utilization, lower harmonics, less switching losses and higher efficiency.

II. THREE PHASE MATRIX CONVERTER

A. Classification of Matrix Converter

The instantaneous power does not have to equal power output. The difference between the input and output power must be absorbed or delivered by an energy storage element within the converter. The matrix converter replaces the multiple conversion stages and the intermediate energy storage element by a single power conversion stage,and uses a matrix of semiconductor bidirectional switches connecting input and output terminals. With this general arrangement of

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switches, the power flow through the converter can reverse. Because of the absence of any energy storage element, the instantaneous power input must be equal to the power output, assuming idealized zero-loss switches.

Matrix converters (MCs) provide a number of advantages, including sinusoidal input and output currents, regeneration capability, and compact size with good power-to-weight ratio. The development of MCs began in the early 1980s when Alensia and Venturini introduced the basic principles of operation. Afterwards, the MCs were applied to the adjustable motor speed drive, for renewable energy applications, power supplies, and many others application.

MCs are classified into direct matrix converters (DMCs) and indirect matrix converters (IMCs) . Both converters are able to generate input/output waveforms with the same performance and the same voltage transfer ratio capability.

B. Direct Matrix Converter

It consists of 9 bidirectional switches which allow any output phase can be connected to any input phase. For 9 switches , switching combination states can be 2^9=512. But all the switching combinations can't be effectively implemented. Because there are two basic constraints which should be taken into consideration. One is input phase voltages should never be interrupted. Second one is output pair should not be opened. By considering these rules, it is concluded that only one bi-directional switch per output phase must be switched on at any instant. Therefore, only 27 switching combinations are possible. Fig.1 below shows schematic diagram of DMC.

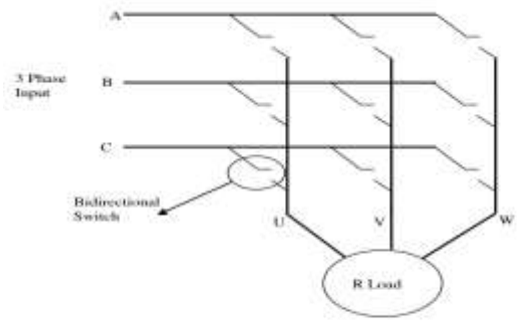

Fig. 1: Indirect Matrix Converter

C. Indirect Matrix Converter

The IMC is now preferable to the DMC because it has many extra advantages over the DMC, such as easy implementation, more secure computation, the possibility power switch number reduction, and the possibility of constructing AC-AC converters with multiple three-phase outputs and multiphase output voltages.

It consists of rectifier and inverter stages. It has no dc-link capacitor.Instead it uses the concept of fictitious dc link. So it provides "all silicon solution". As a result it provides less bulky and compact VFD drives. It has no restriction on input and output frequency. So it is widely used in wind energy power conversion. Figure.2 below shows circuit topology of indirect matrix converter.

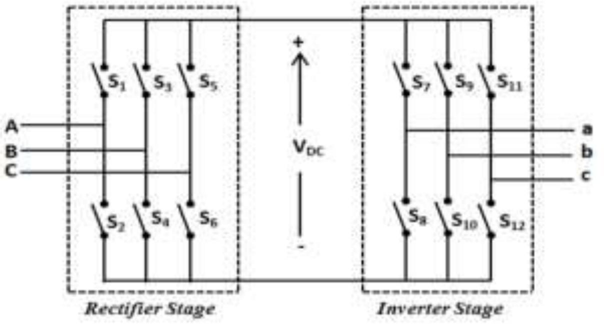

Fig. 2: Indirect Matrix Converter

III. SPACE VECTOR PWM

A. Introduction

In the mid-1980s a form of PWM called space vector modulation (SVM) was proposed, which was claimed to offer significant advantages over natural and regular sampled PWM in terms of performance, ease of implementation, and maximum transfer ratio. In this section, the fundamentals of SVM are presented, and SVM is identified as simply an alternative method for determining switched pulse widths. In fact, the main benefit of SVM is the explicit identification of pulse placement as an additional degree of freedom that can be exploited to achieve harmonic performance gains.

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. There are two possible vectors called zero vector and Active vector.

Space vector modulation (SVM) is quite different from the PWM methods. With PWMs the inverter can be thought of a three separate push-pull driver stages, which create each phase waveform independently.SVM however treats the inverter as the single unit; specifically the inverter can be driven to 8 unique states. The control strategies are implemented in digital systems. SVM is a digital modulating technique where the objective is to generate PWM

Load line voltages in average equal to a given (or reference) load line voltages. This is done in each sampling period by properly selecting the switch states of the inverter and the calculations of the appropriate time period for each state. The selection of the states and their time periods are accomplished by the space vector (SV) transformation.

Space vector pulse width modulation is applied for output voltage and input current control. This method is an advantage because of increased flexibility in the choice of switching vector for both input current and output voltage control. It can yield useful advantage under unbalanced conditions.The three phase variables are expressed in space vectors. For a sufficiently small time interval, the reference voltage vector can be approximated by a set of stationary vectors generated by a matrix converter.If this time interval is the sample time for converter control, then at the next sampling instant when the reference voltage vector rotates to a new angular position, it may correspond to a new set of stationary voltage vectors.Carrying this process onwards by sampling the entire waveform of the desired voltage vector being synthesized in sequence, the average output voltage would closely emulate the reference voltage.

B. Principle of SVPWM

The principle of SVM is based on the fact that there are only eight possible switch combinations for a three-phase inverter. The basic inverter switch states are shown again in Figure 3. Two of these states *(SVo* and *SV7)* correspond to a short circuit on the output, while the other six can be considered to form stationary vectors in the *d-q* complex plane as shown in Figure 4.

Having identified the stationary vectors, at any point in time, an arbitrary target output voltage vector V_o* can be formed by the summation ("averaging") of a number of these *space vectors* within one switching period ΔT/2. This is shown in Figure 5 for a target phasor in the first 60° segment of the plane. From geometric considerations, the minimum number of active space vector components required to create any arbitrary vector on an average basis is at least two.

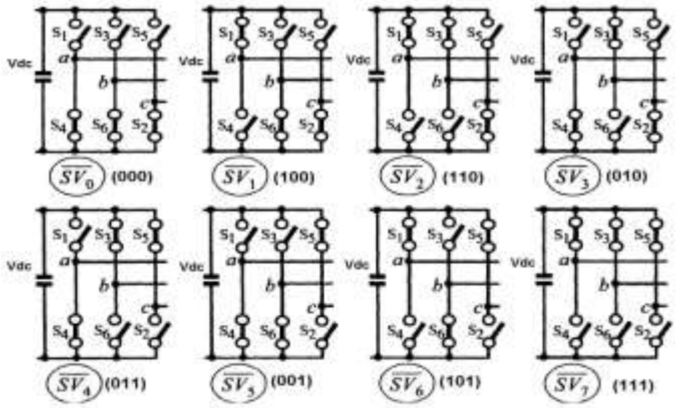

Fig. 3 The eight inverter voltage vectors (V0 to V7).

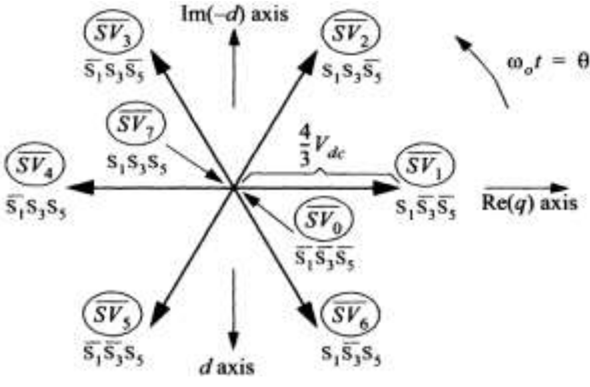

Fig. 4 Location of eight possible stationary voltage vectors for a VSI in the *d-q* (Re-Im) plane, each vector has a length *(4/3)Vdc.*

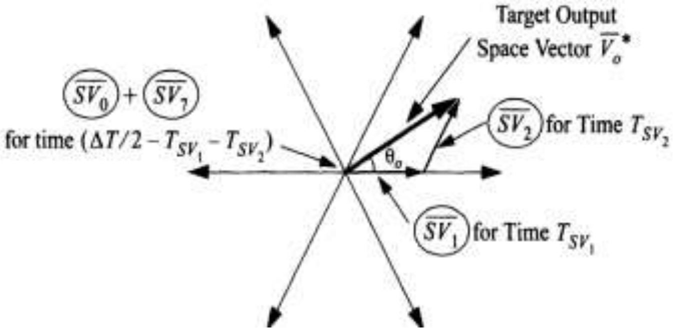

Fig. 5 Creation of an arbitrary output target phasor by the geometrical summation of the two nearest space vectors

As an example, the geometric summation shown in Figure 5 can then be expressed mathematically as

$$\overline{V_o^*} = V_o\angle\theta_o = \frac{T_{SV_1}}{\Delta T/2}\overline{SV_1} + \frac{T_{SV_2}}{\Delta T/2}\overline{SV_2} \tag{1}$$

for each switching period of ΔT/2, where T_{SV1} is the time for which space vector SV_1. is selected and T_{SV2} is the time for which space vector SV_2 is selected. In polar form (using peak voltages), Eq. (1) can be expressed as

$$\frac{\Delta T}{2}V_o\angle\theta_o = T_{SV_1}V_m\angle 0 + T_{SV_2}V_m\angle\pi/3 \tag{2}$$

or in Cartesian form

$$V_o(\cos\theta_o + j\sin\theta_o)\frac{\Delta T}{2} = T_{SV_1}V_m + T_{SV_2}V_m\left(\cos\frac{\pi}{3} + j\sin\frac{\pi}{3}\right) \tag{3}$$

Equating real and imaginary components gives the solution of

$$T_{SV_1} = \frac{V_o\sin\left(\frac{\pi}{3}-\theta_o\right)}{V_m\sin\frac{\pi}{3}}\frac{\Delta T}{2} \qquad \text{(active time for } \overline{SV_1}\text{)}$$

$$T_{SV_2} = \frac{V_o\sin\theta_o}{V_m\sin\frac{\pi}{3}}\frac{\Delta T}{2} \qquad \text{(active time for } \overline{SV_2}\text{)} \tag{4}$$

Therefore in the sector-1 the Target Space Vector can be expressed as

$$\begin{aligned}\overline{V_o}^* &= \frac{T_{SV_1}}{\Delta T/2}\overline{SV_1} + \frac{T_{SV_2}}{\Delta T/2}\overline{SV_2} \\ &= \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o+\frac{\pi}{6}\right)\overline{SV_1} + \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o-\frac{\pi}{2}\right)\overline{SV_2}\end{aligned} \tag{5}$$

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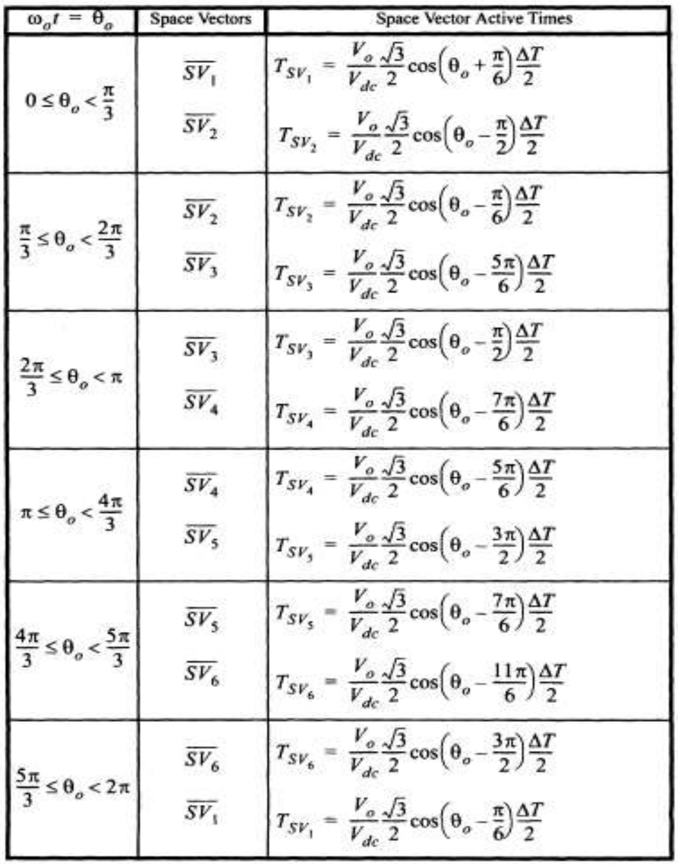
Target Space Vector in remaining sectors can be derived in similar manner. The expressions for Target Space vectors in all sectors in tabulated below in Fig.6.

The circuit model of a typical three-phase voltage source PWM inverter is shown in Fig 7. S1 to S6 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 S1, S3 and S5 can be used to determine the output voltage.



$\omega_o t = \theta_o$	Space Vectors	Space Vector Active Times
$0 \le \theta_o < \frac{\pi}{3}$	$\overline{SV_1}$ $\overline{SV_2}$	$T_{SV_1} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o + \frac{\pi}{6}\right)\frac{\Delta T}{2}$ $T_{SV_2} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{\pi}{2}\right)\frac{\Delta T}{2}$
$\frac{\pi}{3} \le \theta_o < \frac{2\pi}{3}$	$\overline{SV_2}$ $\overline{SV_3}$	$T_{SV_2} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{\pi}{6}\right)\frac{\Delta T}{2}$ $T_{SV_3} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{5\pi}{6}\right)\frac{\Delta T}{2}$
$\frac{2\pi}{3} \le \theta_o < \pi$	$\overline{SV_3}$ $\overline{SV_4}$	$T_{SV_3} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{\pi}{2}\right)\frac{\Delta T}{2}$ $T_{SV_4} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{7\pi}{6}\right)\frac{\Delta T}{2}$
$\pi \le \theta_o < \frac{4\pi}{3}$	$\overline{SV_4}$ $\overline{SV_5}$	$T_{SV_4} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{5\pi}{6}\right)\frac{\Delta T}{2}$ $T_{SV_5} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{3\pi}{2}\right)\frac{\Delta T}{2}$
$\frac{4\pi}{3} \le \theta_o < \frac{5\pi}{3}$	$\overline{SV_5}$ $\overline{SV_6}$	$T_{SV_5} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{7\pi}{6}\right)\frac{\Delta T}{2}$ $T_{SV_6} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{11\pi}{6}\right)\frac{\Delta T}{2}$
$\frac{5\pi}{3} \le \theta_o < 2\pi$	$\overline{SV_6}$ $\overline{SV_1}$	$T_{SV_6} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{3\pi}{2}\right)\frac{\Delta T}{2}$ $T_{SV_1} = \frac{V_o}{V_{dc}}\frac{\sqrt{3}}{2}\cos\left(\theta_o - \frac{\pi}{6}\right)\frac{\Delta T}{2}$

Fig.6 Active Space Vector Components for a VSI

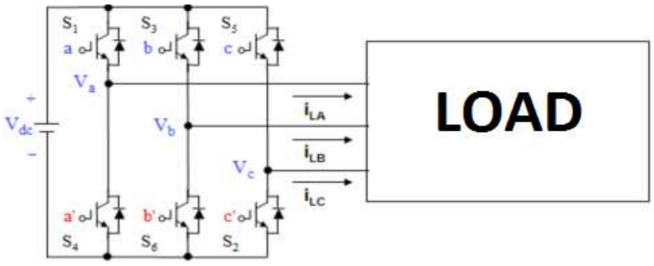


Fig.7 : Three-phase voltage source PWM inverter

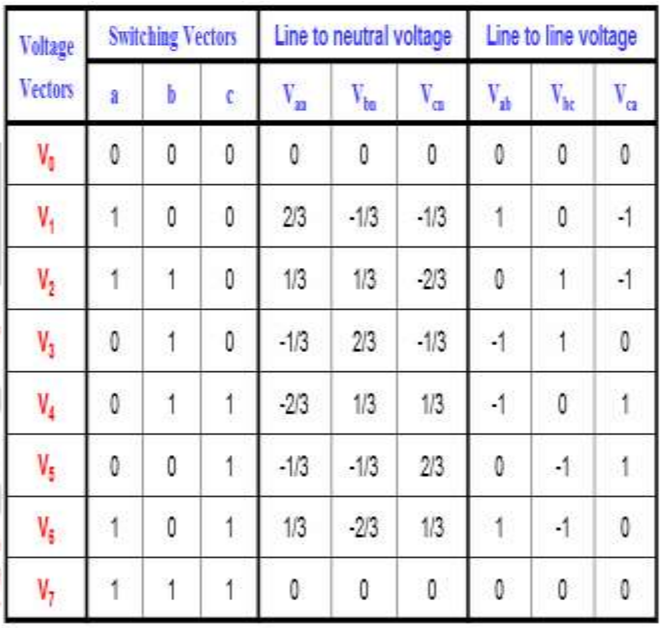
The relationship between the switching variable vector [a, b, c]’ and the line-to-line voltage vector [Vab Vbc Vca]’ is given by (6) in the following:

$$\begin{bmatrix} Vab \\ Vbc \\ Vca \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad (6)$$

Also, the relationship between the switching variable vector [a, b, c]t and the phase voltage vector [VaVbVc]t can be expressed below

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = \frac{Vdc}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad (7)$$

As illustrated in Fig 3, 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 (5) and (6), the eight switching vectors, output line to neutral voltage (phase voltage), and output line-to-line voltages in terms of DC-link Vdc, are given in Fig. 8



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})

Fig.8: Switching vectors, phase voltages and output line to line voltages

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 Vref in the same period.

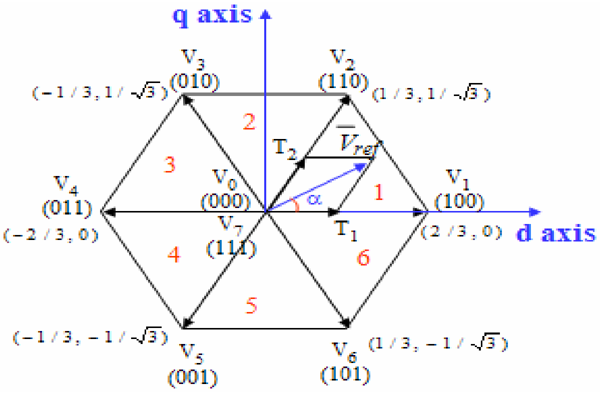


Fig. 9:Basic switching vectors and sectors

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IV. SIMULATION CIRCUITS

The Simulation circuit of three phase conventional converter is shown in Fig. 10.

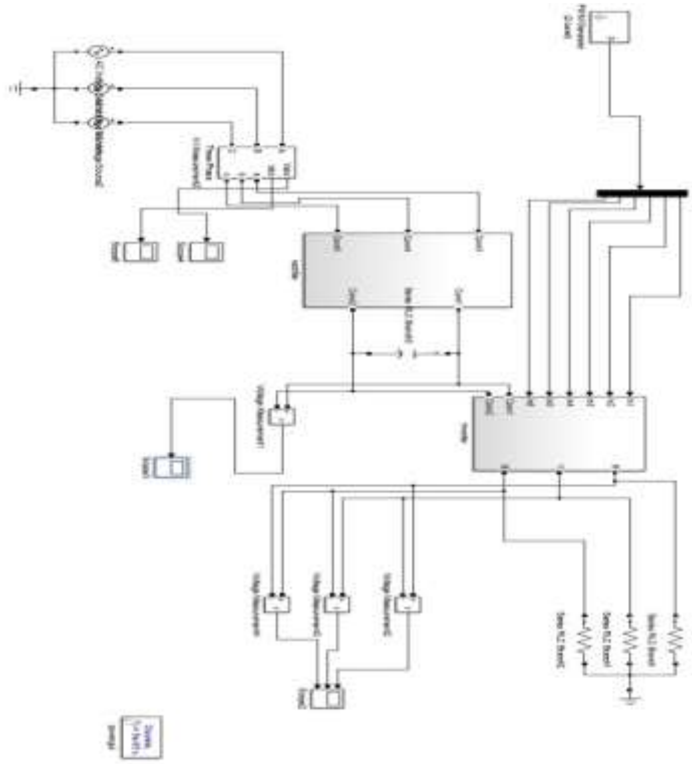

Fig.10: Three phase Conventional converter

Three-phase AC supply of magnitude 415 V_L is given as input to diode bridge rectifier, whose sub circuit is shown in Fig 11. The output of rectifier is given as input to inverter bridge circuit , whose sub circuit is shown in Fig 12. A DC link capacitor 200 mF is used between the rectifier-inverter in order to reduce the ripple content. PWM Generator produces the required switching sequence required for inverter bridge circuit. A resistive load of 100 ohms is used at the output of inverter circuit.

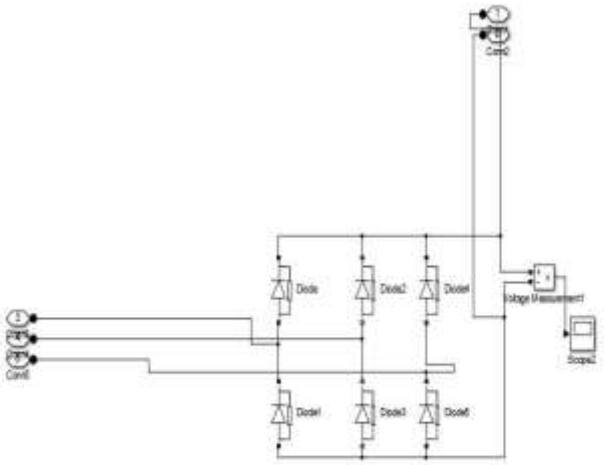

Fig. 11: Sub system for rectifier block

Sub circuit for rectifier as well as inverter is shown below

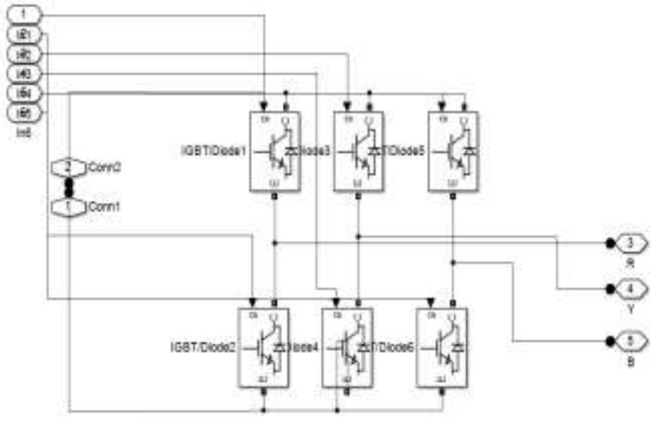

Fig. 12: Sub system for inverter block

The Simulation circuit of three phase matrix converter is shown in Fig 13.

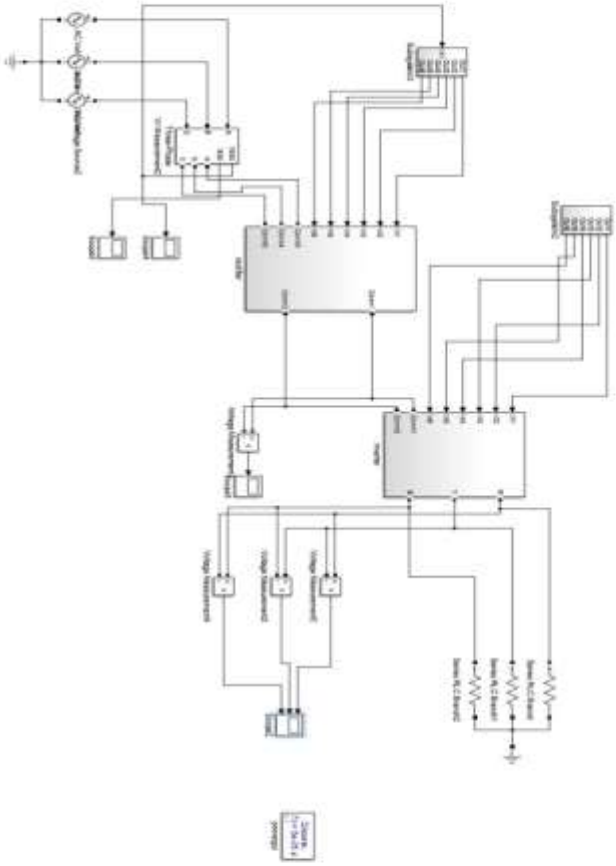

Fig.13 : Three phase Matrix converter

Three-phase AC supply of magnitude 415 V_L is given as input to IGBT bridge rectifier as shown in Fig 14. The switching pulses to the rectifier is given by concept of SVPWM, whose sub circuit is shown in Fig 15. . The output of rectifier is given as input to inverter bridge circuit, whose sub circuit is shown in Fig 16. The switching pulses to the inverter is given by concept of SVPWM, whose sub circuit is shown in Fig 17. A resistive load of ohms is used at the output of inverter circuit.

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Sub circuit for rectifier as well as inverter is shown below

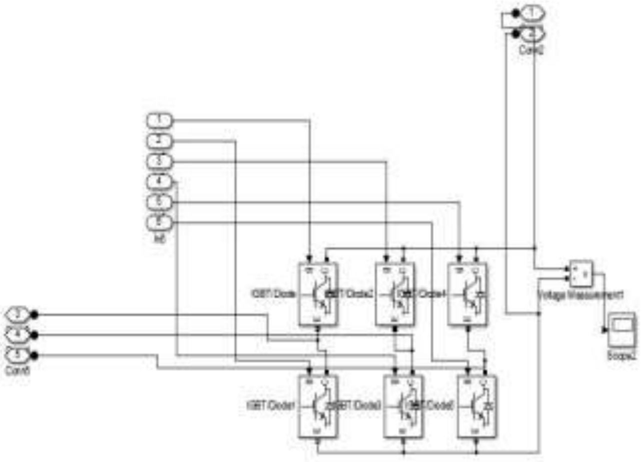

Fig. 14: Sub system for rectifier block

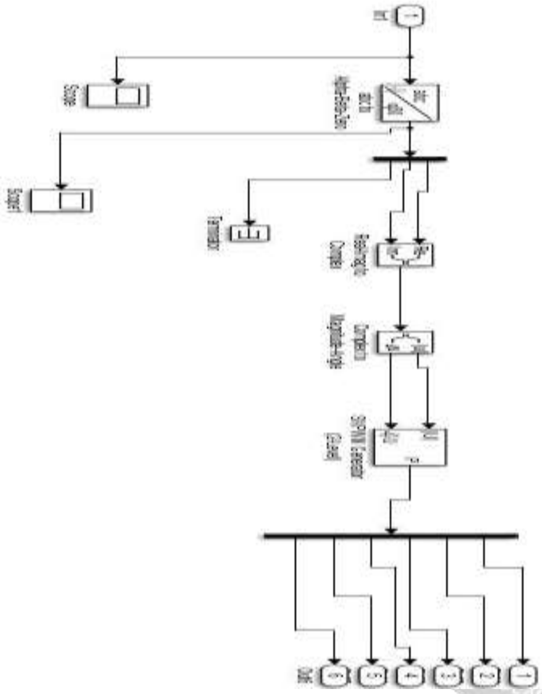

Fig. 15: SVPWM for rectifier block

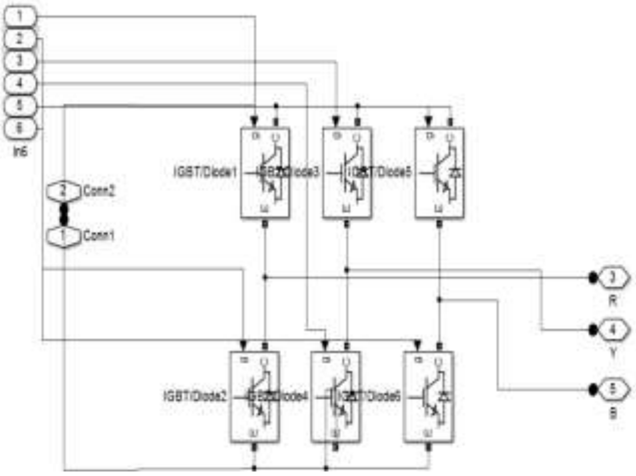

Fig. 16: Sub system for inverter block

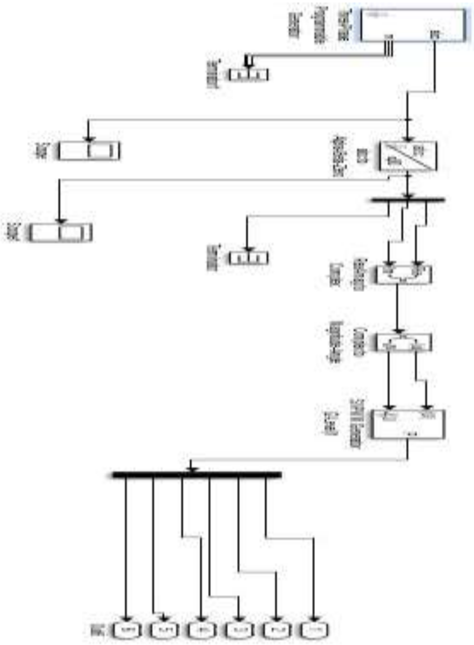

Fig. 17: SVPWM for inverter block

V. SIMULATION RESULTS

The simulation results of Line voltages for three phase Conventional converter is shown in Fig 18. and that of three phase matrix converter are shown below in Fig 19

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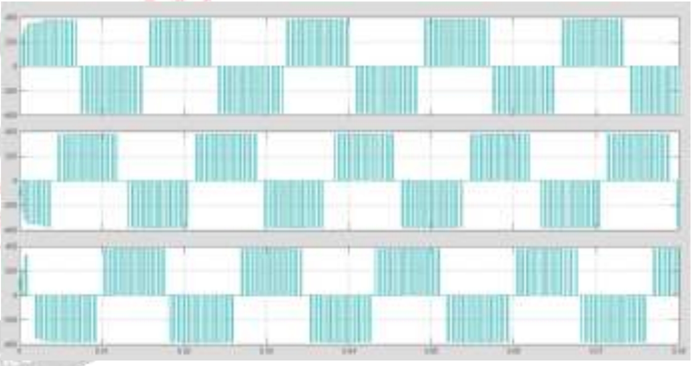

Fig. 18: Waveform of line voltages for conventional converter

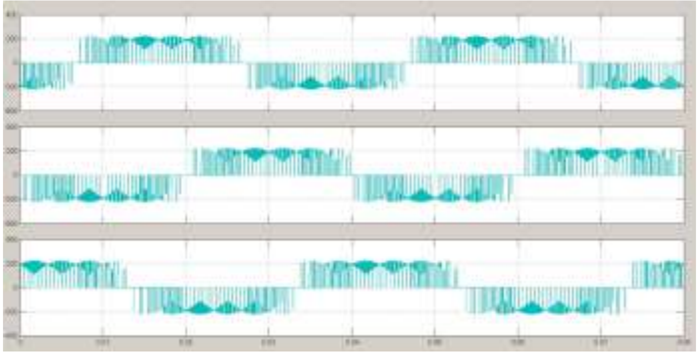

Fig. 19: Waveforms of line voltages for PWM Matrix converter

The THD results of line voltages of three phase Conventional converter is shown in Fig 20. and that of three phase matrix converter are shown below is Fig 21.

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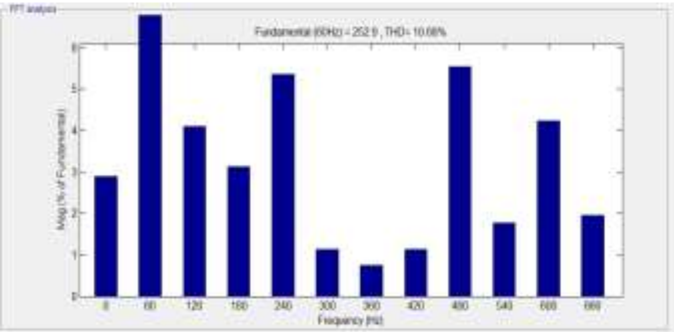

Fig. 20: THD levels of line voltages for conventional converter

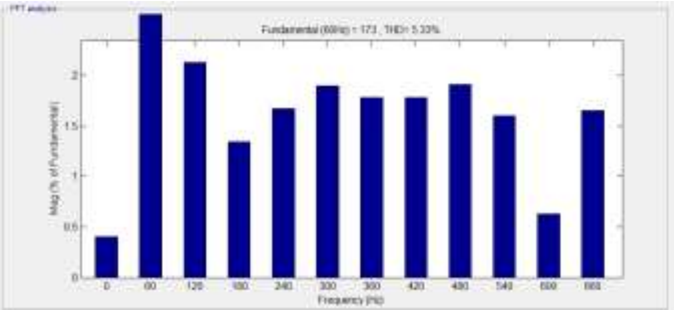

Fig. 21: THD levels of line voltages for Indirect Matrix Converter

It can be observed that THD level of line voltages for Indirect matrix converter is very less when compared to that of Conventional converter.

VI. CONCLUSIONS

The performance of Conventional converter and SVPWM based Indirect Matrix Converter have been analyzed and simulated using MATLAB/SIMULINK. After analyzing SVPWM based Indirect Matrix Converter and AC-DC-AC back to back converter it was observed that THD levels of line voltages for Indirect Matrix Converter has been reduced considerably. It should be noted that absence of dc link capacitor makes matrix converter compact and enables effective control of converter voltages due to SVPWM. The obtained results are tabulated below:

	THD(Line voltages)
CONVENTIONAL CONVERTER	10.66%
INDIRECT MATRIX CONVERTER	5.33%

REFERENCES

[1] Arevalo, S.L, Zanchetta, P.Wheeler, "Control of a matrix converter-based AC power supply for air crafts under unbalanced conditions", In proceedings of IECON2007, Taipei, Taiwan, 5-8 November 2007; pp 1823-18228.

[2] Sebtahmadi S.S, Pirasteh H, Kaboli S.H.A, Radan A, Mekhilef S, " A 12-sector space vector switching scheme for performance improvement of matrix converter based DTC of IM Drive", IEEE Trans. Power Electron. 2015, pp 3804-3817

[3] Jussila.M, Eskola M, Tuusa, "Analysis of non-idealities in direct and indirect matrix converters", Proceedings of EPE-ECCE Europe 2005, Germany, 11-14 September 2005, pp 1-10.

[4] Kolar J.W, Schafmeister F, Round S.D, "Novel three-phase AC-AC sparse matrix converters", IEEE Trans, Power Electron. 2007, pp 1649-1661.

[5] Nguyen T.D, Lee H.H, " Development of a three to five phase indirect matrix converter with carried based PWM based on Space vector modulation analysis, IEEE Trans., Ind. Electron.2016, pp 13-24.

[6] Nguyen T.D, Lee H.H, "Dual three-phase indirect matrix converter with carrier based PWM method", IEEE Trans.,Power Electron., 2014, pp 569-581.

[7] D Tuyen ; Tran Thanh Vu ; Van-Tung Phan ; Phan Quoc Dzung, "SVPWM Method for Dual Indirect Matrix Converter with Zero-Common Mode Voltage 2016 IEEE International Conference on Sustainable Energy Technologies (ICSET), pp. 163–168., January 2017

[8] Rahul Kumar ; Ayush Vardhan Goyal ; Shashank Srivastava ; Satendra Pratap Singh ; Nitin Singh, "Modelling and simulation of matrix converter based DC-DC converter", 2013 International Conference on Energy Efficient Technologies for Sustainability, pp 134-138, April 2013

[9] Poonam B. Shinde , Tanuja N. Date, "Pulse width modulation control of 3-phase AC-AC Matrix converter," 2017 International Conference on Computing Methodologies and Communication (ICCMC), pp. 992–997, July 2017.

[10] Alireza Jahangiri ; Ahmad Radan ; Mehdi Haghshenas, "Comparison of three switching stratergies for Indirect Matrix converter," 2009 13th European Conference on Power Electronics and Applications, October 2009.

[11] Mohd. Arif Khan, Akhilesh Kumar "Control of Three-Phase To Three-Phase Matrix Converter Using Carrier Based Scheme ," International Conference on Emerging Trends in Engineering and Technology, pp. 1–6, Apr. 2012.

[12] D Tuyen ; Tran Thanh Vu ; Van-Tung Phan ; Phan Quoc Dzung, "SVPWM Method for Dual Indirect Matrix Converter with Zero-Common Mode Voltage 2016 IEEE International Conference on Sustainable Energy Technologies (ICSET), pp. 163–168., January 2017

[13] Athulya M. T. ; Shankar Subramanian, "SVPWM based control of Matrix Converter for gearless operation of wind energy power conversion, 2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE), July 2016.

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