IACSIT International Journal of Engineering and Technology, Vol.2, No.2, April 2010
ISSN: 1793-8236

Comparison of Modulation Techniques for Matrix Converter

J.Karpagam, Member IEEE, Dr.A.Nirmal Kumar and V.Kumar Chinnaiyan

***Abstract*—Matrix Converters can directly convert an ac power supply of fixed voltage into an ac voltage of variable amplitude and frequency. Matrix Converter is a single stage converter. The matrix converters can contribute to the realization of low volume, sinusoidal input current, bidirectional power flow and lack of bulky reactive elements. All the reasons lead to the development of matrix converter. Based on the control techniques used in the matrix converter, the performance varies. So this paper analyses the performance of matrix converter with three different modulation techniques such as PWM, SVPWM and SVM. The basic principle and switching sequence of these modulation techniques are presented in this paper. The output voltage, output current waveforms, voltage transfer ratio and THD spectrum of switching waveforms connected to RL load are analyzed by using Matlab/Simulink software. The simulated results are analyzed and shows that the THD is better for SVM technique.**

***Index Terms*—Matrix Converter, Pulse Width Modulation (PWM), Space Vector Pulse Width Modulation (SVPWM), Space Vector Modulation (SVM), Total Harmonic Distortion(THD).**

I. Introduction

The matrix converter has received considerable attention in recent years because of its appealing operational characters. The need to increase the quality and the efficiency of the power supply and the power usage, the three phase matrix converters becomes a modern energy converter and has emerged from the early conventional energy conversion modules. The matrix converter is an alternative to a inverter drive for a frequency control. The matrix converter is also known as an 'all-silicon solution'. The matrix converter is a single stage converter which does not require any capacitor as the dc-link energy storage component. The capacitor can be a critical component because it is large and expensive. In addition, the matrix converter has a high power factor sinusoidal input current with a bi-directional power flow for the whole matrix converter drive system. It has longer life because no capacitor is used. Different switching schemes for an ac/ac matrix converter have been proposed to achieve sinusoidal input and output current waveforms. Several publications on matrix converters have dealt with the modulation strategies to improve the performance of the matrix converter [1]. In this paper matrix converter is made to operate in the following modulation techniques namely PWM, SVPWM and SVM. Compared to PWM technique, SVPWM and SVM are more suitable for digital implementation. Also the maximum voltage transfer ratio can be increased up to 86.6%. The comparative method reveals the superiority of the SVM over PWM technique in terms of THD.

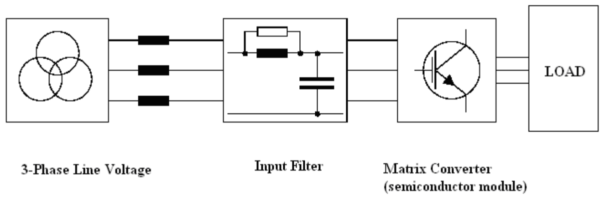


Fig. 1. Block-Diagram for the Matrix Converter Feeding Local Load

Figure 1 shows the block diagram of a matrix converter feeding a stand alone load. The three phase ac line voltage is applied to matrix converter after appropriate filtering. The matrix converter converts the fixed voltage to voltage with variable amplitude and frequency. The output can be supplied to any load that requires variable voltage with variable frequencies such as to drive an induction motor and the permanent magnet synchronous motor.

II. Matrix Converter

A matrix converter is a variable amplitude and frequency power supply that converts the three phase line voltage directly, i.e. without intermediate dc-voltage or current link, into three phase output voltage. It is very simple in structure and has powerful controllability.

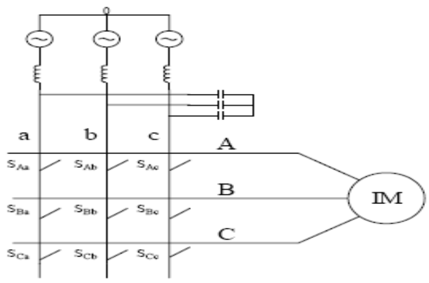


Fig. 2. Topology of Three Phase Matrix Converter with H Bridge Configuration

J.Karpagam, is with the Department of Electrical and Electronics Engineering as Assistant Professor, Bannari Amman Institute of Technology, Coimbatore, India – 638 401 (e-mail: sujisumi@rediffmail.com).

Dr.A.Nirmal Kumar, is with the Department of Electrical and Electronics Engineering as Professor and Head, Bannari Amman Institute of Technology, Coimbatore, India-641 014.

V.Kumar Chinnaiyan, is with the Department of Electrical and Electronics Engineering as Assistant Professor, Bannari Amman Institute of Technology, Coimbatore, India – 638 401. (e-mail: kumarchinn@hotmail.com).

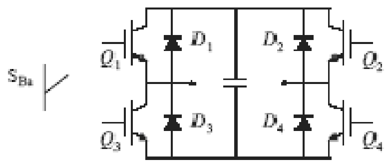


Fig. 3. H-bridge Switch Cell with Capacitor

Figure 2 shows the matrix converter topology for three phase to three phase configuration. The converter consists of nine modular H-bridge capacitor-clamped switch cells, as illustrated in figure 3, connected from each input phase to each output phase. This converter differs from the conventional matrix converter in that it can buck or boost the voltage and inductive filters are employed at the input terminal. The terminal ac voltages of the converter are synthesized from the modulation techniques such as PWM, SVPWM and SVM. The switching pulses for the power devices in each H-bridge are obtained from any of the modulation techniques.

The converter is capable of both increasing and decreasing the voltage magnitude and frequency, while operating with arbitrary power factors. The peak semiconductor device voltages are locally clamped to a dc capacitor voltage, whose magnitude can be regulated. The semiconductor devices are effectively utilized. Multilevel switching can be used to synthesize the voltage waveforms at both the input and output of the converter. The switch cells can be connected in series in each branch of the matrix to increase the voltage rating of the converter. Switch commutation is simpler than the conventional matrix converter. The converter is capable of increasing the number of levels of operation by connecting more than one switch cell in series.

III. PULSE WIDTH MODULATION

Because of advances in solid state power devices PWM based converters are becoming most widely used in drives. PWM inverters make it possible to control both the frequency and magnitude of the voltage and current applied to drive motor. The energy that a PWM converter delivers to a motor is controlled by PWM signals applied to the gates of the power switches. Different PWM techniques are exist, that are Sinusoidal PWM, Hysteresis PWM and the relatively new Space-Vector PWM. These techniques are commonly used for the control of ac induction, Brushless Direct Current (BLDC) and Switched Reluctance (SR) motors. As a result, PWM converter powered motor drives offer better efficiency and higher performance compared to fixed frequency motor drives [3].

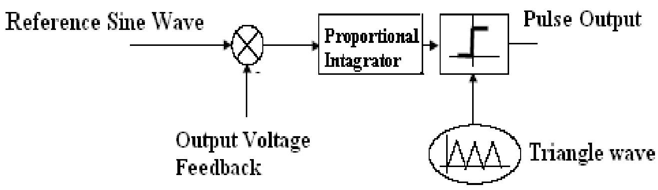


Fig. 4. PWM Pulse Generation Circuit

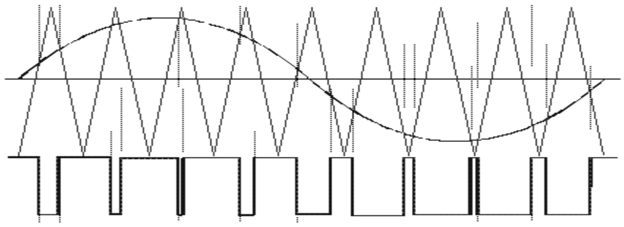


Fig. 5. PWM Triggered Pulse Pattern for Power Devices

The generation of PWM pulse requires reference sine wave and triangular wave. The reference sine wave is compared with the feedback from the output voltage, is amplified and integrated as shown in figure 4. This signal is then compared with a generated triangular wave. The rectangular wave is the result of this comparison. As the sine wave is reaching its peak, the pulses get wider as show in figure 5. It is clearly visible that the duty cycle of the rectangular wave is varying according to the momentary value of the required output voltage. The result is that the effective value of the rectangular wave is the same as that of the output voltage. This pulse is used to switch ON or OFF the power switches. The width of the pulse or duty cycle can be varied by varying the frequency of the reference wave.

IV. SPACE VECTOR PULSE WIDTH MODULATION

SVPWM based converters supplies the AC machine with the desired phase voltages. The space vector modulation concept is used to calculate the duty cycle of the switches which is imperative implementation of digital control theory of PWM modulators. The space vector pulse width modulation technique has the following advantages when compared to the conventional PWM technique.

- Its maximum output voltage is 15.5% greater,
- The number of switching required is about 30% less

So, it is widely used in high performance AC drives.

The modulating signal is generated by injecting selected harmonics to the sine wave. This results in flat-topped waveform and reduces the amount of overmodulation. It provides a higher fundamental amplitude and low distortion of the output voltage. The modulating signal is generally composed of fundamental plus harmonics.

$$V_r = 1.15\sin\omega t + 0.27\sin 3\omega t - 0.029\sin 9\omega t \quad (1)$$

The modulating signal with third and ninth harmonic injections is shown in figure 6. The signal with third and ninth harmonic does not affect the quality of output voltage, because the output of a three-phase converter does not contain triplen harmonics. If only the third harmonics is injected, V_r is given by

$$V_r = 1.15\sin\omega t + 0.19\sin 3\omega t \quad (2)$$

This is same as injecting triplen harmonics to a sine wave. The line to line voltage amplitude of the fundamental component is approximately 15% more than that of a normal sinusoidal PWM.

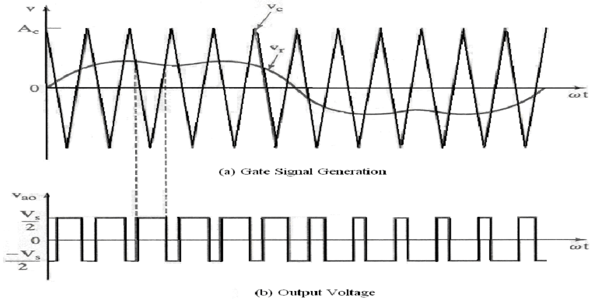


Fig.6. Modulation Waveform of SVPWM

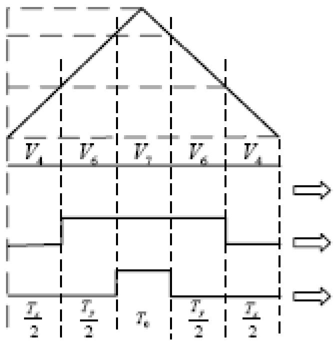


Fig 7 Switching Pattern of SVPWM

Figure 7 shows the switching pattern of the SVPWM technique. Its sequences are symmetrical too. This technique lowers the switching times. Moreover, the algorithm can be implemented easily by DSP [4].

V. SPACE VECTOR MODULATION

The SVM strategy, based on space vector representation becomes very popular due to its simplicity. In contrast to sinusoidal PWM, SVM treats the three phase quantities as a single equation known as space vector.

$$V_s = \frac{2}{3}\left\{V_a(t)+V_b(t)e^{j2\pi/3}+V_c(t)e^{j2\pi/3}\right\} \tag{3}$$

where V_a, V_b and V_c are the phase voltages. If V_a, V_b and V_c are balanced three phase sinusoidal voltage, then the locus of space vector is circular with a radius equals the amplitude of the phase voltage.

The concept of space vector is derived from the rotating field of ac machine which is used for modulating the converter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent two phase quantity either in synchronously rotating frame (or) stationary d-q frame. From this two phase component, the reference vector magnitude can be found and used for modulating the converter output. SVM treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency. This technique approximates the reference voltage V_{ref} by a combination of the eight switching patterns (V_0 to V_7). The representation of rotating vector in complex plane is as shown in figure 7.

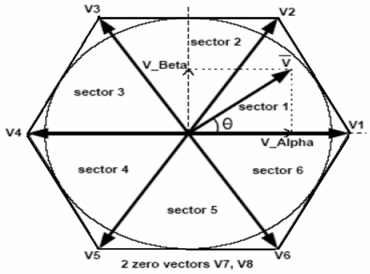


Fig 7. Representation of Rotating Vector in Complex Plane

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \tag{4}$$

$$\alpha = \tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega t = 2\pi f t, \tag{5}$$

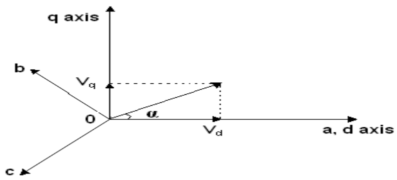


Fig.8.Voltage Space Vector and its Components in (d,q)

The voltage space vector and its components in dq plane is as shown in figure 8. By using the equations (4,5) the two phase voltages can be found.

TABLE I. SWITCHING STATES AND CORRESPONDING OUTPUTS OF A MATRIX CONVERTER

a	b	c	V_a	V_b	V_c	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0	0	0	0
1	0	0	2/3	-1/3	-1/3	1	0	-1
1	1	0	1/3	1/3	-2/3	0	1	-1
0	1	0	-1/3	2/3	-1/3	-1	1	0
0	1	1	-2/3	1/3	1/3	-1	0	1
0	0	1	-1/3	-1/3	2/3	0	-1	1
1	0	1	1/3	-2/3	1/3	1	-1	0
1	1	1	0	0	0	0	0	0

Table 1 shows the switching patterns and the magnitude of the corresponding output voltage of the switches in the matrix converter. For example, if the reference voltage is located in sector 1, voltage vectors V_1, V_2, V_0 and V_7 would be selected and applied within a sampling period.

VI. MODELING OF MATRIX CONVERTER

Implementation of the matrix converter is done using Matlab / Simulink tools. The different modulation techniques are used to provide the pulses for the matrix converter. The converter consists of nine modular H-bridge capacitor clamped switch cells, as illustrated in figure 9 connected from each input phase to output phase.

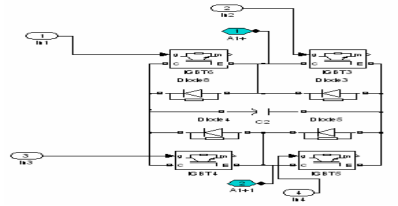


Fig.9. H-Bridge Switch Cell with Capacitor

Figure10 -12 represents the matrix converter unit with PWM, SVPWM and SVM modulation techniques respectively. The ac supply is given to the H- bridge switch cell through the filter circuit. Each switch cell consists of four IGBTs and one capacitor. The gate pluses for the switches are given through the PWM, SVPWM and SVM pulse circuits.

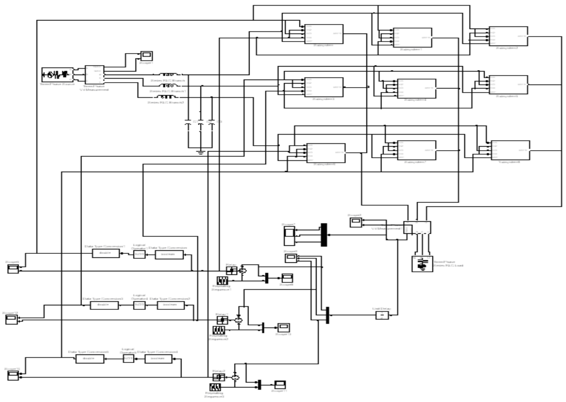


Fig.10. Matlab/Simulink Blocks for Matrix Converter Employing PWM Technique

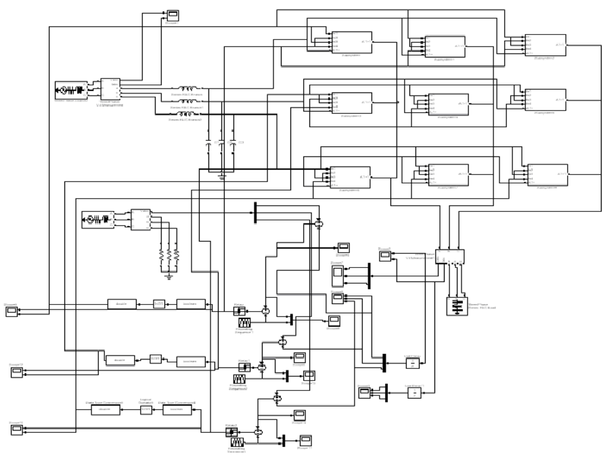


Fig.11. Matlab/Simulink Blocks for Matrix Converter Employing SVPWM Technique

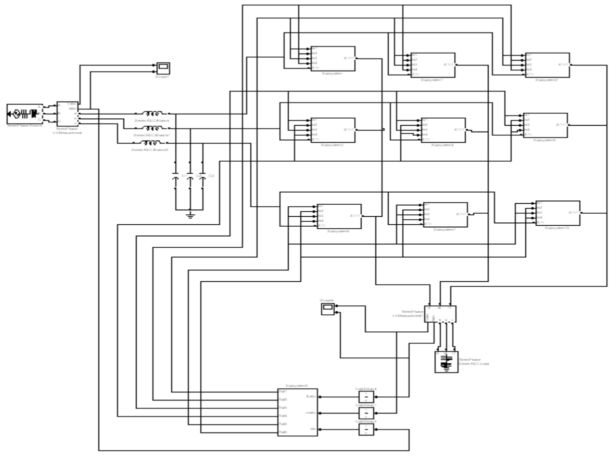
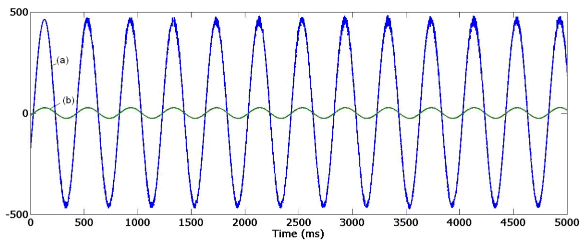


Fig.12. Matlab/Simulink Blocks for Matrix Converter Employing SVM Technique

VII. Simulation Results and Discussion

The proposed control algorithm is tested with an ideal nine-switch three phase to three phase matrix converter feeding a RL load. For this purpose, digital simulations are carried out using Matlab / Simulink software. The simulation parameters are set as; the supply frequency = 50Hz, the input voltage = 480 V, the input current = 27 A, the switching frequency = 2 kHz, resistance =20 Ω, inductance = 310 mH.



(a) Input Voltage (Volts) b) Input Current (Amps)

Fig.13. Input Voltage and Current Waveform in Steady State Condition

Figure 13 shows the input voltage and current waveform given to the matrix converter. The input voltage and current is same for all the three modulation techniques.

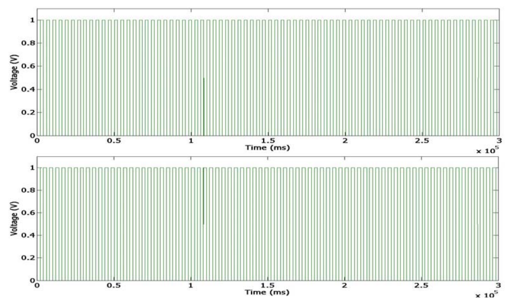


Fig.14.PWM Pulse for Upper and Lower Switches of Phase A

Figure 14 shows the PWM pulses for upper and lower switches of phase A. The pulses for the lower switches are 180^0 out of phase with upper switch pulses. Similarly, the pulses can be obtained for phase B and C with a shift of 120^0 and 240^0 respectively.

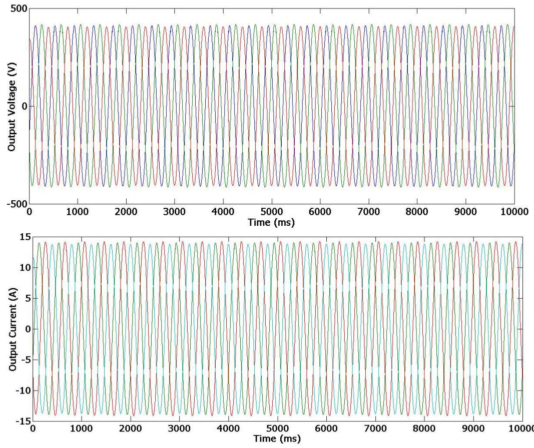


Fig. 15. Output Voltage and Current Waveform of Matrix Converter using PWM Technique

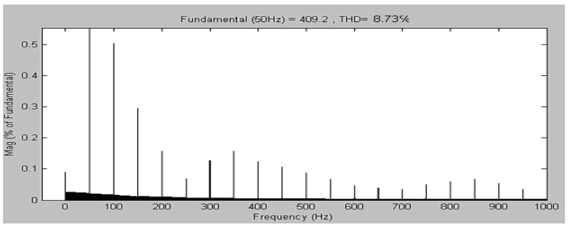


Fig.16. Harmonic Profile of Output Voltage Employing PWM Technique

Figure 15 and 16 displays steady state conditions of the simulated output voltage, current waveforms and the harmonic profile of the output voltage. It can be seen that both output voltage and current are sinusoidal. The fundamental component of the input current waveform is in phase with the input voltage i.e. the input displacement factor is close to unity likewise same in output current waveform is in phase with the output voltage.

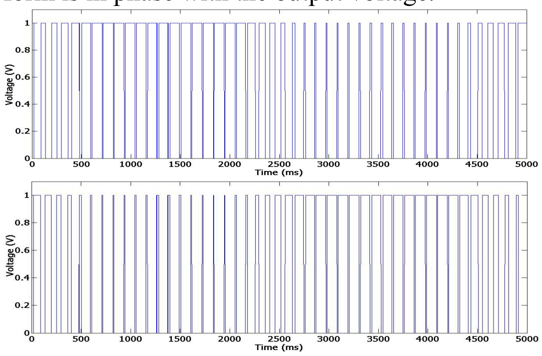
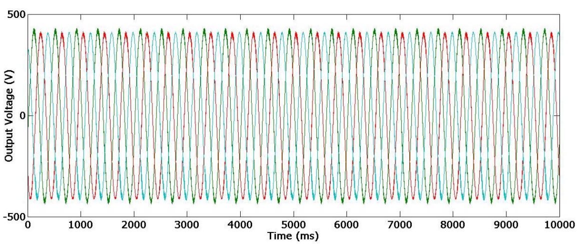


Fig. 17. SVPWM Pulse for Upper and Lower Switches of Phase A

Figure 17 shows the SVPWM pulses for upper and lower switches of phase A. Similarly Phase B and Phase C pulses can be obtained.



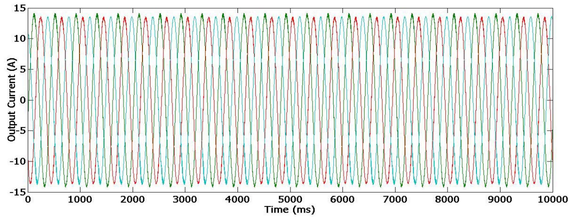


Fig.18. Output Voltage and Current Waveform of Matrix Converter using SVPWM Technique

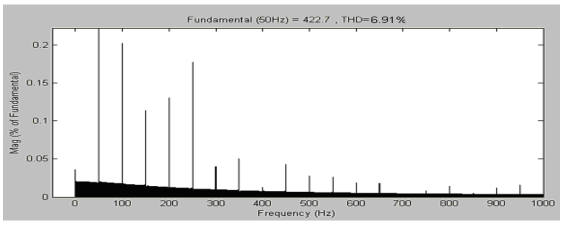


Fig.19. Harmonic Profile of Output Voltage Employing SVPWM Technique

Figure 18 and 19 displays steady state conditions of the simulated output voltage, current waveforms and the harmonic profile of the output voltage.

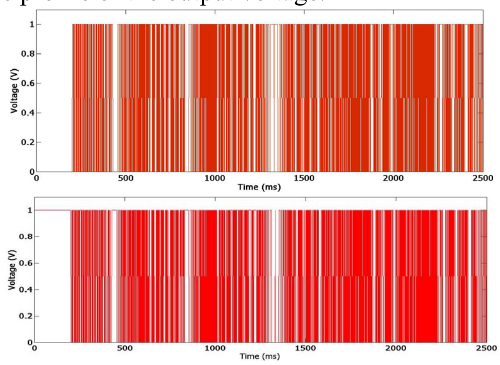


Fig. 20. SVM Pulse for Upper and Lower Switches of Phase A

Figure 20 shows the SVM pulses for upper and lower switches of phase A. Similarly for Phase B and C can be obtained.

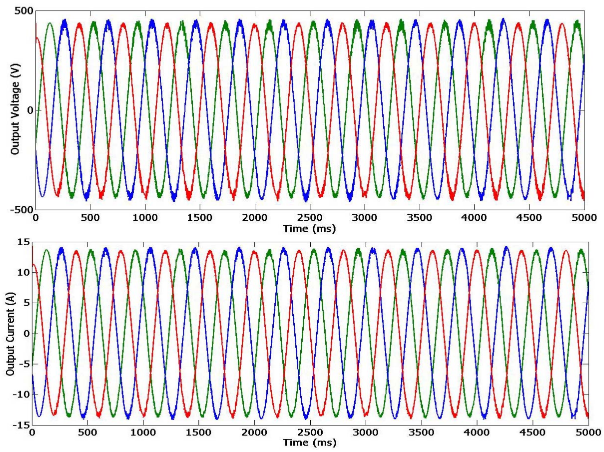


Fig.21. Output Voltage and Current Waveform of Matrix Converter using SVM Technique

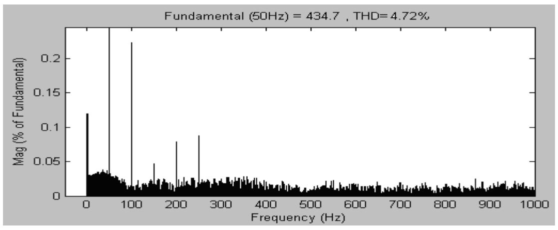


Fig.22. Harmonic Profile of Output Voltage Employing SVM Technique

Figure 21 and 22 displays the steady state conditions the simulated output voltage, current waveforms and the harmonic profile of the output voltage of matrix converter using SVM technique.

TABLE II. PERFORMANCE COMPARISON OF PWM, SVPWM AND SVM TECHNIQUE

S.No	Parameters	PWM	SVPWM	SVM
1	Output Voltage (Volts)	415	436	463
2	Output Current (Amps)	14.0	14.1	14.5
3	Voltage Transfer Ratio (%)	79	84	88
4	THD Level (%)	8.73	6.91	4.72

Table 2 shows a comparison of output voltage, current and THD of the output voltage waveform obtained by applying three different modulating techniques such as PWM, SVPWM and SVM. The detailed analysis revealed that the output line voltage varies with different schemes of these three modulation techniques. Compared to PWM and SVPWM, the SVM has high output for the same value of input. The output current in all the three techniques are almost same. SVM has slightly higher value. The simulated values prove that the input and output voltages and currents are sinusoidal. The voltage transfer capability of the matrix converter is approximately 87% for any type of modulation technique. In this analysis, the SVM modulation has higher voltage transfer ratio than other two modulation techniques. The reason for improvement in voltage transfer ratio in SVM is achieved by redistributing the null output states of the converter. The THD indicates the amount of harmonics present in the system expressed as a percentage. The lower value of THD specifies the lesser harmonics in the output waveform. The THD of the SVM is lowest under the same switching frequency compared to PWM technique and the SVPWM is in-between.

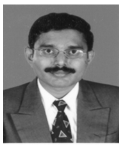
VIII. CONCLUSION

The proposed Matrix Converter with different modulation techniques was simulated using Matlab/ Simulink model blocks. PWM, SVPWM, SVM techniques were analyzed in detail and the outputs were presented. The pulses obtained from various schemes are used to control the output parameters of the matrix converter to convert a given three phase input voltage into a three phase output voltage of a desired frequency and magnitude. Simulation result exhibits that the converter has following performance features: Both the input currents and output voltages are pure sine waveforms with the harmonics around or above the switching frequency. The converter is capable of operating at unity power factor. Four quadrant operations are possible. No bulk DC link capacitors are needed, which means that a large capacity, compact converter system can be designed with better efficiency. It has the same voltage transfer ratio capacity as conventional matrix converter. Compared to PWM, the SVPWM and SVM techniques has better voltage transformation capability. SVM also has the minimum THD level at the output side and hence the reduced losses on the drives. The control algorithms are difficult to understand the switching patters in SVM. Consequently, control circuit to produce pulses is simplest in PWM technique. Although, the SVPWM technique has moderate performance, it can be implemented easily by DSP.

REFERENCES

[1] Patrick W.Wheeler, Jose Rodriguez, Jhon C. Clare, Lee paper title Empringham and Alejandro Weinstein, "Matrix Converters: A Technology Review", IEEE Transactions on Industrial Electronics, Vol.49, Issue 2, pp. 276-288, April 2002.
[2] Apap, M. Clare, J.C. Wheeler and P.W. Bradley, K.J. "Analysis and Comparison of AC-AC Matrix Converter Control Strategies", PESC03, IEEE 34th Annual conference on Power Electronics, Vol. 3, pp. 1287-1292, June 2003.
[3] Zhou and D. Wang, "Relationship Between Space-Vector Modulation and Three-Phase Carrier-Based PWM: A Comprehensive Analysis," IEEE Transactions on Industrial Electronics, Vol. 49, Issue 1, pp. 186–196, Feb. 2002.
[4] Wei-Feng Zhang and Yue-Hui Yu, "Comparison of Three SVPWM Strategies", Journal of Electronic Science and Technology of China, Vol. 5, No.3, pp. 283–287, Sep 2007.
[5] Jun-ichi Itoh, Ikuya Sato, Akihiro Odaka, Hideki Ohguchi, Hirokazu Kodachi and Naoya Eguchi, "A Novel Approach to Practical Matrix Converter Motor Drive System with Reverse Blocking IGBT", PESC04, IEEE 35th Annual Conference on Power Electronics, Vol. 3, pp. 2380-2385, June 2004.
[6] Thiwanka Wijekoon, Christian Klumpner, Pericle Zanchetta, and Patrick W. Wheeler, "Implementation of a Hybrid AC–AC Direct Power Converter with Unity Voltage Transfer", IEEE Transactions on Power Electronics, Vol. 23, Issue 4, pp. 1918–1926, July 2008.
[7] Mahmoud Hamouda, Farhat Fnaiech and Kamal Al-Haddad, "Space Vector Modulation Scheme for Dual-Matrix Converters using Safe-Commutation Strategy", IECON 2005, IEEE 31st Annual Conference on Industrial Electronics, pp.1060-1065, Nov 2005.
[8] L.Wei and T.A.Lipo, Ho Chan, "Matrix Converter Topologies with Reduced Number of Switches" PESC02, IEEE 33rd Annual conference on Power Electronics, Vol. 1, pp. 57-63, Dec 2002.
[9] Vinod Kumar, Ramesh Chand Bansal and Raghuveer Raj Joshi, "Experimental Realization of Matrix Converter based Induction Motor Drive under Various Abnormal Voltage Conditions", International Journal of Control, Automation and Systems, Vol. 6, No. 5, pp. 670-676, Oct 2008.
[10] Shimada, H. and Takeshita, T. "Matrix Converter Control using Direct AC/AC Conversion Method for Reducing Output Voltage Harmonics" APEC06, IEEE 21st Annual Conference on Applied Power Electronics, Vol. 1, pp. 7-13, March 2006.
[11] Casadei, D. Serra, G. Tani, A. and Zarri, L. "Optimal Use of Zero Vectors for Minimizing the Output Current Distortion in Matrix Converters", IEEE Transactions on Industrial Electronics, Vol. 56, Issue 2, pp. 326-336, Feb 2009.
[12] Djahbar, A. Mazari, B. and Latroch, M. "Control Strategy of Three-Phase Matrix Converter Fed Induction Motor Drive System" IEE Pulsed Power Symposium, Vol. 11, pp. 1-6, Sep 2005.

J.Karpagam, She completed her Masters degree in the specialization of Power Electronics and Drives from Anna University Chennai, India. This author became a Member (M) of IEEE. Presently she is working as Assistant Professor in the department of Electrical and Electronics Engineering at Bannari Amman Institute of Technology Tamilnadu, India and she is in this profession since 1999. Currently she is pursuing her Ph.D. in the area of matrix converter applications to AC Drives under Anna University Coimbatore. Her area of interest includes Power Electronics, Power Converters, AC & DC drives, Solid State Drives, DSP applications to Power Electronics and Wind Power Generation. So far she has published around fifteen papers in national level and International conferences.



Dr. A.Nirmal Kumar was born in Kerala, India, on May 22, 1951. He received his B.Sc.(Engg) degree in Electrical Machines from N.S.S. college of Engineering, Palakad. He completed his M.Sc.(Engg) degree in Power Electronics at Calicut University, Kerala and he received his Ph.D. in Power Electronics, Bharathiyar Univresity, Coimbatore. He has total experience of 38 years in teaching and he is currently working as a Professor and Head, EEE Department in Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu. His research interests are Power Converters, Electrical machines, Wind Power Generation and Solid State Drives.

V.Kumar Chinnaiyan, He completed his M.E. in Power Electronics and Drives from PSG College of Technology, Coimbatore, India. He has the industrial experience of around three years. At present he is working as a Assistant Professor in EEE Department at Bannari Amman Institute of Technology, Sathyamangalam and he is in this profession since 2002. Till now he completed two consultancy projects. Currently he is working in another sponsored project funded by DST, New Delhi, in the domain of multilevel inverters which is also his research topic for his Ph.D. pursuing under Anna University, Chennai. His area of interest includes Power Quality, Harmonics, DSP solution for AC and DC Drives, Embedded systems. So far he published around thirty five papers in national level and International conferences.