CARRIER FREQUENCY SELECTION OF THREE-PHASE MATRIX CONVERTER

Pawan Kumar Sen[1], Neha Sharma[2], Ankit Kumar Srivastava[2], Dinesh Kumar[2], Deependra Singh[2] and K.S. Verma[2]

[1]Department of Electrical and Electronics Engineering, K.N.I.P.S.S., Sultanpur (U.P.), India
[2] Department of Electrical Engineering, K.N.I.T, Sultanpur (U.P.), India

ABSTRACT

Analysis and design of Three-phase Matrix converter for R and R-L load is presented. In this paper Carrier (switching) frequency for matrix converter is defined on behalf of the different values of R and R-L loads. An Indirect space vector modulation (ISVM) technique is used for controlling the switching pattern of matrix converter as operating in rectifier and inverter mode.

KEYWORDS

Direct Matrix Converter, Indirect Space Vector Modulation (ISVM) ISVM, Harmonics.

1. INTRODUCTION

In General, direct converter can be identified as three distinct topological approaches. The first and simplest topology can be used to change the amplitude of an ac waveform. It is known as an ac controller. The second can be utilized if the output frequency is much lower than the input source frequency. This topology is called a Cycloconverter, and it approximates the desired output waveform by synthesizing it from pieces of the input waveform. The last is matrix converter and it is most versatile without any limits on the output frequency and amplitude. It 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, with a switch connected between each input terminal to each output terminal as shown in Fig. 1.

Among the most desirable features in power frequency changers are-

- Simple and compact power circuit.
- Generation of load voltage with arbitrary amplitude and frequency.
- Sinusoidal input and output currents.
- Operation with unity power factor for any load.
- Regeneration capability.

These ideal characteristics can be fulfilled by Matrix Converters. The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics, it has inherent bi-directional energy flow capability, and the input power factor can be fully controlled. Last but not least, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime- limited energy-storing capacitors. [2], [3].

With nine bi-directional switches the matrix converter can theoretically assume 512 (29) different switching states combinations. But not all of them can be usefully employed. Regardless to the control method used, the choice of the matrix converter switching states combinations to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted.

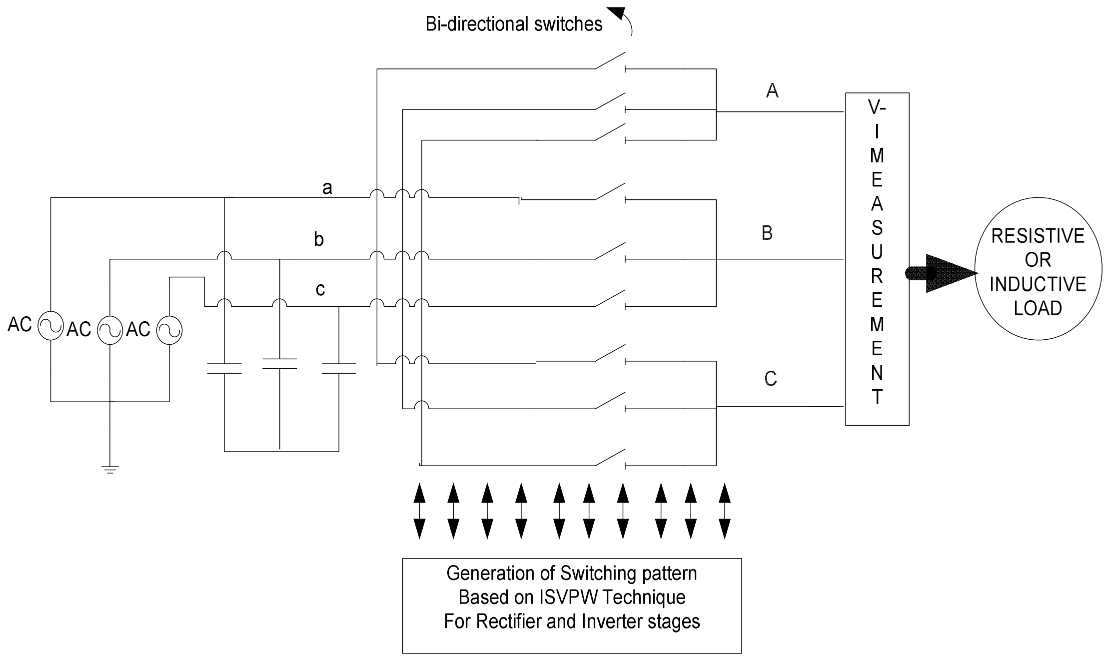

Fig 1. Three-phase matrix converter

2. MODULATION TECHNIQUE

The block diagram of the Matrix Converter is represented in Fig.1, various modulation techniques can be applied to the AC-AC matrix Converter to achieve sinusoidal output voltages and input currents. An optimal modulation strategy should minimize the input current and the output voltage harmonic distortion and device power loss [4]. The first modulator proposed for Matrix Converters, known as the Venturini modulation, employed a scalar model [5]. This model gives a maximum voltage transfer ratio of 0.5. An injection of a third harmonic of the input and output voltage was proposed in order to fit the reference output voltage in the input system envelope. This technique is used to achieve a voltage transfer ratio with a maximum value of 0.866.

2.1 Venturini's Optimum Method

This method improves the target output voltage matrix Vo(t) to include third harmonics of the input and output frequencies. The target output voltages in Equation 1 are modified in order to include the third harmonics. The maximum theoretical output to input voltage ratio, q, can be increased up to 86%, [6]

$$V_o(t) = qV_{im}\begin{bmatrix} Cos\,(\omega_0 t) \\ Cos\left(\omega_{0t} + \frac{2\pi}{3}\right) \\ Cos\left(\omega_{0t} + \frac{4\pi}{3}\right) \end{bmatrix} \tag{1}$$

The voltage transfer ratio may be defined as the output fundamental to the input fundamental ratio and its maximum value is 0.866.

$$V_o(t) = qV_{im}\begin{bmatrix} Cos(\omega_0 t) - \frac{1}{6}Cos(3\omega_0 t) + \frac{1}{2\sqrt{3}}Cos(3\omega_i t) \\ Cos\left(\omega_{0t} + \frac{2\pi}{3}\right) - \frac{1}{6}Cos(3\omega_0 t) + \frac{1}{2\sqrt{3}}Cos(3\omega_i t) \\ Cos\left(\omega_{0t} + \frac{4\pi}{3}\right) - \frac{1}{6}Cos(3\omega_0 t) + \frac{1}{2\sqrt{3}}Cos(3\omega_i t) \end{bmatrix} \quad (2)$$

2.2 Output Voltage

Each output voltage waveform is synthesized by sequential piecewise sampling of the input voltage waveforms. The sampling rate has to be set much higher than both input and output frequencies, and the duration of each sample is controlled in such a way that the average value of the output waveform within each sample period tracks the desired output waveform. In Fig. 2. the output voltage waveform of a matrix converter is shown and compared to the output waveform of a traditional voltage source inverter (VSI), [4, 5, 6].

2.3 Input Current

The input currents are directly generated by the output currents, synthesized by sequential piecewise sampling of the output current waveforms. If the switching frequency of the matrix converter is set to a value that is much higher than the input and output frequency, the input currents drawn by the converter are sinusoidal, their harmonic spectrum consists only of the fundamental desired component plus a harmonic content around the switching frequency. In Fig. 3 The input current drawn by a matrix converter for a 2 kHz switching frequency is shown.

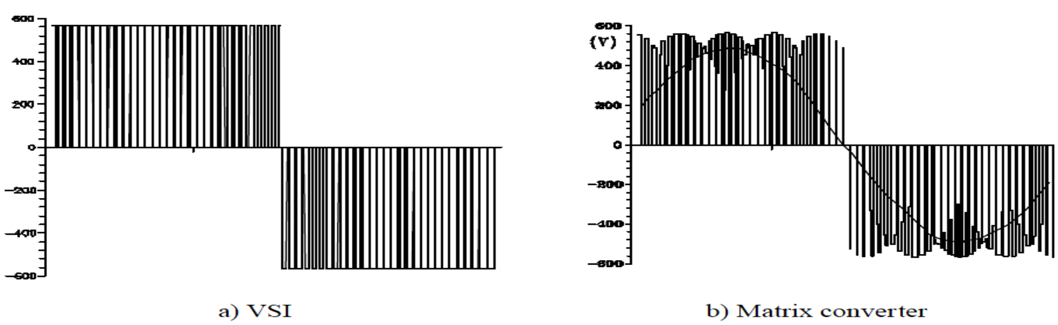

Fig 2. Output voltage waveform generated by a VSI and a matrix converter

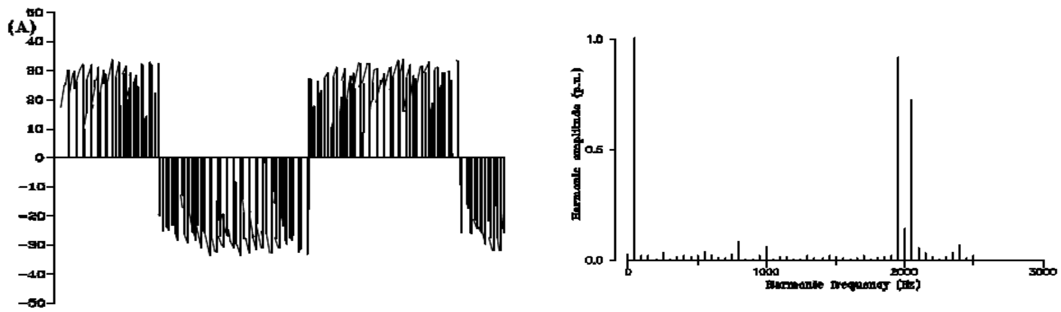

Fig 3. Matrix converter input current and harmonic spectrum. Switching frequency 2 KHz.

3. INPUT FILTER

The input filter acts as an interface between the matrix converter and the AC mains In general, the design of an input filter for static power converters operating from an ac power system has to meet three main requirements:

- Carrying out the required switching noise attenuation.
- Having a low input displacement angle between filter input voltage and current.
- Guaranteeing overall system stability, [7].

4. MAIN SIMULATION MODEL

Simulation results of three-phase to three-phase matrix converter (TPMC) are presented in the following figures. The simulation parameters are shown in Table 1. There is different simulation results of TPMC presented in this work that shows the variation of switching frequency of IGBTs. The results show that the harmonics in the output waveform goes on decreasing as we increase the switching frequency.

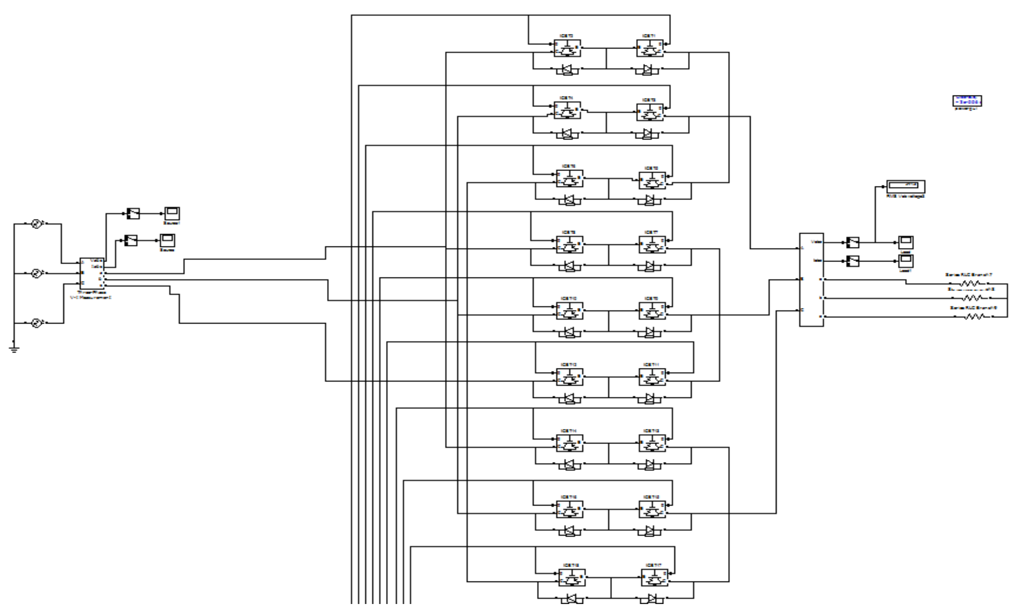

Fig 4. Main circuit model of TPMC for R load without filter.

Table 1 Simulation Parameters for TPMC with R Load

Input Source (AC)	110 Vpeak
Reference Frequency signal (fr)	60 Hz
Switching Frequency	Variable
Type of Load	Resistive
Value of Resistance	100Ω

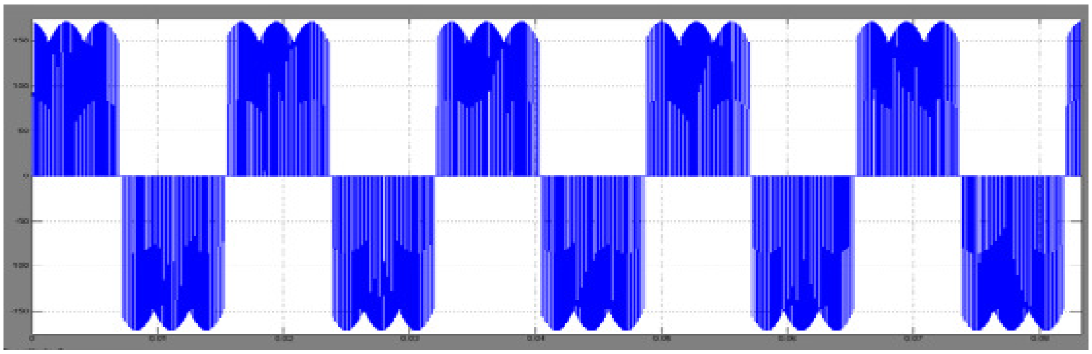

Fig. 5. Voltage waveform of TPMC for R load without LC filter

Case 1: f_c= 5 KHz

In this case the switching frequency or simply say the carrier frequency of sinusoidal pulse width modulation is taken as 5 kHz. Hence we can see that considerable amount of harmonics are present in output voltage waveforms. The output waveforms for case 1 are presented in Fig. 6-9.

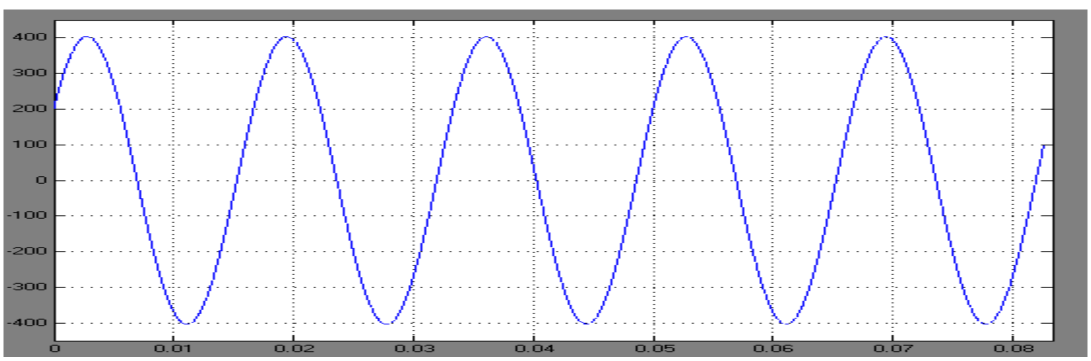

Fig.6. Input Voltage waveform of TPMC for R load with LC filter.

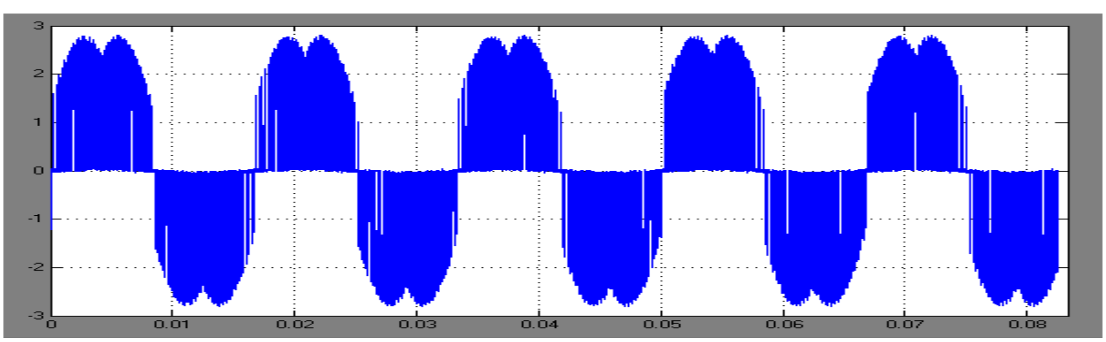

Fig.7. Input Current waveform of TPMC for R load with LC filter

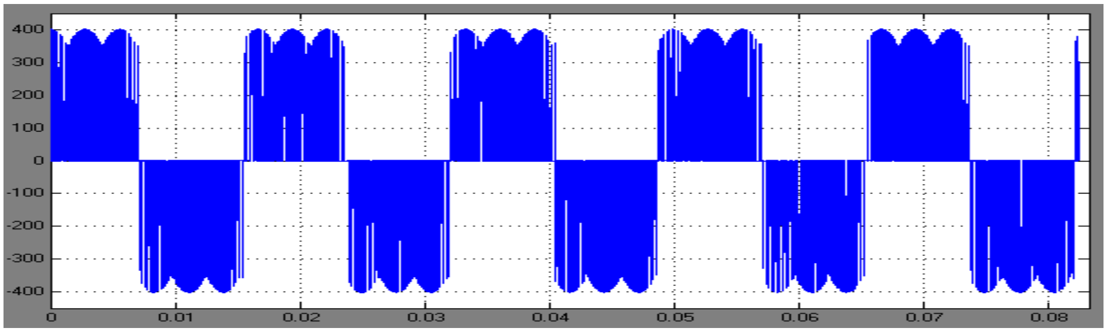

Fig.8. Output Voltage waveform of TPMC for R load with LC filter

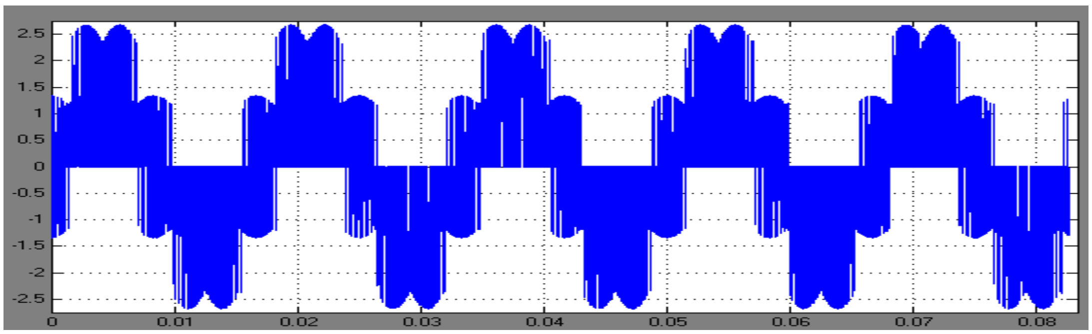

Fig.9. Output Current waveform of TPMC for R load with LC filter.

Case 1: f_c= 6 KHz

In this case the switching frequency or simply say the carrier frequency of sinusoidal pulse width modulation is taken as 6 kHz. Hence we can see that considerable amount of harmonics are present in output voltage waveforms but lesser than as in case 1. The output waveforms for case 2 are presented in Fig. 10-13.

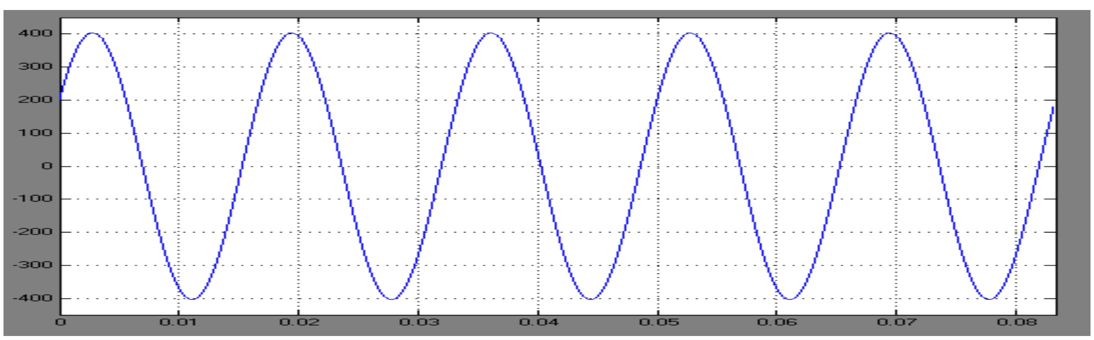

Fig.10. Input Voltage waveform of TPMC for R load with LC filter

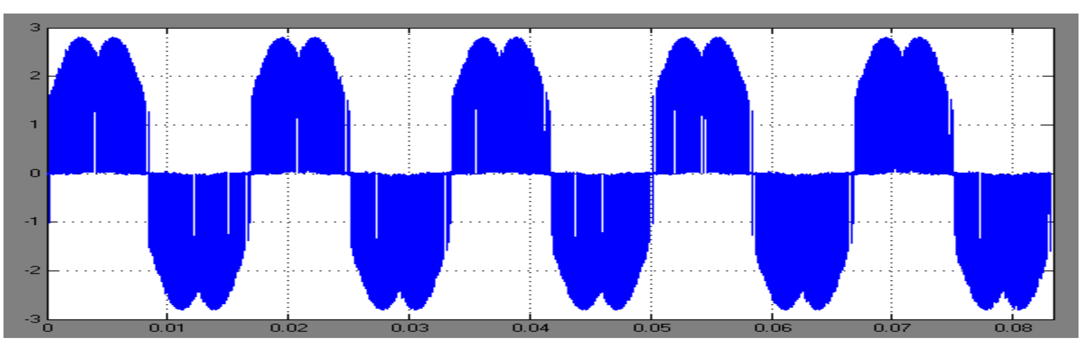

Fig.11. Input Current waveform of TPMC for R load with LC filter

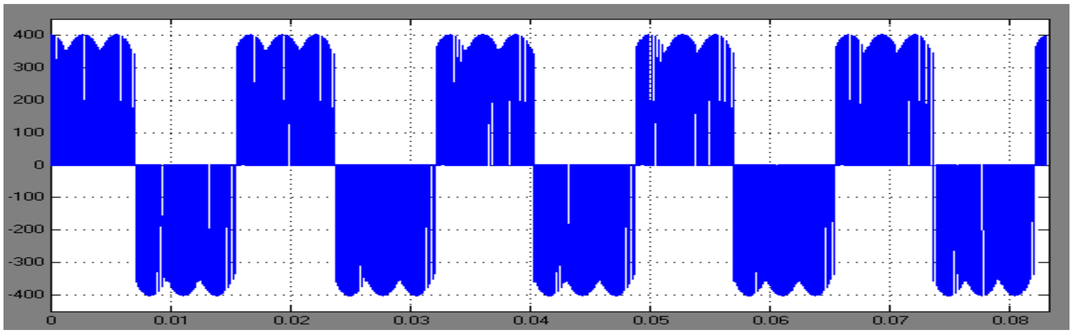

Fig.12. Output Voltage waveform of TPMC for R load with LC filter

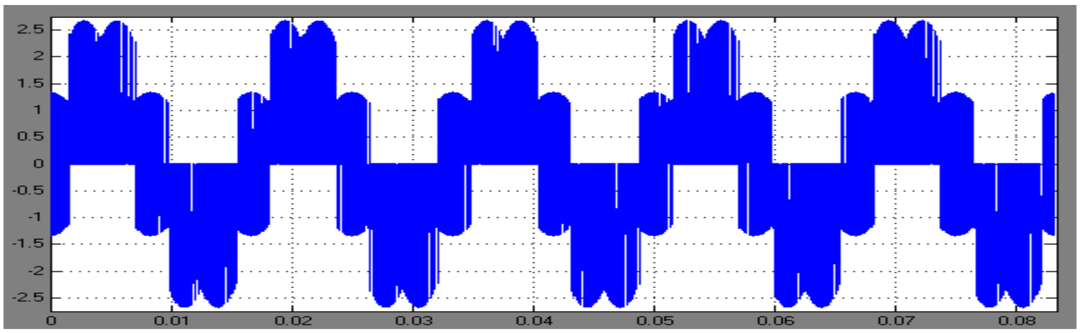

Fig.13. Output Current waveform of TPMC for R load with LC filter.

Case 1: f_c= 10 KHz

In this case the switching frequency or simply say the carrier frequency of sinusoidal pulse width modulation is taken as 10 kHz. Hence we can see that considerable amount of harmonics are present in output voltage waveforms but lesser than as in case 1. The output waveforms for case 2 are presented in fig. 14-17.

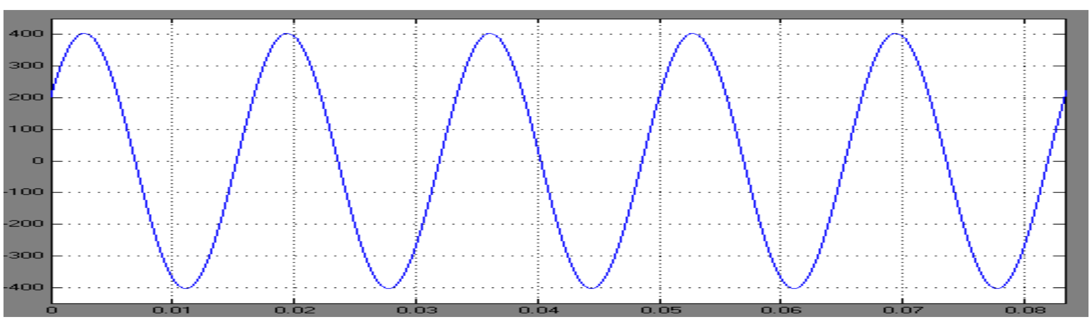

Fig.14. Input Voltage waveform of TPMC for R load with LC filter

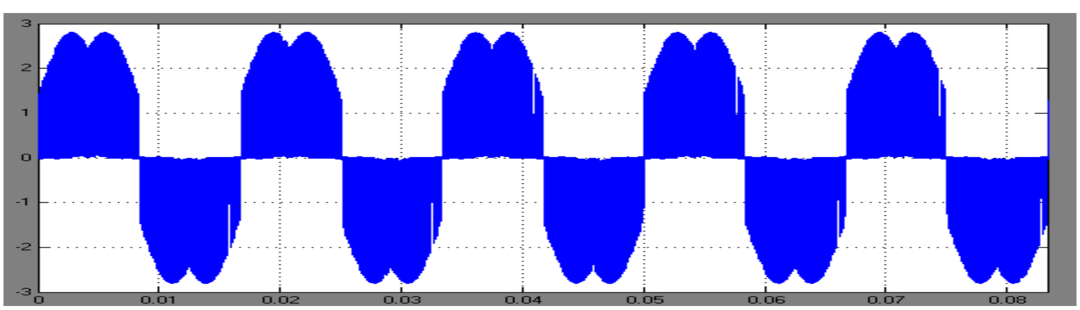

Fig.15. Input Current waveform of TPMC for R load with LC filter

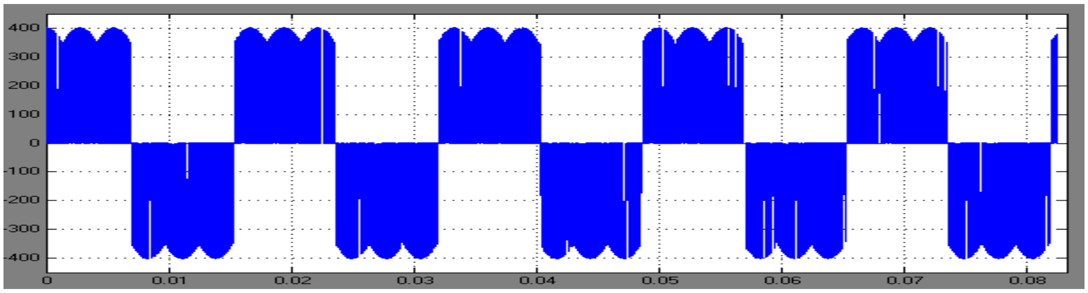

Fig.16. Output Voltage waveform of TPMC for R load with LC filter

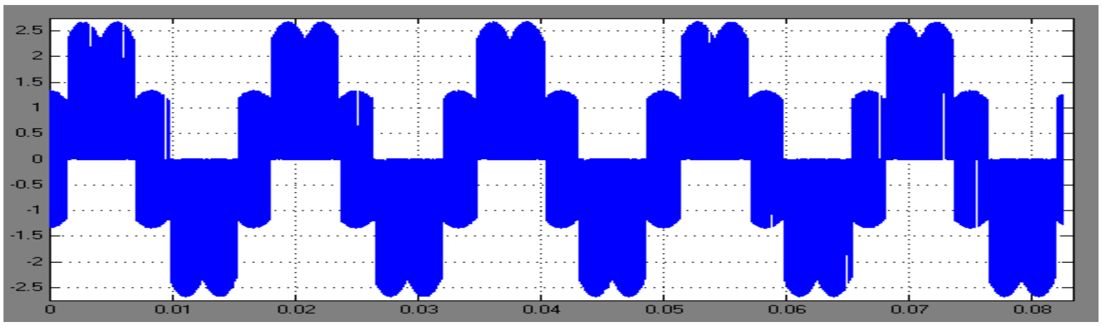

Fig.17. Output Current waveform of TPMC for R load with LC filter.

Case 1: f_c **= 20** ***KHz***

In this case the carrier frequency is taken as 20 kHz. From output waveforms it is clearly visible that the harmonics have become almost negligible. The output waveforms are presented in fig. 18-21.

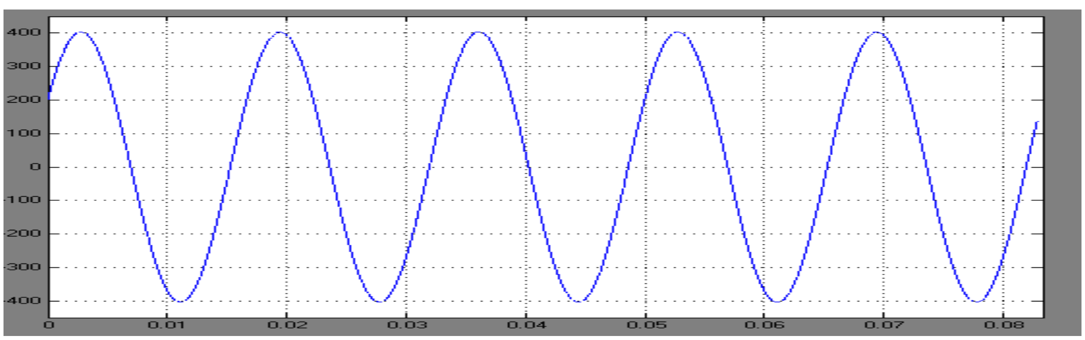

Fig.18. Input Voltage waveform of TPMC for R load with LC filter

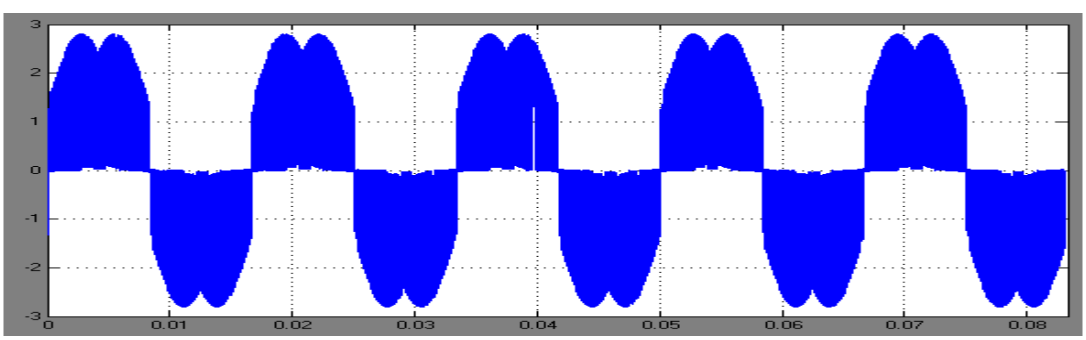

Fig.19. Input Current waveform of TPMC for R load with LC filter

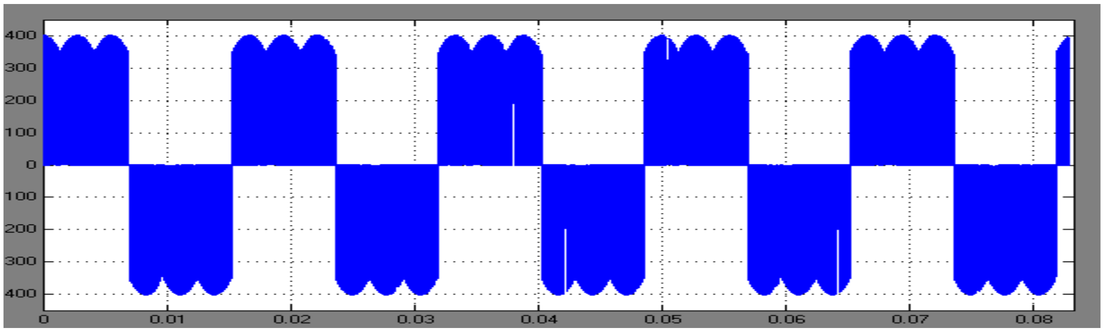

Fig.20. Output Voltage waveform of TPMC for R load with LC filter

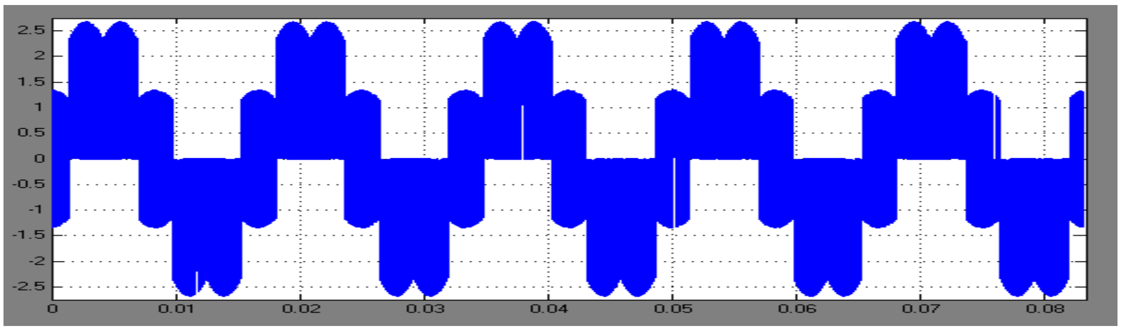

Fig.21.Output Current waveform of TPMC for R load with LC filter.

The study of all above simulation results shows that as we are increasing the switching frequency of the bi-directional switches or simply say the carrier frequency of the sinusoidal pulse width modulation, we get better results. The unnecessary harmonic contents have also been reduced. At carrier frequency of 20 kHz the results are very smooth, and the harmonic contents become almost zero.

4.2 SIMULATION RESULTS OF TPMC WITH R-L LOAD

The simulation MODEL in Fig. 4 could be used to study the behavior of the three-phase matrix converter under variety of the operating conditions, including different reference frequency and variety of load. However, the three-phase matrix converter with R-L load is also studied as shown in figure 22-33.

Case 1: $L= 0.1\ \mu H$

As discussed earlier we get the optimum result from simulation model in fig. 4 for fc=20 kHz for R Load. Now simulating the model of fig. 4 with R-L Load, taking L as a variable at fc =20 kHz. Initially the value of inductor is taken as 0.1 μH. The results are presented in fig. 22-25, shows the effect of load inductance on the input and output voltage as well as current.

Table 2 simulation parameters for three phase matrix converter with R-L load

Input Source (AC)	110 V_{peak}
Reference Frequency signal (fr)	60 Hz
Switching Frequency	3kHz
Type of Load	Resistive-Inductive (R-L)
Input filter (L)	0.0010 H
Input filter (C)	0.01118 F

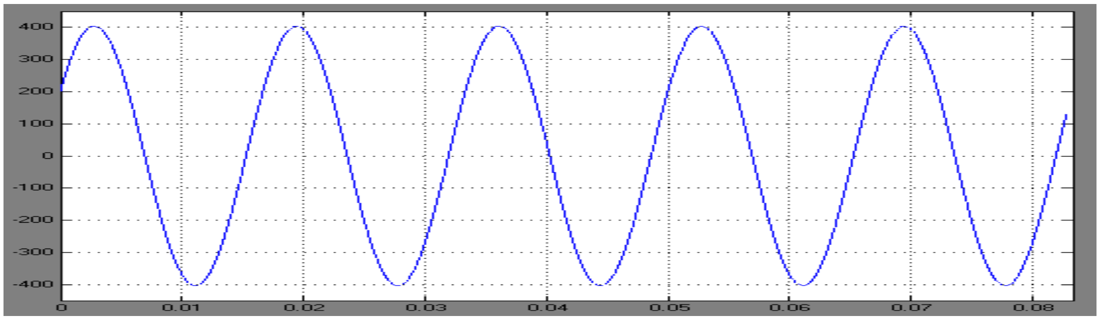

Fig.22. Input Voltage waveform of TPMC for R-L load with LC filter

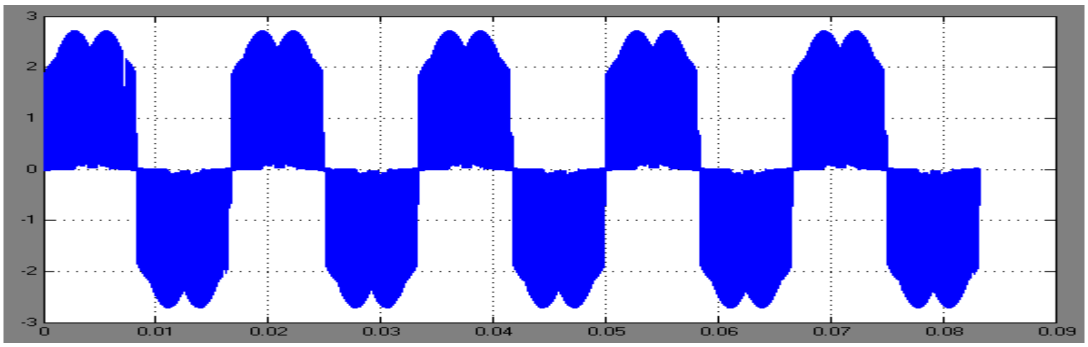

Fig.23. Input Current waveform of TPMC for R-L load with LC filter

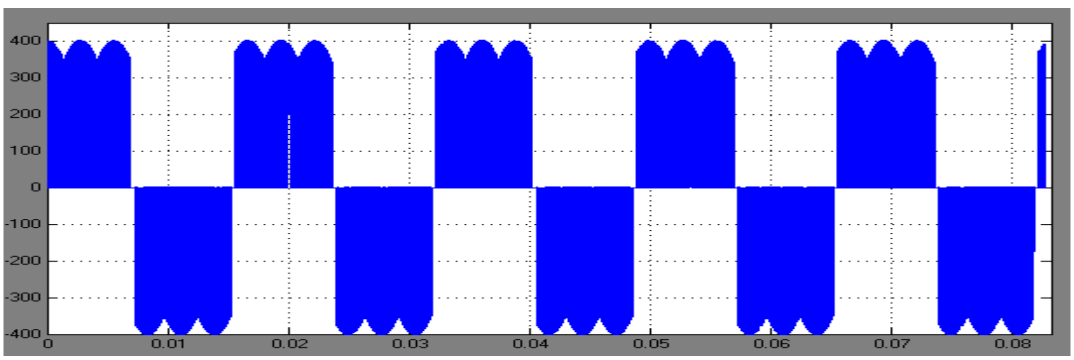

Fig.24. Output Voltage waveform of TPMC for R-L load with LC filter

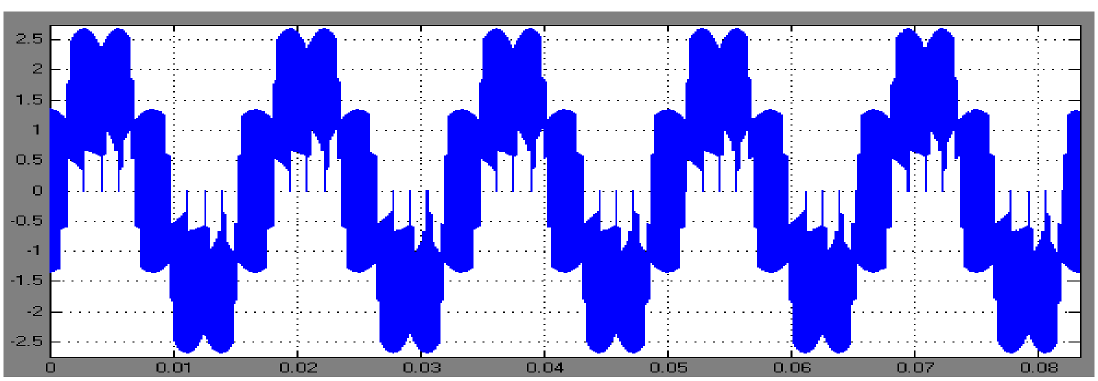

Fig.25. Output Current waveform of TPMC for R-L loads with LC filter.

Case 1: ***L*** **= 1 µ**

As discussed earlier we get the optimum result from simulation model in fig.4 for fc=20 kHz for R Load. Now simulating the model of fig. 4 with R-L Load, taking L as a variable at fc =20 kHz.

Initially the value of inductor is taken as 0.1 μH. The results are presented in fig. 22-25, shows the effect of load inductance on the input and output voltage as well as current.

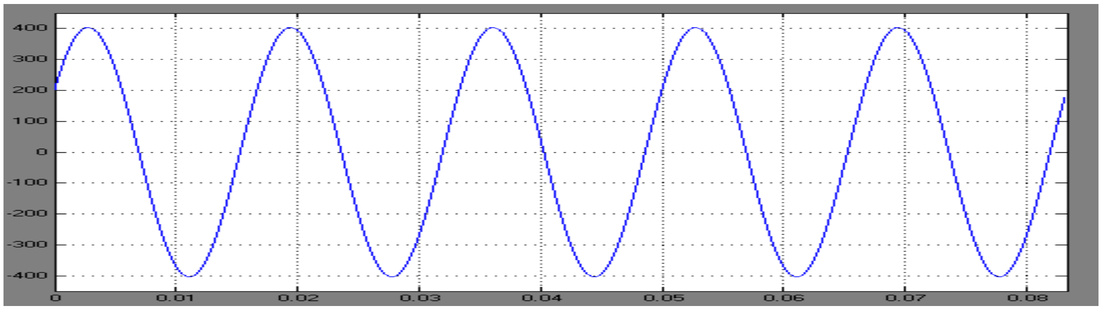

Fig.26.Input Voltage waveform of TPMC for R-L load with LC filter

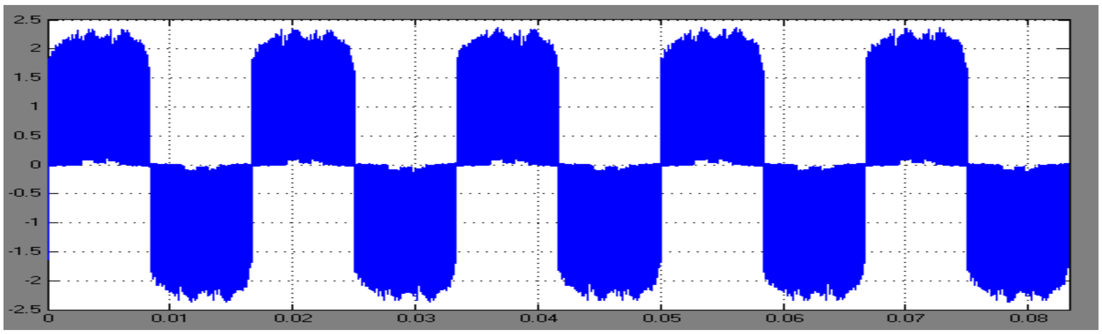

Fig.27. Input Current waveform of TPMC for R-L load with LC filter

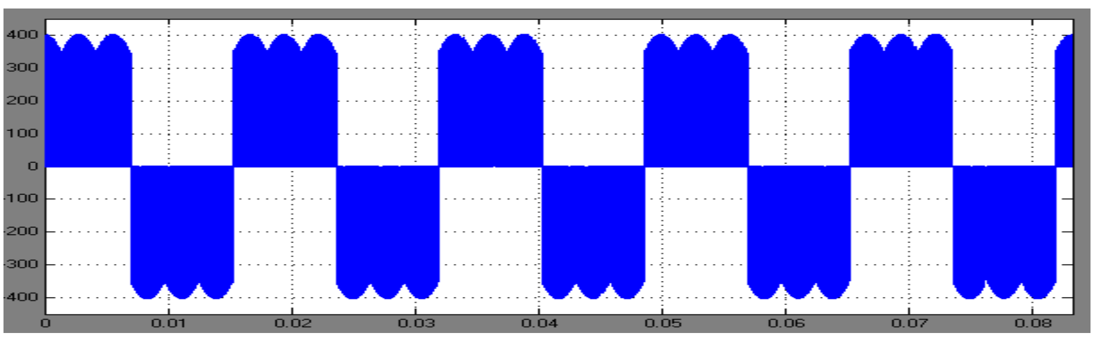

Fig.28. Output Voltage waveform of TPMC for R-L load with LC filter

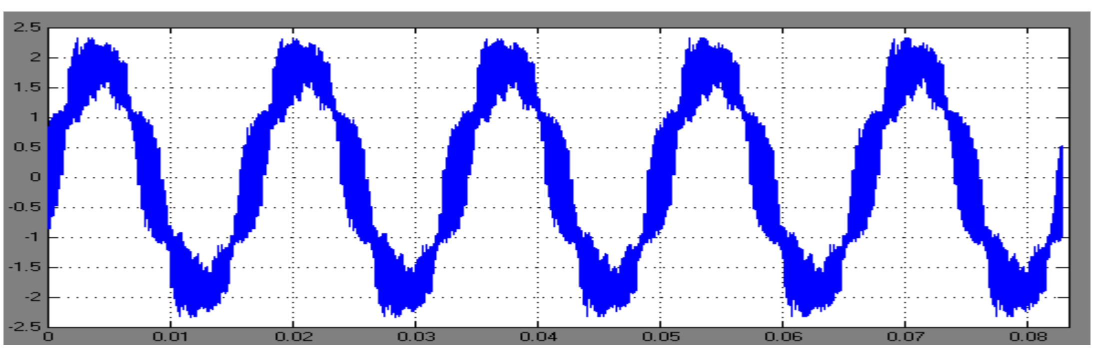

Fig.29. Output Current waveform of TPMC for R-L load with LC filter.

Case 1: ***L*= 10 μ*H***

As discussed earlier we get the optimum result from simulation model in fig. 4 for fc=20 kHz for R Load. Now simulating the model of fig. 4 with R-L Load, taking L as a variable at fc =20 kHz. Initially the value of inductor is taken as 0.1 μH. The results are presented in fig. 22-25, shows the effect of load inductance on the input and output voltage as well as current.

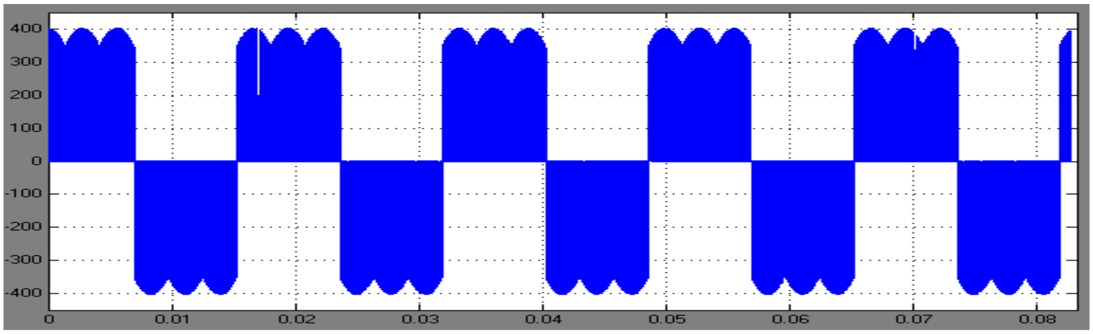

Fig.30. Output Voltage waveform of TPMC for R-L load with LC filter

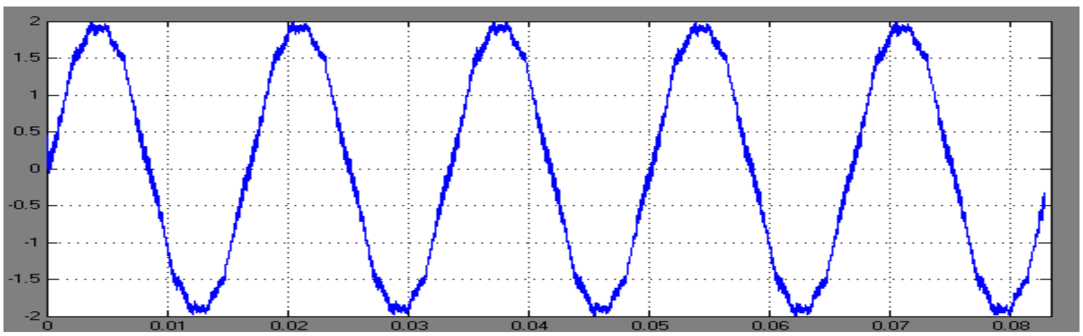

Fig.31. Output Current waveform of TPMC for R-L load with LC filter

Case 1: *L*= 100 µ*H*

As discussed earlier we get the optimum result from simulation model in fig. 4 for fc=20 kHz for R Load. Now simulating the model of fig. 4 with R-L Load, taking L as a variable at fc =20 kHz. Initially the value of inductor is taken as 0.1 µH. The results are presented in fig. 22-25, shows the effect of load inductance on the input and output voltage as well as current.

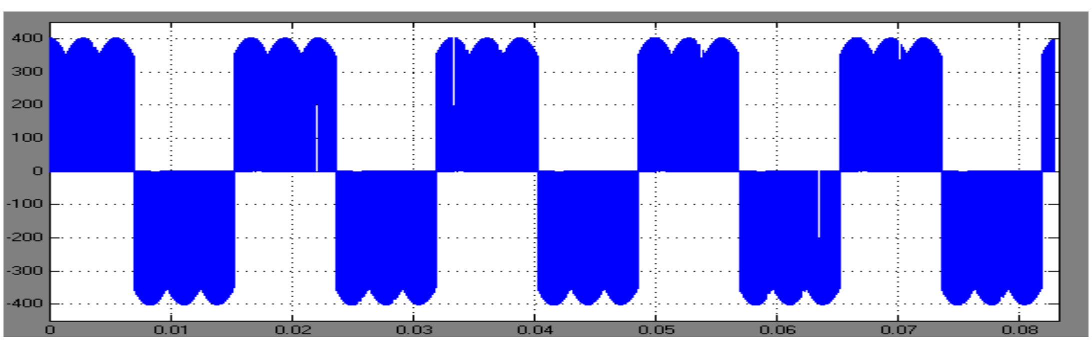

Fig.32. Output Voltage waveform of TPMC for R-L load with LC filter.

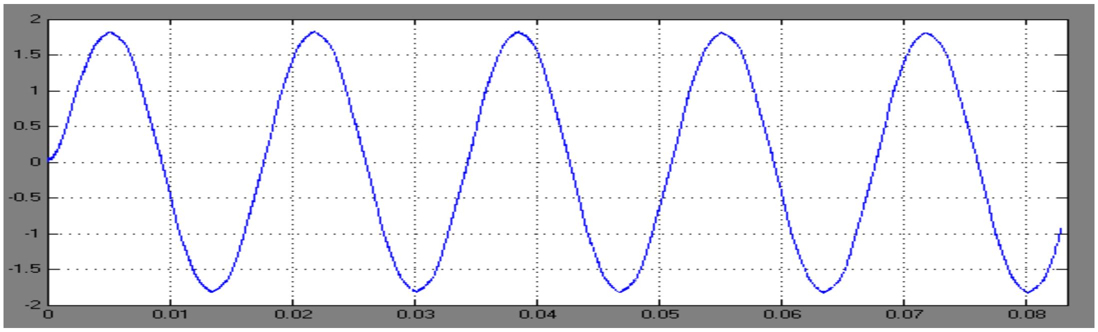

Fig.33. Output Current waveform of TPMC for R-L load with LC filter

Above results with R-L load shows that, the waveform of three-phase to three-phase matrix converter have almost negligible deviation from R load at very low value of inductance. When we are increasing the value of inductance gradually there is a very small change seen in the waveform. So the matrix converters can be used in such applications where the need of variation in the load inductance. The effect of load inductance is illustrated in fig. 22-33.

5. CONCLUSIONS

From the above simulation results it is concluded that, for the constant resistive load (R=100 ohm) if the switching frequency of the matrix converter is increased, hence the performance of matrix converter should be increased in term of reduction in harmonics contents presented in the input and output voltage waveforms. And at the higher frequency (20 kHz) of matrix converter if the inductivity of the load is increased than the output voltage waveform should be smooth and have no harmonics content. The Table 3 show the Performance Evaluation Table of Matrix Converter for R and R-L Load.

Table 3 Performance Evaluation Table of Matrix Converter for R and R-L Load

Switching Frequency	**Load**		**Effects/Performance**
	Type	**Value**	
f_c =5 kHz	Purely Resistive	100 Ω	High degree of harmonics
f_c =6 kHz	Purely Resistive	100 Ω	Harmonic content decrease
f_c =10 kHz	Purely Resistive	100 Ω	Less degree of harmonics
f_c =20 kHz	Purely Resistive	100 Ω	Harmonic contents are negligible
f_c =20 kHz	R-L Load	R=100 Ω, L=0.1µH	Smooth output waveform
f_c=20 kHz	R-L Load	R=100 Ω, L=1 µH	Smooth output waveform
f_c =20 kHz	R-L Load	R=100 Ω, L=10 µH	Smooth output waveform
f_c =20 kHz	R-L Load	R=100 Ω, L=100 µH	Smooth output waveform

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Authors:

Pawan Kumar Sen received his B.Tech degree in Electrical Engineering in 2008 U. P. Technical University Lucknow (U.P.), India. he obtained is M.Tech degree in Power Electronics and Drives in Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, (U.P.), India, affiliated to G.B. Technical University Lucknow (U.P.), India. Currently he is working as assitant professor in department of electrical and electronics engineering KNIPSS, Sultanpur(U.P.) His interests are in the areas of Microprosessor and Power Electronics and drive.

Neha Sharma received her B.Tech degree in Electrical Engineering in 2007 U. P. Technical University Lucknow (U.P.), India. Currently, she is pursuing M.Tech in Power Electronics and Drives in Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur. Her interests are in the areas of Control System and Drive.

Ankit Kumar Srivastava received his B.Tech Degree in Electrical Engineering in 2008 from the VBS Purvanchal University, Jaunpur (U.P.), India. Currently, he is pursuing M.Tech in Power Electronics and Drives in Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, (U.P.), India, affiliated to G.B. Technical University Lucknow (U.P.), India. His interests are in the area of Power Electronics and drive.

Dinesh Kumar received his B.Tech degree in Electrical Engineering in 2009 from G.B. Technical University Lucknow (U.P.), India. Currently, he is pursuing M.Tech in Power Electronics and Drives in from Kamla Nehru Institute of Technology, Sultanpur, (U.P.), India, affiliated to G.B. Technical University Lucknow (U.P.), India. His interests are in the area of Power Electronics and Control System.

Deependra Singh received the B. Tech and M.E degrees both in electrical engineering in 1997 and 1999 from Harcourt Butler Technological Institute, Kanpur, India and University of Roorkee, Roorkee, India, respectively. He obtained his Ph.D in Electrical Engineering from U.P. Technical University, Lucknow, India. Presently, He is associate professor in department of electrical engineering in Kamla Nehru Institute of Technology, Sultanpur (UP), India. His research interests are distributed generation planning and distribution system analysis.

K. S. Verma received the B. Tech and M.Tech. degrees both in electrical engineering from department of electrical engineering, Kamla Nehru Institute of Technology, Sultanpur (UP), India respectively. He obtained his Ph.D in Electrical Engineering from Indian Institute of Technology (IIT), Roorkee, Uttaranchal, India. Presently, He is professor in department of electrical engineering and also working as the Director in Kamla Nehru Institute of Technology, Sultanpur (UP), India. His research interests are FACTS, open power market, simulation and design of power systems, distributed generation planning.