MODELING AND SIMULATION OF THREE-PHASE MATRIX CONVERTER USING MATLAB

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ABSTRACT

This paper addresses about the performance of the matrix converter which is the direct AC-AC converter. Matrix converter consists of an array of controlled semi conductor switches that connects directly the three phase source to the three phase load. The gating signals for the semi–conductor switches are produced using space vector modulation for three phase matrix converter. Simulation of matrix converter feeding different loads is carried out in MATLAB/SIMULINK .The simulation results like output phase voltage, output phase current, input current, rotor speed, and electromagnetic torque at resistive, inductive and dynamic loads are presented in this paper.

Keywords: MATLAB/SIMULINK, Matrix converter, Pulse width modulation, Simulation, Space vector modulation

I INTRODUCTION

Most of all industrial applications are depended on ac to ac power conversion. The ac to ac converters are widely used in the industry application because of its ease of use and provide the output voltage and current of desired magnitude. The ac to ac converter takers takes power from one ac system and delivers it to another ac system with the waveform having different amplitude, frequency, and phase. There are two ac to ac converter i.e. indirect converters and direct converter. Indirect converter are those converters which utilize a dc link between the two ac systems and direct converters are those which provide direct conversion. Matrix converter provides the direct conversion from ac to ac. The matrix converter is a single-stage converter which has an array of p×q bidirectional power switches to connect, directly, a p -phase voltage source to a q-phase load. It does not have any DC-link circuit and does not need any large energy storage elements. It consist of nine bi-directional switches which are arranged as three sets of three so that any of the three input phases can be connected to any of the three output lines. These bi-directional switches are capable of providing fully four quadrant operation to the matrix converter and these are regarded as a key element for the operation of matrix converter.

II MODULATION TECHNIQUE

The purpose of these modulation techniques is to change the voltage transfer ratio. There are different types of Modulation techniques available which can be used for producing the gating signals. These are Alesina –Venturini

modulation technique, Scalar modulation technique, Space vector modulation technique, indirect modulation technique. The main modulation techniques which have wide applications are Venturini modulation technique and the space vector modulation technique. In this paper space vector modulation is used for producing the gating signals for three phase matrix converter.

2.1 Control Scheme For Three Phase Matrix Converter

The object of the modulation strategy is to synthesize the output voltages from the input voltages and the input currents from the output currents matrix converter can be represented by a 3 by 3 matrix form because the nine bidirectional switches can connect one input phase to one output phase directly without any intermediate energy storage elements. Therefore, the output voltages and input currents of the matrix converter can be represented by the transfer function T and the transposed T^T such as:

$$V_0 = T.V_I \tag{1}$$

$$\begin{bmatrix} V_A \\ -V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_{aA} & S_{bA} & S_{cA} \\ S_{aB} & S_{bB} & S_{cB} \\ S_{aC} & S_{bC} & S_{cC} \end{bmatrix} . \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2}$$

$$I_I = T^T.I_O \tag{3}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} S_{aA} & S_{aB} & S_{aC} \\ S_{bA} & S_{bB} & S_{bC} \\ S_{cA} & S_{cB} & S_{cC} \end{bmatrix} . \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} \tag{4}$$

Where V_a, V_b and V_c are input phase voltages, V_A, V_B and V_C are output phase voltages, I_a, I_b and I_c are input currents and I_A, I_B and I_C are output currents.

The indirect space vector modulation is gaining as a standard technique in the matrix converter modulations. Matrix converter can be considered to be equivalent to the circuit combining current source rectifier and voltage source inverter connected through virtual dc link as shown in Fig.1. Inverter stage has a standard voltage source inverter topology consisting of six switches, S_7 to S_{12} and rectifier stage has the same power topology with another six switches, S_1 to S_6.

The basic idea of the indirect modulation technique is to decouple the control of the input current and the control of the output voltage. This is done by splitting the transfer function T for the matrix converter in into the product of a rectifier and an inverter transfer function.

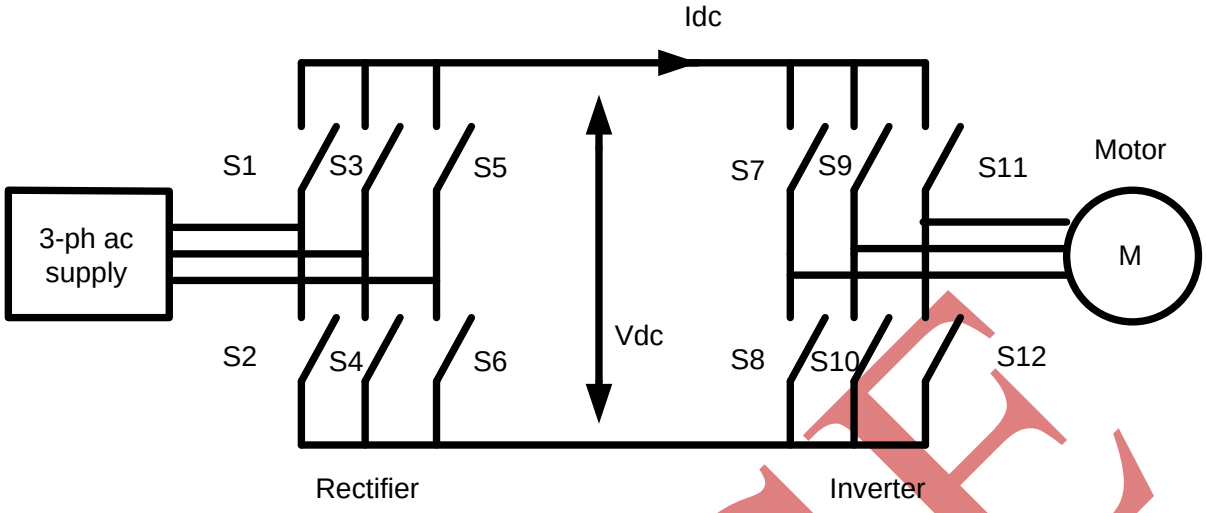

Fig. 1. Equivalent circuit for modulation

$$T = I.R \qquad (5)$$

$$\begin{bmatrix} S_{aA} & S_{bA} & S_{cA} \\ S_{aB} & S_{bB} & S_{cB} \\ S_{aC} & S_{bC} & S_{cC} \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \qquad (6)$$

TABLE-1 Switching strategy for three phase matrix converter

Group	A	B	C	V_{AB}	V_{BC}	V_{CA}	I_A	I_B	I_C	S_{Aa}	S_{Ab}	S_{Ac}	S_{Bb}	S_{Ba}	S_{Bc}	S_{Ca}	S_{Cb}	S_{Cc}
	a	b	c	V_{ab}	V_{bc}	V_{ca}	I_A	I_B	I_C	1	0	0	0	1	0	0	0	1
	a	c	b	$-V_{ca}$	$-V_{bc}$	$-V_{ab}$	I_A	I_C	I_B	1	0	0	1	0	1	0	1	0
I	b	a	c	$-V_{ab}$	$-V_{ca}$	$-V_{bc}$	I_B	I_A	I_C	0	1	0	0	0	0	0	0	1
	b	c	a	V_{bc}	V_{ca}	V_{ab}	I_C	I_A	I_B	0	1	0	1	0	1	1	0	0
	c	a	b	V_{ca}	V_{ab}	V_{bc}	I_B	I_C	I_A	0	0	1	0	0	0	0	1	0
	c	b	a	$-V_{bc}$	$-V_{ab}$	$-V_{ca}$	I_C	I_B	I_A	0	0	1	0	1	0	1	0	0
	a	c	c	$-V_{ca}$	0	V_{ca}	I_A	0	I_A	1	0	0	0	0	1	0	0	1
	b	c	c	V_{bc}	0	$-V_{bc}$	0	I_A	I_A	0	1	0	0	0	1	0	0	1
II-A	b	a	a	$-V_{ab}$	0	V_{ab}	I_A	I_A	0	0	1	0	1	0	0	1	0	0
	c	a	a	V_{ca}	0	$-V_{ca}$	I_A	0	I_A	0	0	1	1	0	0	1	0	0
	c	b	b	$-V_{bc}$	0	V_{bc}	0	I_A	I_A	0	0	1	0	1	0	0	1	0
	a	b	b	V_{ab}	0	$-V_{ab}$	I_A	I_A	0	1	0	0	0	1	0	0	1	0

	c	a	c	V_{ca}	$-V_{ca}$	0	I_B	0	I_B	0	0	1	1	0	0	0	0	1
	c	b	c	$-V_{bc}$	V_{bc}	0	0	I_B	0	0	0	1	0	1	0	0	0	1
II-B	a	b	a	V_{ab}	$-V_{ab}$	0	I_B	I_B	I_B	1	0	0	0	1	0	1	0	0
	a	c	a	$-V_{ca}$	V_{ca}	0	I_B	0	I_B	1	0	0	0	0	1	1	0	0
	b	c	b	V_{bc}	$-V_{bc}$	0	0	I_B	I_B	0	1	0	1	0	1	0	1	0
	b	a	b	$-V_{ab}$	V_{ab}	0	I_B	I_B	0	0	1	0	0	0	0	0	1	0
	c	c	a	0	V_{ca}	$-V_{ca}$	I_C	0	I_C	0	0	1	0	0	1	1	0	0
	c	c	b	0	$-V_{bc}$	V_{bc}	0	I_C	I_C	0	0	1	0	0	1	0	1	0
II-C	a	a	b	0	V_{ab}	$-V_{ab}$	I_C	I_C	0	1	0	0	1	0	0	0	1	1
	a	a	c	0	$-V_{ca}$	V_{ca}	I_C	0	I_C	1	0	0	1	0	0	0	0	1
	b	b	c	0	V_{bc}	$-V_{bc}$	0	I_C	I_C	0	1	0	0	1	0	1	0	0
	b	b	a	0	$-V_{ab}$	V_{ab}	I_C	I_C	0	0	1	0	0	1	0	0	0	0
	a	a	a	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0
III	b	b	b	0	0	0	0	0	0	0	1	0	0	1		0	1	0
	c	c	c	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1

Where the matrix I is the inverter transfer function and the matrix R is the rectifier transfer function. This way to model the matrix converter provides the basis to regard the matrix converter as a back-to back PWM converter without any dc-link energy storage.

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_7 & S_8 \\ S_9 & S_{10} \\ S_{11} & S_{12} \end{bmatrix} \begin{bmatrix} S_1 & S_3 & S_5 \\ S_2 & S_4 & S_6 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (7)$$

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_7 S_1 + S_8 S_2 & S_7 S_3 + S_8 S_4 & S_7 S_5 + S_8 S_6 \\ S_9 S_1 + S_{10} S_2 & S_9 S_3 + S_{10} S_4 & S_9 S_5 + S_{10} S_6 \\ S_{11} S_1 + S_{12} S_2 & S_{11} S_3 + S_{12} S_4 & S_{11} S_5 + S_{12} S_6 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (8)$$

The above transfer matrix exhibits that the output phases are compounded by the product and sum of the input phases through inverter switches S7 to S12 and rectifier switches S1 to S6. Therefore the indirect modulation technique enables well-known space vector PWM to be applied for a rectifier as well as an inverter stage.

III SIMULATION RESULTS

The system consists of a three-phase matrix converter constructed from nine back-to-back IGBT switches. The Matrix converter is supplied by an ideal 400V, 50Hz three-phase source and drives a static resistive load and inductive load. The switching algorithm is based on an indirect space-vector modulation in which it considers the Matrix converter as a rectifier and inverter connected via a DC link with no energy storage. Indirect space-vector modulation allows direct control of input current and output voltage and hence allows the power factor of the source to be controlled. The simulation is carried out in MATLAB/Simulink environment.

Fig. 2 shows the simulink model for the three phase matrix converter. It consists of nine bidirectional switches of IGBT's. With proper gating signal to the gate terminal of the IGBT'S and with proper control of operation output voltage will be generated across the load.

3.1 With R Load

Fig. 3 shows the input voltage for phase a is supplied to the matrix converter and further waveforms shows the simulation results obtained for the R load for the matrix converter. Fig. 4 shows the output voltage for phase 'a' Fig. 5 shows the output current for phase 'a' and Fig. 6 shows the output voltage and output current for three phases.

3.2 With RL Load

Fig. 7 shows the input voltage for phase 'a' which is supplied to the matrix converter and further waveforms shows the simulation results obtained for the RL load for the matrix converter. Fig. 8 shows the output voltage for phase 'a' Fig. 9 shows the output current for phase 'a' and Fig.. 10 shows the output voltage and output current for three phases.

3.3 With Dynamic Load (3-ph Induction Motor load of 4kW)

Figures given below are simulation results for the induction motor which is connected as a load to the matrix converter. The induction motor is supplied by the matrix converter. Fig. 11 shows the rotor speed of the induction motor. By proper controlling of the matrix converter the speed of the induction motor can be controlled. Fig. 12 shows the electromagnetic torque for the electromagnetic torque. It can be seen that when electromagnetic and load torque becomes equal then the speed of the rotor becomes constant. Fig. 13 shows the input supply voltage for phase a. Fig.14 shows the output voltage for phase 'a' and from Fig. 13 and Fig. 14 comparison between the input and output voltage can be seen. Fig. 15 shows the output current for phase a. Fig. 16 shows the three phase output current and voltage Fig. 17 shows the output current for the single phase and three phases. Fig. 18 shows the output voltage and output current for all phases individually.

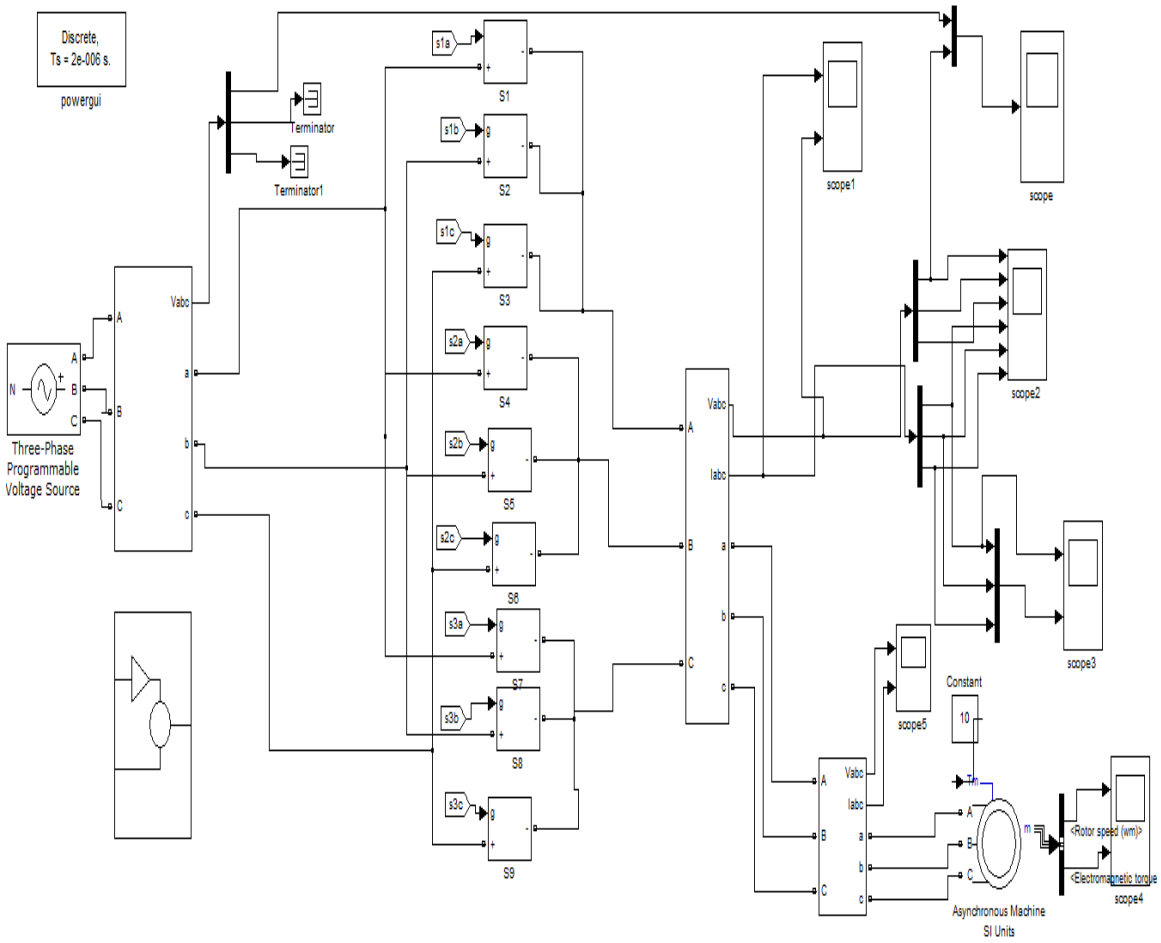

Fig. 2 Simulink Model For Three Phase Matrix Converter

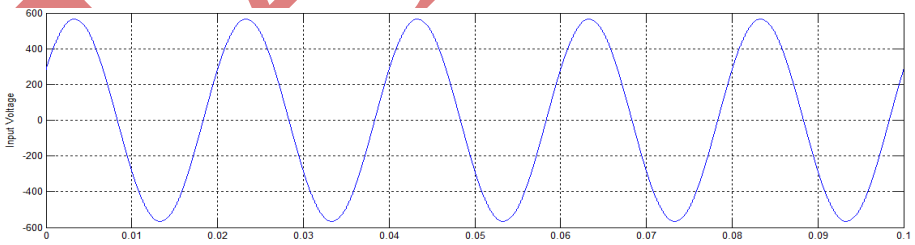

Fig. 3 Input Voltages for Phase 'a' For R Load

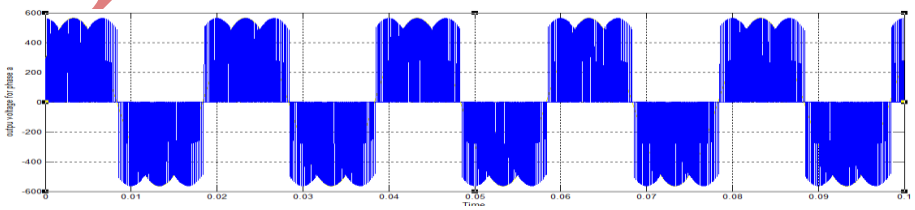

Fig 4 Output Voltage Waveform for Phase 'a' For R Load

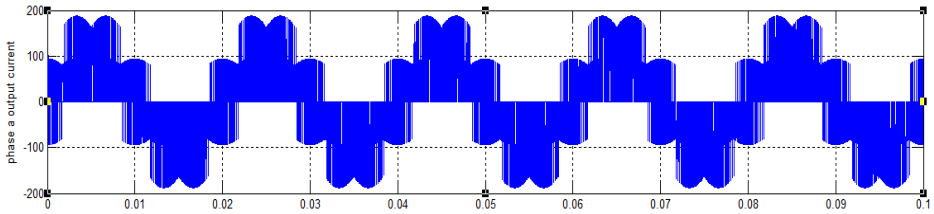

Fig 5 Output Current Wave for R Load

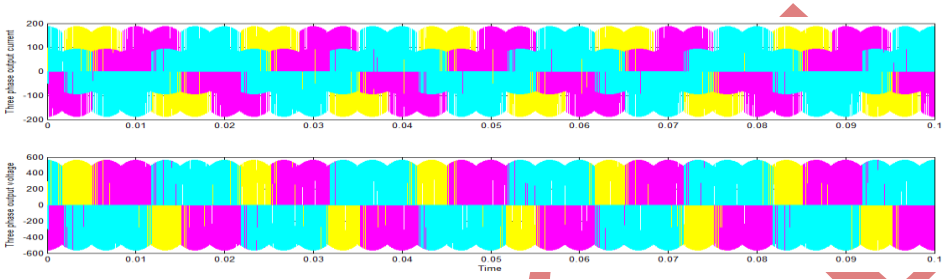

Fig 6 Three Phase Output Current and Voltage for R Load

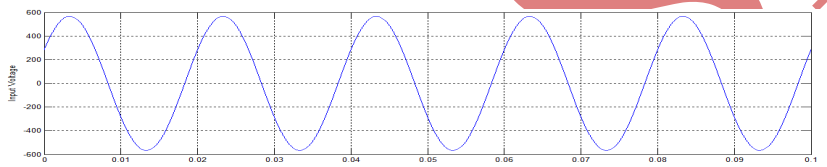

Fig 7 Input voltage for Phase a for RL load

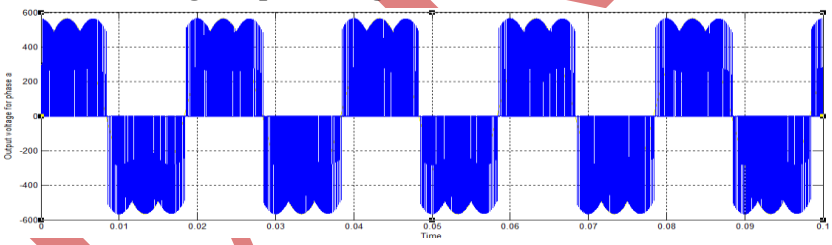

Fig. 8 Output voltage for phase a for RL load

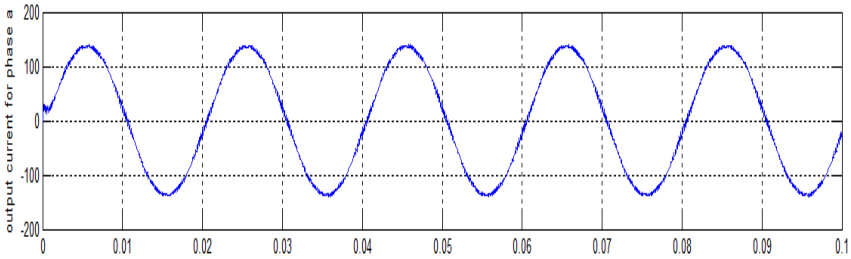

Fig. 9 Output current waveform for Phase 'a' for RL load

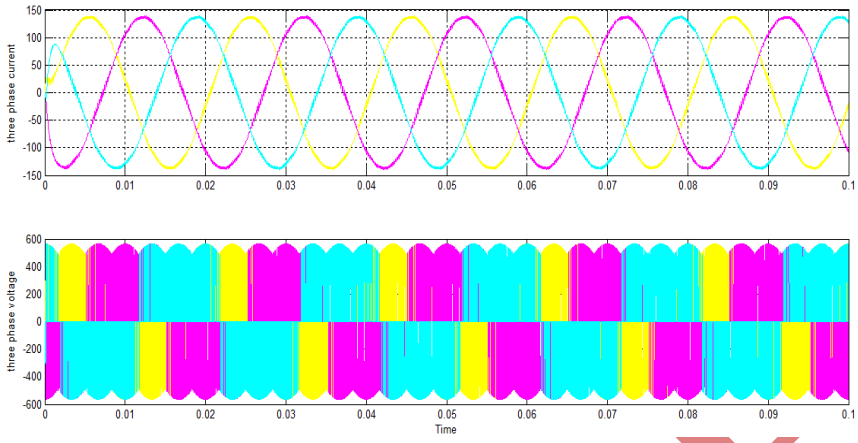

Fig 10 Three Phase Output Current and Voltage Waveform for RL Load

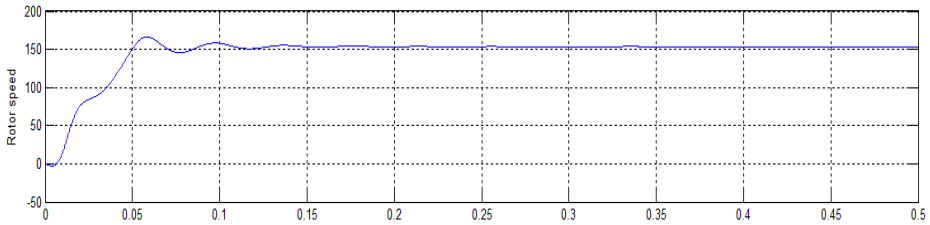

Fig 11 Rotor Speed

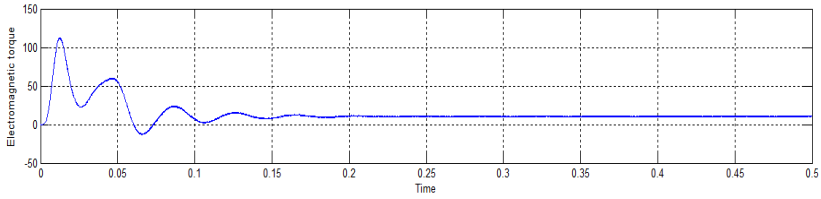

Fig 12 Electromagnetic torque

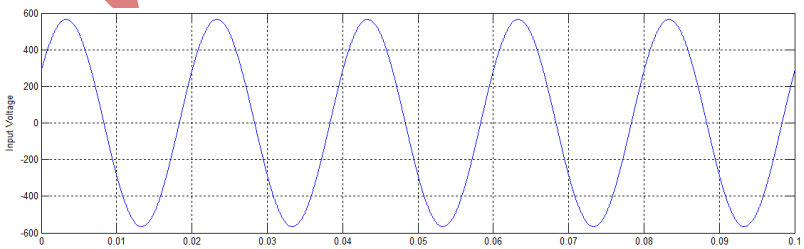

Fig. 13 Input supply voltage for phase 'a'

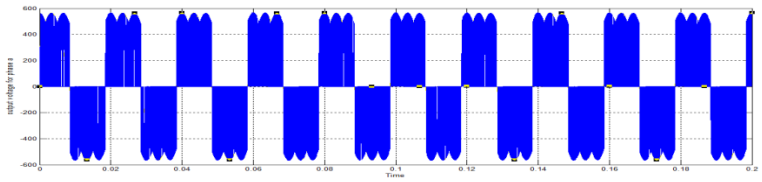

Fig. 14 Output Voltage for Phase 'a'

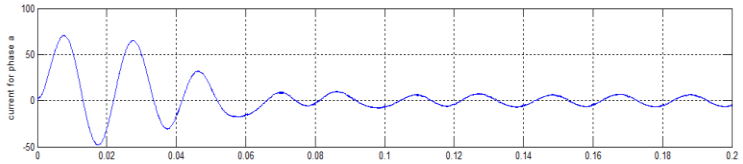

Fig. 15 Phase 'a' Output Current for Motor

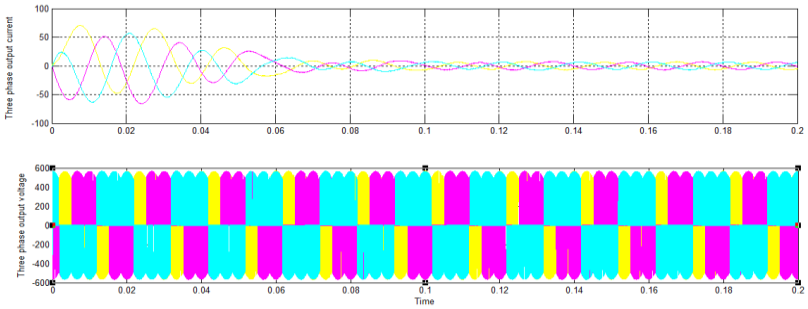

Fig. 16 Three Phase Output Current and Voltage Waveform For Motor

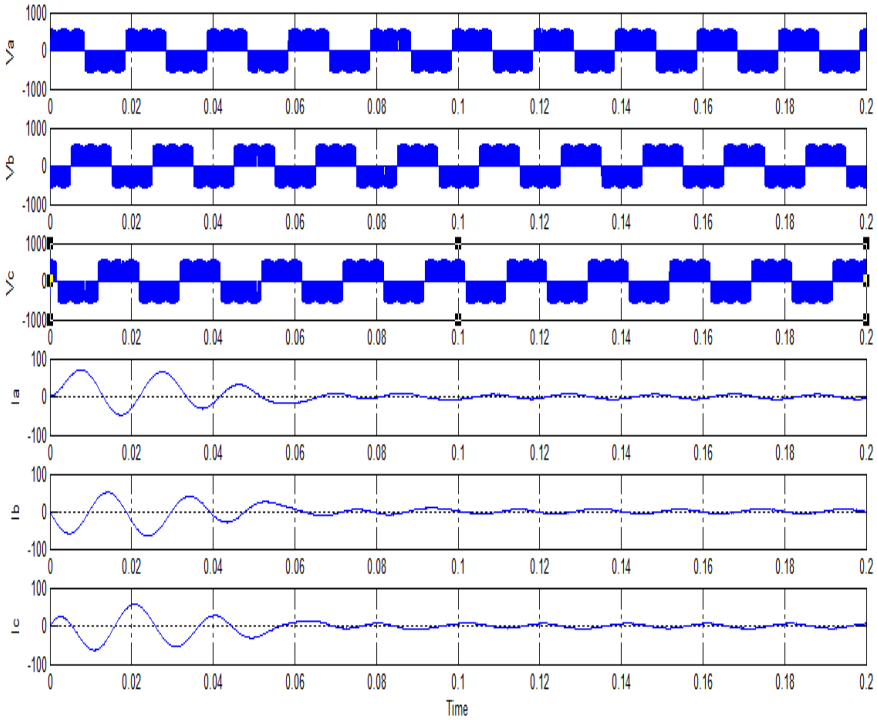

Fig 18 Output current and voltage of all phases for motor

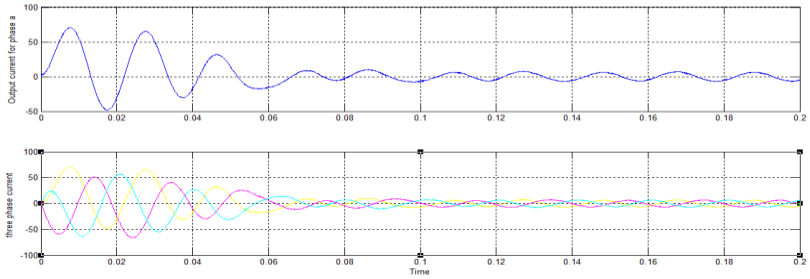

Fig 17 Single (for phase a) and Three phase output current for motor

The simulation for the resistive and inductive load is being done in 0.1 seconds and for the motor the simulation is being done in 0.5 seconds for rotor speed and electromagnetic torque. For output current and voltage of matrix converter with motor connected as a load simulation is done in 0.1 second.

IV CONCLUSION

Simulation model of three phase matrix converter fed induction motor drive and different passive loads are presented. As the matrix converter is a single stage power conversion device, it provides tremendous interest in industrial as well as in domestic application where the variable frequency and variable speed is needed. It is concluded that with the variation of load torque of induction motor and carrier frequency of matrix converter, the output performance of motor can be evaluated.

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