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Modeling and Simulation of Space Vector Modulated Matrix Converter fed Induction Motor

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ABSTRACT

Matrix Converters (MC) are compact voltage source converters capable of providing variable voltage with variable frequency as the output. Compared with traditional topologies the MCs do not require an intermediate dc link and provides sinusoidal output waveform with minimum higher order harmonics. To yield higher RMS O/P voltage, it was proposed to use Space Vector Modulation (SVM) algorithm for the voltage control of converter. The time arc information of the supply voltages and the desired output frequency were used to identify the sectors of the SVM technique, to generate the pulses of desired duration. This algorithm used a simpler method than the other algorithms to control the input power factor. In addition, it has lower switching losses and easy implementation. Simulation had been implemented for various output frequencies at unity input power factor. The simulation results of output voltage waveforms were presented with their spectra.

1. INTRODUCTION

The matrix converter was the most common converter-type in the family of AC to AC direct converters. While, the matrix converter fulfilled the requirements to provide a sinusoidal voltage at the load side, it was also possible to adjust the unity power factor on the mains side under certain conditions. Since there was no d.c.-link as in common converters, the matrix converter could be built as a full-silicon structure. However, a mains filter was necessary to smooth the pulsed currents on the input side of the matrix converter. Using a sufficiently high pulse frequency, the output voltage and input current both were shaped sinusoidal.

The Figure 1 shows the Matrix Converter of three phase Induction motor. By using Space Vector Modulation (SVM) switching technique in matrix converter for the three phase AC to AC source the output had been connected to the three phase Induction motor.

In this paper, the authors proposed a variable speed control by using variable frequency. The simulation study of the induction motor performance and total harmonic distortions (THD) in the matrix converter output were obtained.

The matrix converter could comply with four quadrants of motor operations, while generating no higher harmonics in the three-phase a.c. power supply. Compared with conventional drives, there was potential for reduction in cost of manufacture, maintenance, and increased power/weight and power/volume ratios. The circuit was inherently capable of bi-directional power flow and also offered virtually sinusoidal input current, without the harmonics usually associated with present commercial inverters. The physical realization of the matrix converter was not straightforward, due to the fact that there were no freewheeling paths. In addition, the number of devices in the power circuit was high compared with that in the inverter (for instance 18 switches and 18 diodes).

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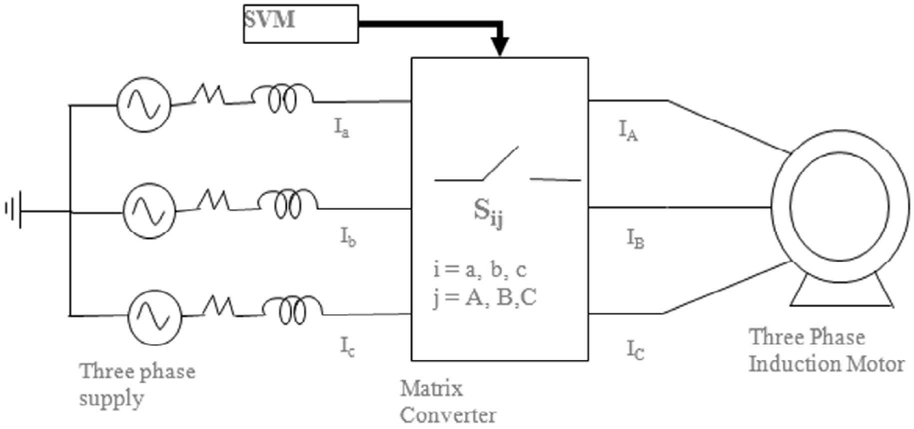


Figure 1: Matrix converter of three phase induction motor

2. PRINCIPLE OF THE MATRIX CONVERTER

An arbitrary number of input lines could be connected to an arbitrary number of outputs directly using bidirectional semiconductor switches. The multiple conversion stages and energy storage components of conventional inverter and cyclo-converter circuits could be replaced by one switching matrix. With ideal switches the matrix was subjected to power invariance so that the instantaneous input power always be equal to the instantaneous output power. The numbers of input and output phases did not have to be equal so that rectification, inversion and frequency conversion were all realizable. The phase angles between the voltages and currents at the input could be controlled to give unity displacement factor for any loads. Both sides of the matrix could not be voltage sources simultaneously since that would involve the direct connection of unequal voltages. If the input was the voltage source, then the output would be the current source, and vice versa. The basic requirement is that the switching function would not short-circuit the voltage sources or open-circuit the current sources.

3. MATRIX CONVERTER CIRCUIT

The basic circuit of a three-phase-to-three-phase matrix converter is shown in figure2 consists of three-phase groups. Each of the nine switches could either block or conduct the current in both directions thus allowing any of the output phases to be connected to any of the input phases.

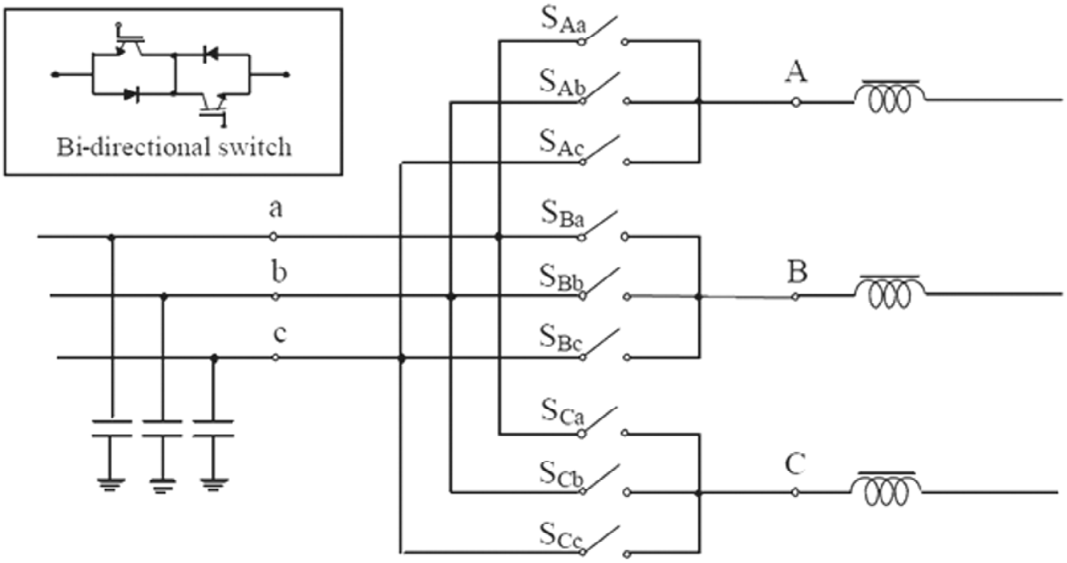


Figure 2: Matrix Converter Schematic Block Diagram Representation

Two Insulated Gate Bipolar Transistors (IGBTs) were connected using a common collector configuration. Since an IGBT does not have reverse blocking capability, two fast recovery diodes were connected in series, each in inverse parallel across an IGBT, to sustain a voltage of either polarity when both IGBTs were switched off. Independent control of the positive and negative currents could be obtained that permits safe use of commutation technique.

3. SPACE VECTOR MODULATION CONTROL METHOD

The Space Vector Modulation technique constructed the desired sinusoidal output three-phase voltage by selecting the valid switching states of a three phase matrix converter and calculating their corresponding on-time durations. The Space Vector algorithm was based on the representation of the three phase input current and three phase output line voltages on the space vector plane.

3.1. Space Vector Representation Of Three-Phase Variables

For a balanced three-phase sinusoidal system the instantaneous voltages were expressed as

$$\begin{bmatrix} V_{AB}(t) \\ V_{BC}(t) \\ V_{CA}(t) \end{bmatrix} = V_{0l} \begin{bmatrix} \cos \omega_0 t \\ \cos(\omega_0 t - 120) \\ \cos(\omega_0 t - 240) \end{bmatrix} \tag{1}$$

That could be analyzed in terms of complex space vector

$$V_0 = \frac{2}{3}\left[V_{AB}(t) + V_{BC}(t) e^{j2\pi}/3 + V_{BC}(t) e^{j4\pi}/3\right] = V_{0l} e^{j} \omega_0 t \tag{2}$$

Where,

$e^{j\theta} = \cos\theta + j \sin\theta$ represented a phase shift operator and 2/3 was a scaling factor equal to the ratio between the magnitude of the output line-to-line voltage and that of the output voltage vector. The angular velocity of the vector was ω_0 and its magnitude was V_{0l}.

Similarly, the space vector representation of the three-phase input voltage was given by

$$\vec{V}_i = V_i e^{j} (\omega_i t) \tag{3}$$

where,

V_i was the amplitude and ω_i was the constant input angular velocity.

If a balanced three-phase load was connected to the output terminals of the converter, the space vector forms of the three-phase output and input currents were given by

$$\vec{I}_0 = I_0 e^{j} (\omega_0 t - \phi_0) \tag{4}$$

$$\vec{I}_i = I_i e^{j} (\omega_i t - \phi_i) \tag{5}$$

Respectively, where ϕ_0 was the lagging phase angle of the output current to the output voltage and ϕ_i was that of the input current to the input voltage.

In the SVM method, the valid switching states of a matrix converter were represented as a voltage vectors. Within a sufficiently small interval a set of these vectors were chosen to approximate a reference voltage vector with the desired frequency and amplitude. At the next sample instant, when the reference voltage vector rotated to a new angular position, a new set of stationary voltage vectors were selected. Carrying that process onward by sequentially sampling the complete cycle of the desired voltage vector, the average output voltage emulated closely to the reference voltage. Implementation of the SVM involved two main procedures: switching vector selection and vector on-time calculation.

In matrix converters, each output phase was connected to each input phase depending on the state of the switches. For safe switching in the matrix converter conditions were as follows, i) input phases should never be short-circuited, ii) Owing to the presence of inductive load, the load currents should not be interrupted at any switching time. There are 27 different switching combinations for connecting output phases to input phases if the above two rules are provided. These switching combinations can be analyzed in three groups.

3.2. Group 1

Synchronously rotating vectors group consisted of six combinations having each of the three output phases connected to a different input phase. Each of them generated a three-phase output voltage having magnitude and frequency equivalent to those of the input voltages but with the phases sequence altered from that of the input voltages. As the input frequency was not related to the output frequency, the SVM could not use the above said vectors to synthesize the reference voltage vector that rotates at the frequency ω_0.

3.3. Group 2

Stationary vectors was the second group it was classified into three sets, each of which had six combinations and had a common feature of connecting two output phases to the same input phase. The corresponding vectors of those combinations had a constant phase angle, thus being named as stationary vectors. The magnitude of those vectors, however varied with changes of the instantaneous input line-line voltages.

3.4. Group 3

Zero vectors: The final three combinations in the table, form the last group. These had three output phases switched simultaneously on to the same input phase resulting in zero line-line voltages and were called zero voltage vectors. When a three phase load was connected to the converter output terminals, a three-phase output current was drawn from the power source. Output line voltage and input current space vectors were used in the application of the space vector control technique to the matrix converter.

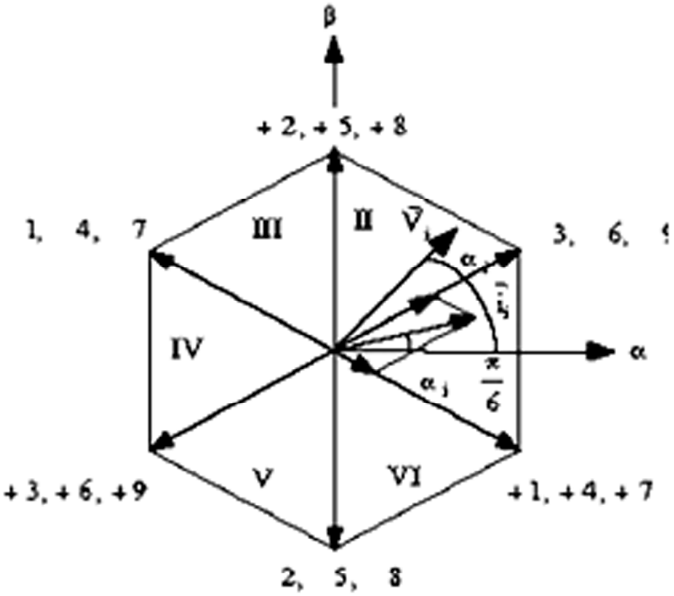


Figure 3: Representation of the Input Current Space Vectors.

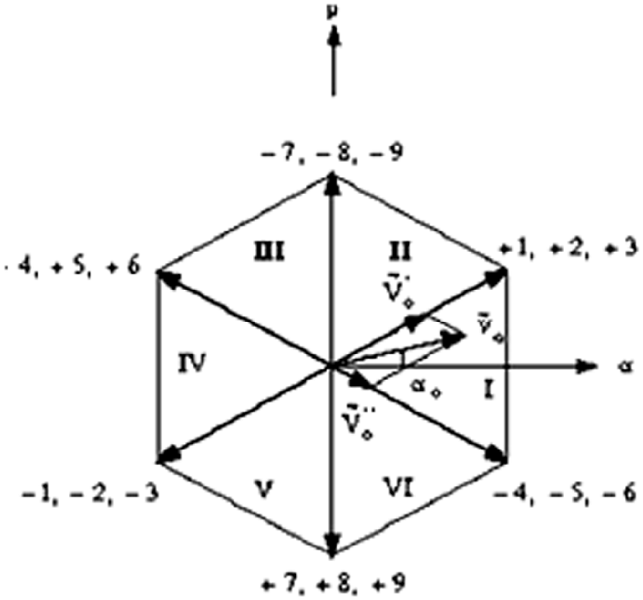


Figure 4: Representation of the Output Voltage Space Vectors.

4. SELECTION OF STATIONARY VECTORS

Switch combinations for matrix converter control, the SVM method was designed to choose appropriately four out of 18 switch combinations from a second group at any instant.

The selection process followed three distinct criteria namely, that at the instant of sampling, the chosen switch combinations must simultaneously result in

- The stationary output voltage vectors being adjacent to the reference voltage vector in order to enable the adequate output voltage synthesis.
- The input current vectors being adjacent to the reference current vector in order that the phase angle between the input line-line voltage and phase current, and hence the input power factor, being desired value.
- The stationary voltage vectors having the magnitudes corresponding to the maximum available line-line input voltages.

Table 1
Selected set of Switch combinations

	Input sextant 1	*Input Sextant 2*	*Input sextant 3*	*Input sextant 4*	*Input sextant 5*	*Input sextant 6*
Output sextant 1	1P, 4N, 6P, 3N	5N, 2P, 3N, 6P	2P, 5N, 4P, 1N	6N, 3P, 1N, 4P	3P, 6N, 5P, 2N	4N, 1P, 2N, 5P
Output sextant 2	3N, 9P, 7N, 1P	9P, 3N, 2P, 8N	1N, 7P, 8N, 2P	7P, 1N, 3P, 9N	2N, 8P, 9N, 3P	8P, 2N, 1P, 7N
Output sextant 3	4P, 7N, 9P, 6N	8N, 5P, 6N, 9P	5P, 8N, 7P, 4N	9N, 6P, 4N, 7P	6P, 9N, 8P, 5N	7N, 4P, 5N, 8P
Output sextant 4	6N, 3P, 1N, 4P	3P, 6N, 5P, 2N	4N, 1P, 2N, 5P	1P, 4N, 6P, 3N	5N, 2P, 3N, 6P	2P, 5N, 4P, 1N
Output sextant 5	7P, 1N, 3P, 9N	2N, 8P, 9N, 3P	8P, 2N, 1P, 7N	3N, 9P, 7N, 1P	9P, 3N, 2P, 8N	1N, 7P, 8N, 2P
Output sextant 6	9N, 6P, 4N, 7P	6P, 9N, 8P, 5N	7N, 4P, 5N, 8P	4P, 7N, 9P, 6N	8N, 5P, 6N, 9P	5P, 8N, 7P, 4N

5. COMPUTATION OF VECTOR TIME INTERVAL

The vector time intervals could be computed using the following equations

$$\delta_1^+ = \frac{2}{\sqrt{3}} T_s q \sin\left(\alpha_0 + \frac{\pi}{6}\right) \sin\left(\frac{\pi}{3} - \alpha_i\right) \tag{6}$$

$$\delta_3^- = \frac{2}{\sqrt{3}} T_s q \sin\left(\alpha_0 + \frac{\pi}{6}\right) \sin\left(\alpha_i\right) \tag{7}$$

$$\delta_4^- = \frac{2}{\sqrt{3}} T_s q \sin\left(\frac{\pi}{6} - \alpha_0\right) \sin\left(\frac{\pi}{3} - \alpha_i\right) \tag{8}$$

$$\delta_6^+ = \frac{2}{\sqrt{3}} T_s q \sin\left(\frac{\pi}{6} - \alpha_0\right) \sin\left(\alpha_i\right) \tag{9}$$

$$\delta_1^+ + \delta_3^- + \delta_4^- + \delta_6^+ \le T_s \tag{10}$$

Where, q is the voltage transfer ratio α_0 and α_i were the phase angles of the output voltage and input current vectors, respectively whose values were limited within 0° – 60° range. The above equations were valid for when the reference output-voltage vectors staied in output sextant 2 while the reference input-current vector was in input sextant 1. For different sets of vectors the same principle was applied.

6. SIMULATION MODEL

The Software like Mat lab, Simulink toolbox was used to carry out the simulation study. The figure 5 shows the simulink model of the space vector controlled matrix converter fed induction motor drives. The matrix converter outputs were connected to the 5.4 HP, 400 V, 50HZ asynchronous machine. The matrix converter totally nine bidirectional switches were used, each switches had two IGBT used for both directional control. Three output legs connected to input of the drive. The each bidirectional switching pulses were given by the technique of space vector modulation, totally nine different types of the pulses generated for the matrix conversion.

7. SIMULATION RESULT

The matrix converter simulation results were obtained for the frequencies 50HZ and 25HZ. The results were obtained for the time of one second in simulink. The matrix output voltage, current waveforms and

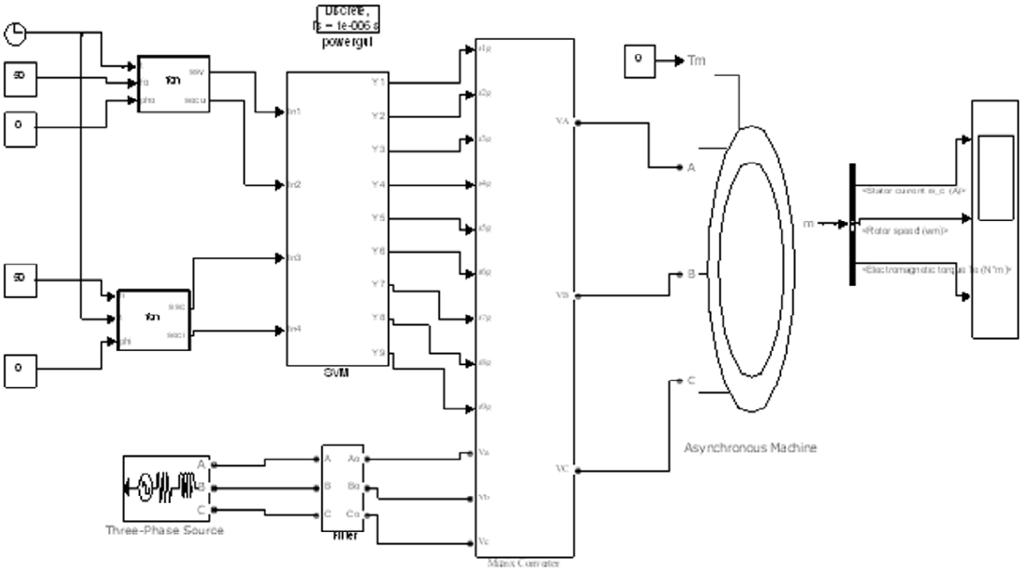
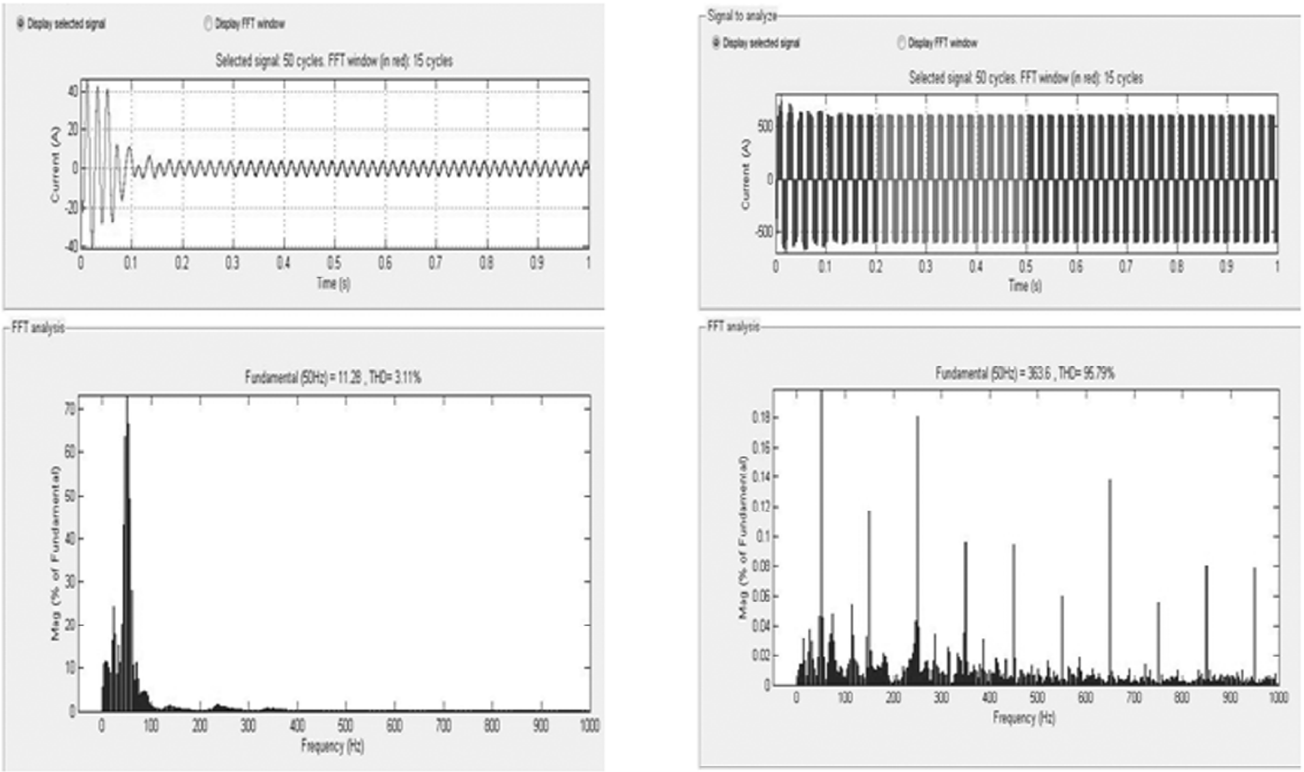
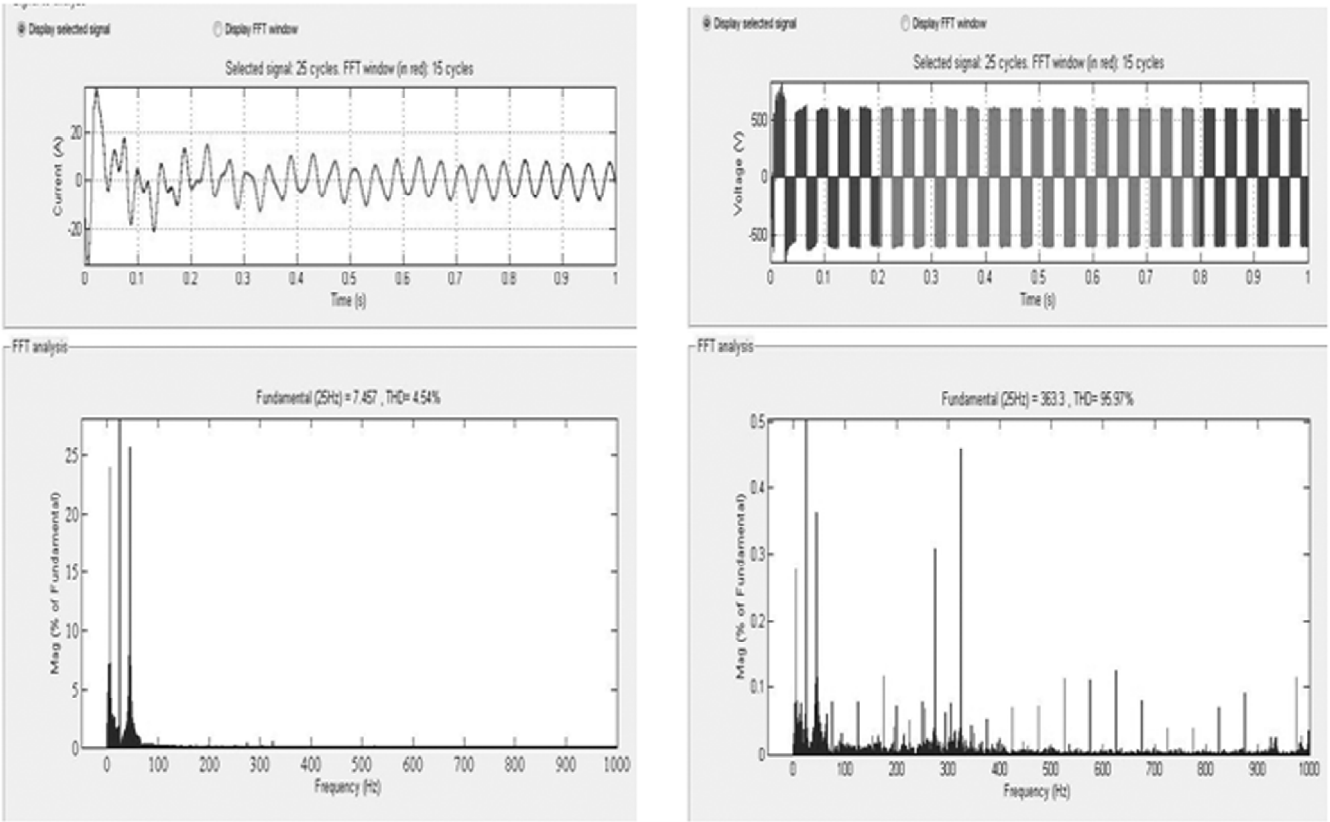


Figure 5: Simulink Model of the Controlled system



(a) (b)

Figure 6: Matrix Converter output frequency - 50 HZ (a) Output voltage and THD (b) Output current and THD



◉ Display selected signal ○ Display FFT window

Selected signal: 25 cycles. FFT window (in red): 15 cycles

FFT analysis

Fundamental (25Hz) = 7.457 , THD= 4.54%

◉ Display selected signal ○ Display FFT window

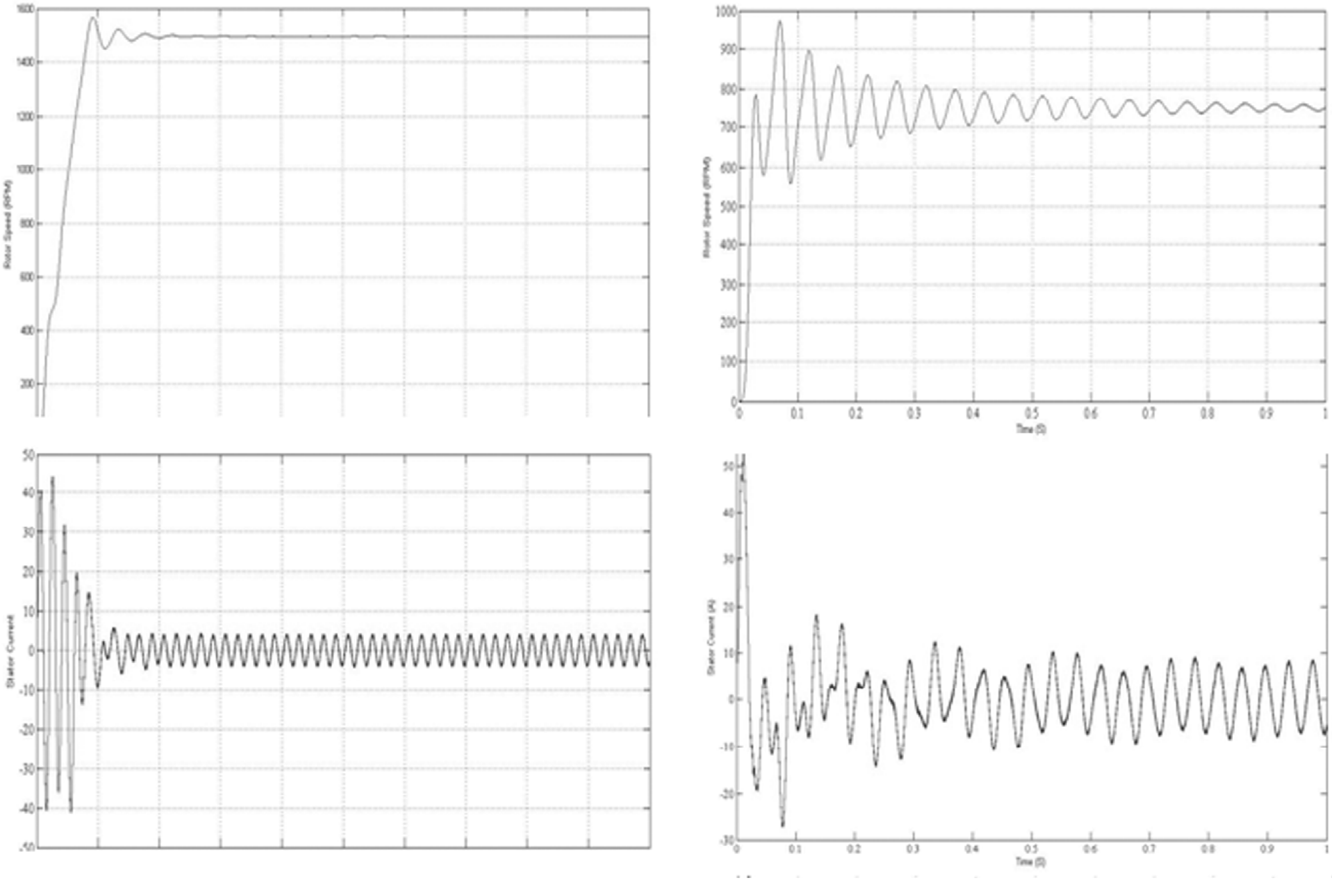
Selected signal: 25 cycles. FFT window (in red): 15 cycles

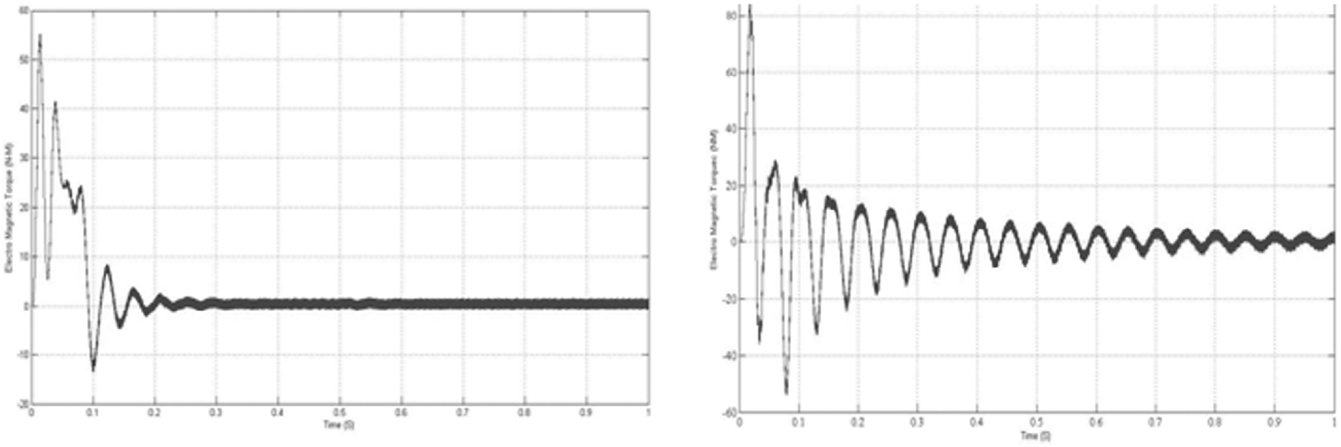
FFT analysis

Fundamental (25Hz) = 363.3 , THD= 95.97%

(a) **(b)**

Figure 7: Matrix Converter output frequency - 100 HZ
(a) Output voltage and THD (b) Output current and THD





(a) (b)

Figure 8: Stator Current, Rotor Speed, Electromagnetic Torque for Matrix Converter Fed Induction Motor drive (a) 50 HZ frequency (b) 25 HZ frequency

harmonic analysis were shown in figure 6 and 7 for the various frequencies. The figure 8 shows the results obtained for the various drive characteristics like rotor speed, stator current and electromagnetic torque for 25 and 50HZ frequency.

8. RESULT & DISCUSSION

Table 2
Comparisons statement for rotor speed and THD

Frequency (HZ)	*Rotor Speed (RPM)*	*Matrix Converter output THD (%)*	
		Current	*Voltage*
50	1500	3.11	95.79
25	750	4.54	95.97

The table 2 represents the comparison between two frequencies. The rotor speed were maximum in the both conditions and the THD value was also obtained for the matrix converter output voltage and current. The matrix converter response rapidly reached the maximum speed and maintained at that speed.

9. CONCLUSION

In this study, modeling and simulation of the three phase matrix converter with Induction Motor employing space vector control algorithm had been realized in Simulink/Matlab package program. The input and output waveforms of the converter for various output frequencies had been investigated. Simulation results had been demonstrated that the output waveforms did not have major harmonics except for those around switching frequency. It had been known from the harmonic analysis that the first harmonic of the unfiltered input current was in phase with the input voltage.

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