Harmonics Analysis of Three Phase Matrix Converter Fed Induction Motor Drive in Open Loop Mode

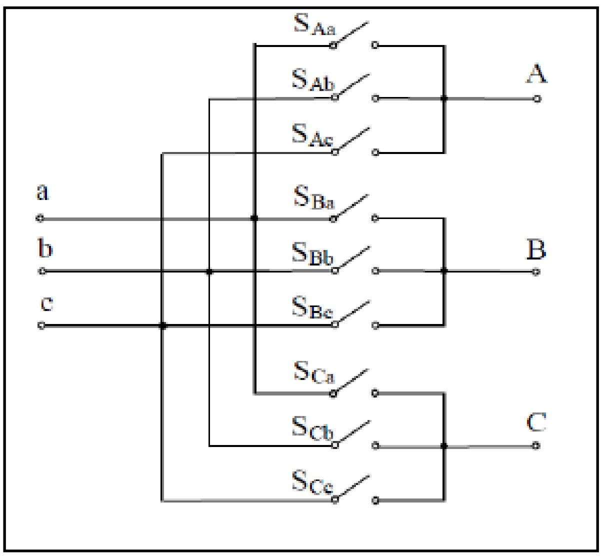
[1]R. A. Gupta, [2]Rajesh Kumar, [3]Virendra Sangtani, [4]Ajay Kr. Bansal
[1,2,3]Dept. of Electrical Engg., Malaviya National Institute of Technology, Jaipur, Rajasthan, India

Abstract
Matrix converter is basically direct three phase to three phase converter and it's operation is based upon switching pattern of all nine switches, which are available in this converter. The output of ac converter is fed as the input of three phase induction motor. The performance of three phase matrix converter fed induction motor drive is analyzed by the switching pattern obtained by matrix converter. In this paper, simulation, and implementation of three-phase to three-phase matrix converter and its switching pattern are obtained using Venturini algorithm have been presented and then the harmonics analysis of output voltages at different output voltage and different frequencies have been carried out by keeping the ratio of output voltage to frequency constant.

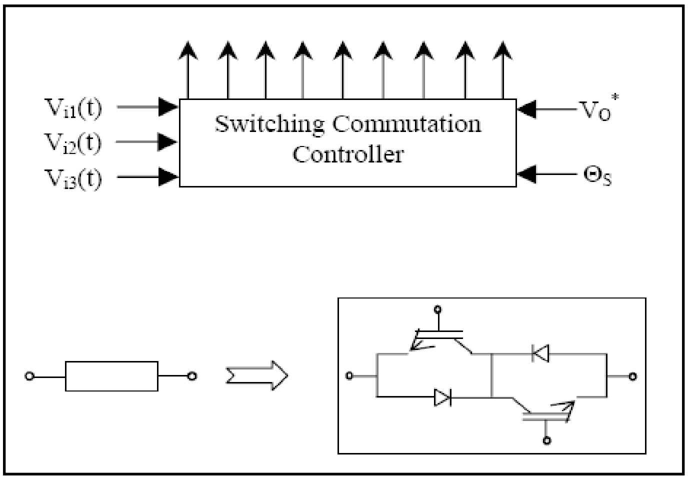
Keywords
Matrix Converter, Total Harmonic Distortion, Duty Cycle, Switching Pattern, Bi-Directional Switch

I. Introduction
The input ac power at given frequency is converted to an output ac power at different frequency (ac to ac) can be obtained by different systems i.e. employing rotating electrical machinery or static circuits, which contains fully controlled power electronics switches. The ac to ac power conversion technique using static circuits can be categorized into two basic schemes i.e. indirect ac / ac power frequency conversion scheme and direct ac/ac power frequency conversion scheme. As the name implies that indirect power conversion scheme consists of two or more stages for convert the ac into desired ac, which also requires dc link. A typical structure of indirect power conversion scheme includes diode-bridge rectifier-inverter structure, in which first ac power can be converted into dc power with diode rectifier and then it is reconverted into ac power at desired frequency with inverter [1,3]. While direct conversion scheme includes single stage ac/ac power frequency conversion.
Indirect ac/ac frequency conversion has some drawbacks as ac currents, which are drawn by diode bridge rectifier consists predominant harmonics, which produces distortion at input line voltages. These distorted input line voltages creates negative impact on performance of various loads and equipments, which are connected to same three phase supply. Current harmonics also causes additional harmonic losses in utilities, which leads large over voltages. So this conversion scheme has serious concern as power quality issue in last year's [4]. The controlled rectifiers were developed in early 1930's, then it was realized that there is possibility of generating ac of variable frequency from fixed frequency ac directly, i.e. positive rectifier supplies positive half cycles of currents whereas negative rectifier supplies negative half cycles. This scheme is called as cycloconverters. The output voltage waveform of cycloconverter is obtained by piecing together of selected segments of input voltages. Basically there are two types of cycloconverter i.e. Naturally Commutated Cycloconverter (NCC) and Forced Commutated Cycloconverter (FCC) [2, 7, 10]. As compared to indirect dc link converter, naturally commutated cycloconverter has advantages of lower conduction and commutation losses, due to which it has more compact design and bidirectional power flow capability. It has also some disadvantages i.e. low output frequency upper limit, lower input/output voltage transfer ratio, poor power factor and large number of thyristors, which requires complex control. Due to these restrictions, NCC are restricted up to low speed and high power reversible AC drives. Many NCC limitations can be overcome with FCC by using semiconductor devices with self turn off capability so it is possible to implement control algorithms, which uses high switching frequency allows output frequency to be higher than input frequency, input power factor as well as input/output voltage transfer ratio must be improved.
Matrix converter consists of nine bidirectional switches, arranged as three groups of three switches, as shown in fig. 1 (a). This arrangement of switches connects any input lines to any of the output lines. If any switch of matrix converter is on, it is represented by 1 and if any switch is off, it is represented by 0, so for a particular switch total two possibilities are there. In this manner for all nine switches of matrix converter, total 29i.e. total 512 combinations of switching states exists, but only 27 switching states are useful states for matrix converter if basic two rules are applied to operate on matrix converter i.e. two different input lines are not to be connected with the same output line (short-circuit of main causes over current) and does not disconnect the output line currents so closed path is available for induction motor [8-9]. As compared with indirect ac / ac conversion scheme as well as cycloconverters, matrix converter is capable to perform frequency conversion with sinusoidal output voltages and currents at desired output frequency and it also allows bi-directional power flow [11]. The converter also offers the advantages as sinusoidal input and output waveforms, bidirectional power flow capability, minimum energy storage components, controllable input power factor and compact size.

II. Matrix Converter Theory



(a)



(b)

Fig: 1: Schematic Diagram of Three Phase to Three Phase Matrix Converter (a) and Topology of Bi-Directional Switch (b).

The schematic diagram of three-phase matrix converter is represented as in fig. 1(a). The three phase supply voltages are basically the input of matrix converter, which are 120 degree phase displaced with each other as represented by Eq. (1) and its output are three phase voltages i.e. V_{o1}, V_{o2}, V_{o3}, represented by Eq (2), which can be applied to three phase induction motor. Matrix converters have nine bi-directional switches i.e (S_{Aa}. S_{Ab} ….. S_{Cc}), which have capability of blocking the voltages in both directions. Each bi- directional switch of matrix converter consists of two diodes, which are connected in antiparallel with two Insulated Gate Bipolar Transistors (IGBT's) as shown in fig. 1(b).

The input three phase voltages for matrix converter are expressed as:

$$\begin{pmatrix} v_{i1} \\ v_{i2} \\ v_{i3} \end{pmatrix} = V_i \begin{pmatrix} \cos(\omega_i t) \\ \cos(\omega_i t + 2\pi/3) \\ \cos(\omega_i t + 4\pi/3) \end{pmatrix} \quad (1)$$

The required first harmonic of the output phase voltages of unloaded matrix converter is expressed as:

$$\begin{pmatrix} v_{o1} \\ v_{o2} \\ v_{o3} \end{pmatrix} = V_o \begin{pmatrix} \cos(\omega_o t) \\ \cos(\omega_o t + 2\pi/3) \\ \cos(\omega_o t + 4\pi/3) \end{pmatrix} \quad (2)$$

The switching angles of the matrix converter are determines as with input voltages as per Eq. (1), the first harmonic of the output voltages will represented as Eq. (2).

III. Switching Algorithm

The duty cycle of all nine bidirectional switches determines the switching algorithm for matrix converter. The switching algorithms per Venturini algorithm expresses the duty cycle for switch connected between the input phase β and output phase γ as:

$$T_{\gamma\beta} = T_s\left[\frac{1}{3} + \frac{2}{3V_{im}^2}V_{o\gamma}V_{i\beta} + \frac{2q}{9q_m}\sin(\omega_i t)\sin(3\omega_{im} t + \psi_\beta)\sin(3\omega_i t)\right] \quad (3)$$

Where ψ_β is 0, $2\pi/3$, $4\pi/3$ corresponds to the input phases a, b and c, respectively, q_m is the maximum voltage ratio (0.866), q is the desired voltage ratio, V_{im} is the input voltage vector magnitude and $V_{o\gamma}$ is represented as:

$$V_{o\gamma} = \left[qV_{im}\cos(\omega_o t + \psi_\gamma) - \frac{q}{6}V_{im}\cos(3\omega_o t) + \frac{q}{4q_m}V_{im}\cos(3\omega_i t)\right] \quad (4)$$

Where, ψ_γ is 0, $2\pi/3$, $4\pi/3$ corresponds to the output phases A, B and C, respectively and ω_0 is angular output frequency.

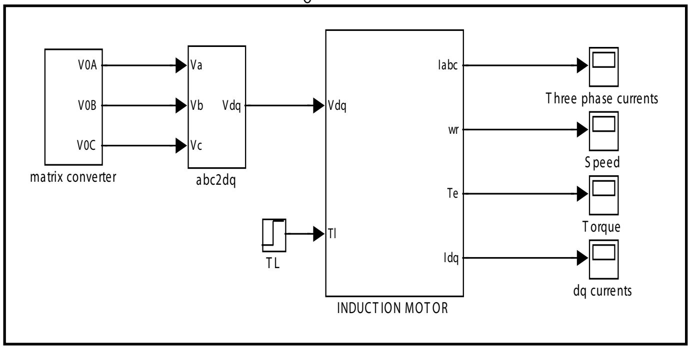


Fig. 2: Simulink Model of the Matrix Converter With Venturini Algorithm

The duty cycle for switches connected between the input phase a, b and c and output phase A, can be represented as:

$$T_{Aa} = T_s\left[\frac{1}{3} + \frac{2}{3V_{im}^2}V_{oA}V_{ia} + \frac{2q}{9q_m}\sin(\omega_{im} t)\sin(3\omega_{im} t)\right] \quad (5)$$

$$T_{Ab} = T_s\left[\frac{1}{3} + \frac{2}{3V_{im}^2}V_{oA}V_{ib} + \frac{2q}{9q_m}\sin(\omega_{im} t + \frac{2\pi}{3})\sin(3\omega_{im} t)\right] \quad (6)$$

$$T_{Ac} = T_s\left[\frac{1}{3} + \frac{2}{3V_{im}^2}V_{oA}V_{ic} + \frac{2q}{9q_m}\sin(\omega_{im} t + \frac{4\pi}{3})\sin(3\omega_{im} t)\right] \quad (7)$$

Similarly the duty cycle for switches connected between the input phase a, b and c and output phase B and similarly the duty cycle for switch connected between the input phase a, b and c and output phase C can be easily calculated using Eq. 3.

The three phase output voltages for matrix converter are given as:

$$V_{OA} = qV_{im}\cos(\omega_{om} t) - \frac{q}{6}V_{im}\cos(3\omega_{om} t) + \frac{q}{4q_m}V_{im}\cos(3\omega_{om} t) \quad (8)$$

$$V_{OB} = qV_{im}\cos\left(\omega_{om} t + \frac{2\pi}{3}\right) - \frac{q}{6}V_{im}\cos(3\omega_{om} t) + \frac{q}{4q_m}V_{im}\cos(3\omega_{om} t) \quad (9)$$

$$V_{OC} = qV_{im}\cos\left(\omega_{om} t + \frac{4\pi}{3}\right) - \frac{q}{6}V_{im}\cos(3\omega_{om} t) + \frac{q}{4q_m}V_{im}\cos(3\omega_{om} t) \quad (10)$$

IV. Simulation And Implementation of Matrix Converter fed IM Drive

The describing Eqs (3-4) by Venturini algorithm has been used to calculate duty cycle of all nine bidirectional switches. Fig.2 shows Simulink model of the three phase matrix converter fed induction motor drive with Venturini algorithm. First part contains three phase to three phase matrix converter, by which three phase output voltages are obtained i.e. VOA, VOB, VOC as shown in fig. 2. These three phase voltages are converted into dq voltages using Park's transformation and then it is applied to three phase induction motor. The generation of duty cycles for the switches, which are connected to output phase A, are expressed as Eqs. (5-7). Similarly the duty cycles for switches connected to phases

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B and C are calculated from Eq (3). The output voltage for matrix converter is calculated using nine bidirectional switches and three phase input voltages of matrix converter.

The duty cycle for switch connected between the input phase β and output phase γ are calculated at every sampling period. For implementation of matrix converter fed induction motor drive, it is essential to measure any two of three input line-to-line voltages. Then, V_{im} and ω_i^t are calculated as:

$$V_{im}^{\;2} = \frac{4}{9}\left[V_{ab}^{\;2} + V_{bc}^{\;2} + V_{ab}V_{bc}\right] \tag{11}$$

$$\omega_i t = \arctan\frac{-V_{bc}}{\sqrt{3}\left(\frac{2}{3}V_{ab} + \frac{1}{3}V_{bc}\right)} \tag{12}$$

Where V_{ab}, V_{bc} are the instantaneous values of input line voltage.

V. Simulation Results and Harmonics Analysis

In this paper, matrix converter fed induction motor drive using Venturini algorithm have been simulated. Harmonics analysis of matrix converter fed induction motor drive is determined by calculation of total harmonics distortion (THD) in the output voltages of three phase matrix converter. The total harmonic distortion (THD) is defined as the root mean square (rms) value of total harmonics of all available signals to the rms value of its fundamental signal.THD basically provides all the information regarding total harmonics contents in output three phase voltages of matrix converter and it also shows the total magnitude of individual harmonics. For voltage harmonics, THD is defined as

$$THD = \frac{V_H}{V_F} \tag{13}$$

Where $V_H = \sqrt{V_2^2 + V_3^2 + ------V_n^2}$, V_F is the rms value of fundamental voltage and V_n is the rms value of harmonic n. The knowledge of contents of harmonics in output voltage is quite necessary not only the determination of the filtering requirement in any particular application as well as assessing the limits of performance of matrix converter. The output voltage of matrix converter consists of selected time segments of input voltages, which are pieced together so as to form an overall shape in which the predominant component is sinusoidal of desired output frequency. The proper switching of all nine bidirectional switches are obtained at every instant by venturini algorithm and total 172 combinations of switching has been produced to obtain instantaneous voltages in only one cycle.

The speed of three phase motor, motor three phase currents, three phase instantaneous output voltages of matrix converter, and finally the harmonics spectrums are shown at 50, 45 and 25 hz as in figs. 3(a-d) to figs. 5 (a-d) respectively. The Speed responses contains more spikes as frequency is reduced, which is clearly shown by speed response below for three different frequencies. Similarly Table 1 shows the THD analysis of output phase and line voltages of matrix converter and it is easily shown from table that harmonics components are reduced in line voltages as compared to their respective phase voltages. It is also clear from Table 1 that although there is more THD at 50 hz frequency but there are higher order harmonics, which are predominant in nature and as higher order harmonics are also easily filtered out.

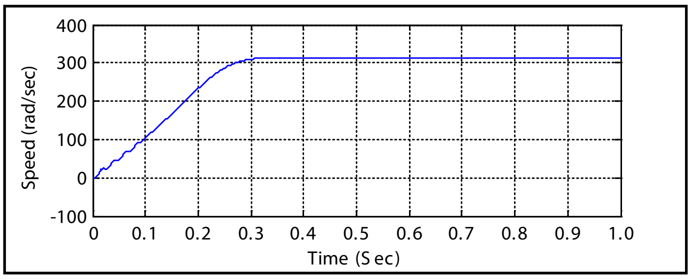

Fig. 3(a): Induction Motor Speed

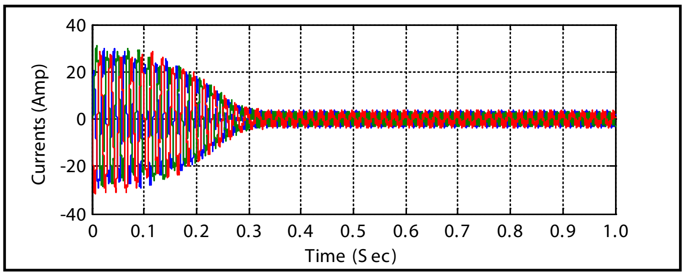

Fig. 3(b): Induction Motor Three Phase Currents

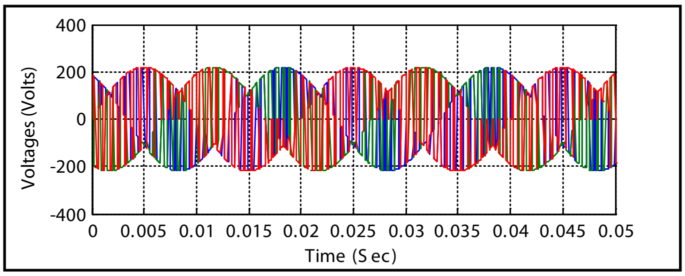

Fig. 3(c): Induction Motor Three Phase Voltages

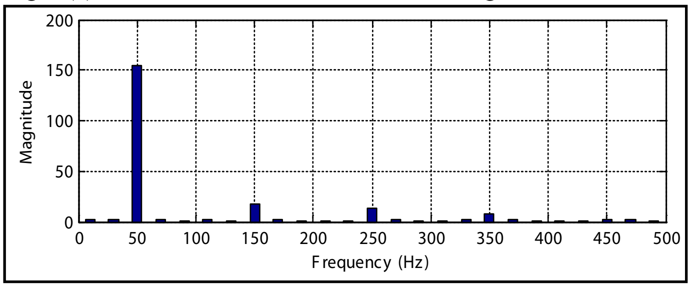

Fig. 3(d): Harmonic Spectrum of Output Voltage at 50 hz

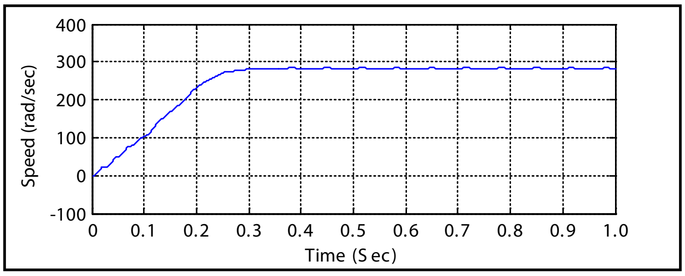

Fig. 4(a): Induction Motor Speed

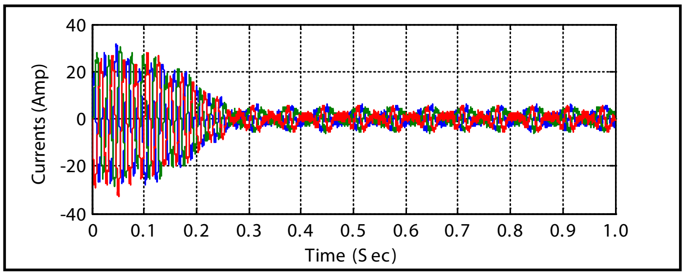

Fig. 4(b): Induction Motor Three Phase Current

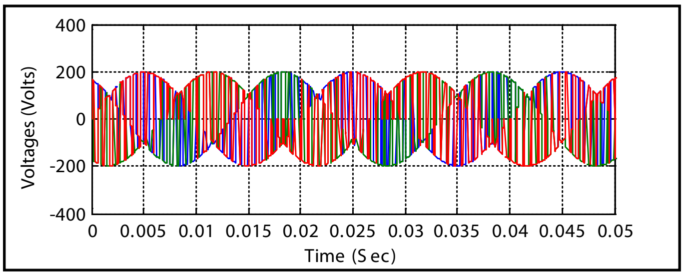

Fig. 4(c): Induction Motor Three Phase Voltages

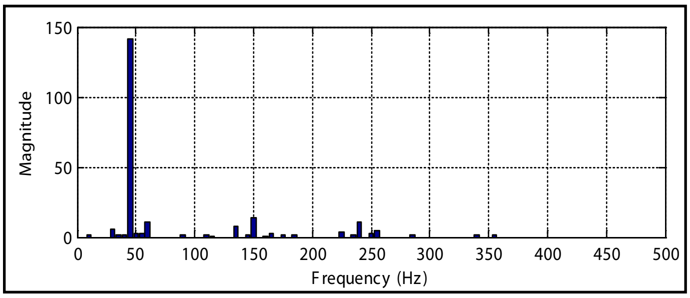

Fig. 4(d): Harmonic Spectrum of Output Voltage at 45 hz

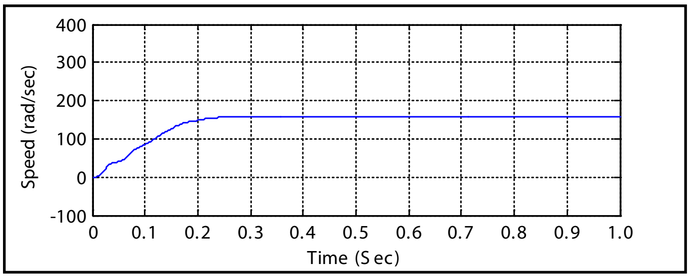

Fig. 5(a): Induction Motor Speed

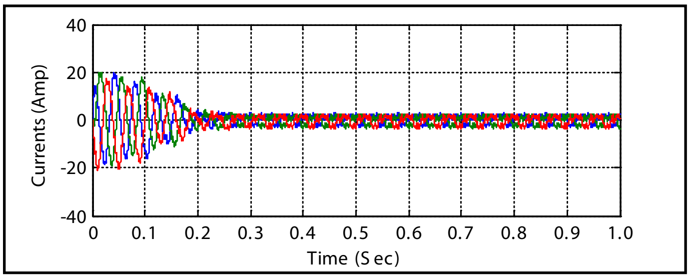

Fig. 5(b): Induction Motor Three Phase Current

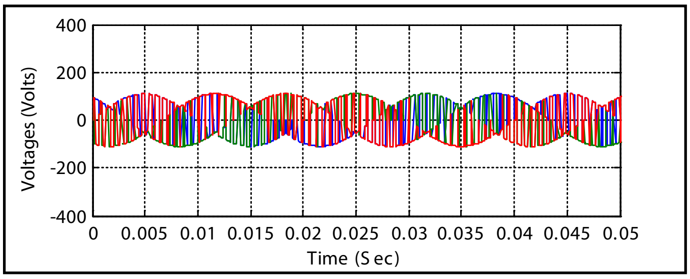

Fig.5(c): Induction motor three phase voltages

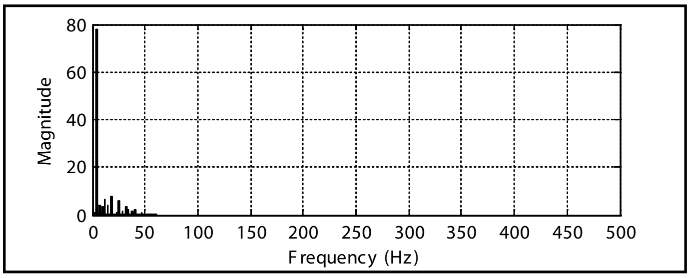

Fig. 5(d): Harmonic Spectrum of Output Voltage at 25 hz

Table 1: THD Analysis in Output Line and Phase Voltages

S. No.	Voltage/Frequency	THD (Phase)	THD (Line)
1	220/50	115.8%	80.60%
2	198/45	23.43%	20.45%
3	110/25	112.7%	77.53%

VI. Conclusion

Matrix converter modeling and simulation using Venturini algorithm have been done. It is clearly seen from the simulation results that the output of the induction motor is same as if when three phase input applied is sinusoidal to three phase induction motor. In this paper, It is observed from above table that total harmonics distortions are reduced in line voltages as compared to their respective phase voltages as magnitudes of triplen harmonics are almost zero in line voltages in all above three cases.While calculating the THD in all three cases the ratio of output voltages to frequency are kept constant and it was found that harmonic component in second case is minimum i.e. 23.43% as compared to other two cases. Although the harmonics components are less at 45 hz as compared to operation at 50 hz but the speed response contains more spikes as compared to speed response at 50 hz.

References

[1] A. Alesina, M. Venturini,"Analysis and Design of optimum-amplitude nine switch direct AC-AC converters", IEEE Trans. Power electron., Vol. 4, pp. 101-112,Jan 1989.
[2] Ebubekir Erdem, Yetkin Tatar, SedatSunter,"Effects of Input Filter on Stability of Matrix Converter Using Venturini Modulation Algorithm", International Symposium on Power Electronics, Electrical Drives, Automation and Motion, Speedam 2010, pp. 1344-1349.
[3] A.Zuckerberger, D.Weinstock, A.Alexandrovitz,"Simulation of three thase loaded matrix converter", 1EE Proc.-Elecrr. Power Appl., Vol. 143, No. 4, July 1996, pp. 294-300.
[4] L.Hasegawa,T.Takashita,"PWM Strategy of Voltage Harmonics for Matrix Converters", IEEE Proceedings, 2010, pp. 668-673.
[5] L.zhang, C Watthanasam, W. Shepherd,"Application of Matrix Converter for a variable- speed Wind- Turbine driving a double_ fed induction Generator", IECON Proceedings, V2. 1997, pp. 906-911.
[6] MATLAB for Microsoft Windows (The Math Works, Inc., 1993).
[7] C. Klumper, P. Nilesan, I. Boldea, F. Blaabjerg,"New steps toward a low-cost power electronic building for matrix converters", In Conf. Rec IEEE-IAS Annu. Meeting, Vol. 3, Rome, Italy, Oct. 8-12, 2000, pp. 1964-1971.
[8] Lin Yong, He Yikang,"The modeling and Simulation of a three-phase Matrix Converter", IEEE Trans. On Ind. App., Vol. 28, No. 3, May/June, 1992, pp. 546-551.
[9] R. A. Gupta, R. Kumar, V. Sangtani, A. K. Bansal, "Comparative analysis of three phase matrix converter fed induction motor drive", IEEE conference on computing, communication and applications., Feb, 2012, pp. 1-6.
[10] Neft, C.L., Schauder,C.D.,"Theory and design of a 30-hp Matrix Converter", Proceedings of IEEE/IAS annual meeting conference record, 1988, pp. 934.

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[11] P. Ziogas, S. Khan, M. Rashid,"Some improved force commutated cycloconverters structures", IEEE Trans. Ind Application, Vol. IA-21, pp. 1242-1253, Sept/Oct.1985.
[12] P. WOOD,"General theory of switching power converters", In Proc. IEEE-PESC 79, Vol. 1, pp. 3-10.