Design and Development of Novel Matrix Converter Performance Enhancement Technique for Induction Motor Drive

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Abstract—*Matrix converter is a direct AC-AC converter topology that directly converts energy from an AC source to an AC load without the need of a bulky and limited lifetime energy storage element. Due to the significant advantages offered by matrix converter, such as adjustable power factor, capability of regeneration and high quality sinusoidal input/output waveforms. Matrix converter has been one of the AC–AC topologies that hasreceived extensive research attention for being an alternative to replace traditional AC-DC-AC converters in the variable voltage and variable frequency AC drive applications. In the present paper an indirect space vector modulated matrix converter is proposed. The basic idea of an indirect modulation scheme is to separately apply SVM to the rectification and inversion stages, before combining their switching states to produce the final gating signals. The paper encompasses development of a laboratory prototype of 230V, 250VA three phase to three phase DSP controlled matrix converter fed induction motor drive. The observations and real time testings have been carried out to evaluate and improve the stability of system under various typical abnormal input voltage conditions*

Keywords—Fuzzy Image Fusion, Image Enhancement, Image Sharpening,Magnitude Gradient, Standard Deviation.

I. INTRODUCTION

AC/AC converters take power from an AC system and deliver it to another with waveforms of adjustable amplitudes and frequencies. In direct AC/AC converters, the cyclo-converter is the most commonly employed topology in three-phase to three-phase applications, making use of semiconductor switches to connect directly the power supply to the load, converting a three-phase AC voltage to a three-phase AC voltage with adjustable magnitude and variable frequency. It allows power flow in either direction. The operating output frequency of this direct converter should be less than the input frequency. In addition to the cyclo-converters, matrix converters have enjoyed increasing interest as direct converters in recent years.

Most of the converters use diode-rectifiers (followed by a DC-link capacitor), which draw non-sinusoidal currents (i_A, i_B, i_C) even when fed with a balanced sinusoidal voltages (V_A, V_B, V_C). Only considering the load side currents (i_a, i_b, i_c), the diode rectifier based VSI may be a good solution, but its side currents (i_A, i_B, i_C) are highly distorted, containing high amounts of low order harmonics which may further interfere with the other electric systems in the network. In addition, the current flow on diodes cannot be reversed. Thus, bi-directional power flow cannot be provided without using an auxiliary circuit.

A conventional solution for the harmonics in input current waveforms and bi-directional power flow problems is to use a controlled bridge rectifier i.e. back-to-back voltage source converter (BBVSC) instead of diode rectifier as shown in Fig. 1. The BBVSC draws sinusoidal current waveforms (iA, iB, iC) from the AC supply. It contains a DC-link capacitor between controlled bridge rectifier and the inverter bridge and supply filter inductors.

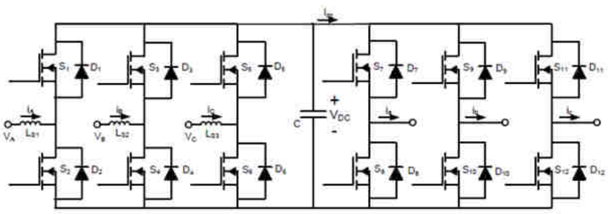

Fig. 1: Fuzzy inference system

The arrangement has limitation of bulkier and heavy supply filter inductors (Ls) andDC-link capacitorin low and medium power conversion.

II. MATRIX CONVERTERS

Cyclo-converter cannot be seen as an optimal solution for low and medium power level converters because of restricted output frequencies and poor harmonic performance. However, for the high power levels, cyclo-

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converter can be seen as an optimal solution due to the low loses and robustness. Matrix convertor is much versatile without imposing any limits on the operating output frequencies. It performs direct AC/AC power conversion process from AC utility to AC load, with neither intermediate DC conversion nor DC energy storage elements. Thus, it replaces the multiple conversion stages by a single power conversion stage. By the way, the converter size and volume can be greatly reduced compared to the indirect AC/AC power converters which have DC-link components. Thus, direct converter topologies may provide a solution for application where large passive components are not allowed.

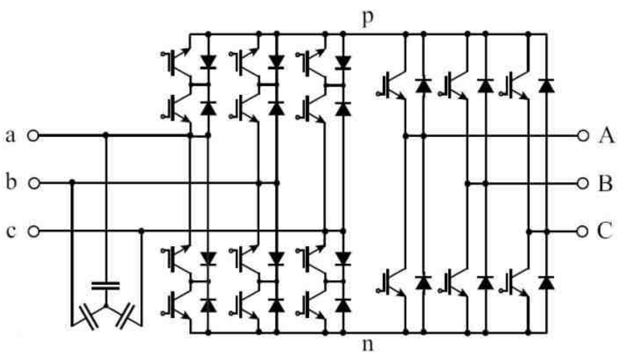

Fig. 2: Indirect Matrix Converter

Due to the independence of the voltage form and frequency on the input and output sides, the matrix convertor topology holds a promising potential for universal power conversion such as: ac-dc, dc-ac, dc-dc and ac-ac (Mohan et al. 2003).

The real development of the matrix converter starts with the work of Venturini and Alesina who proposed a mathematical analysis and introduced the Low-Frequency Modulation Matrix concept to describe the low frequency behavior of the matrix converter. In this, the output voltages are obtained by multiplication of the modulation matrix or transfer matrix with the input voltages.

III. METHODOLOGY

The proposed work mainly focuses on an indirect space vector modulation. The main idea of the indirect modulation is to consider the matrix converter as a two-stage transformation converter. This separation allows known PWM strategies to be implemented in both the rectifier and the inverter stage. During each sampling interval, DSP will first start the on board A/D converter to sample the input three phase voltages, then make them through comparators to determine the sector code of the input voltage vector. According to the displacement angle set, the switching table is formulated. At last, DSP converts the switching times data to switching pulses, and then sends the sector codes to the PLD (Programmable Logic Device) board. In DSP, the duty cycles of the five switching combinations are calculated and PWM pulses are generated. PLD will deliver the pulses to the appropriate bidirectional switches and fulfil the four-stepped commutation.Block diagram of the proposed DSP controller based matrix converter for induction motor control is shown in figure 3.

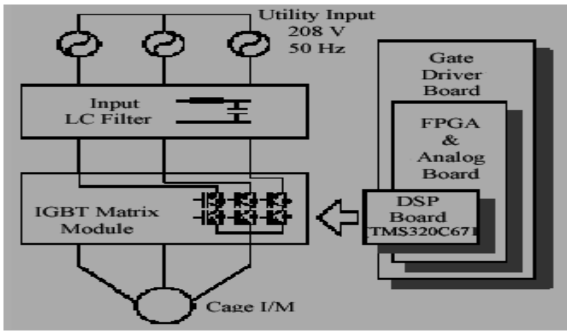

Fig. 3: Flowchart of proposed approach

Modulation synthesize the output voltages from the input voltages and the input currents from the output currents. The first modulator proposed for Matrix Converters, known as the Venturini modulation, employed a scalar model. 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. The three phase 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. Both power stages are directly connected through virtual dc-link and inherently provide bidirectional power flow capability because of its symmetrical topology.

IV. DSP-BASED SVM ALGORITHM IMPLEMENTATION

The general requirements for generating the switch control signals for a matrix converter on-line in real-time are as follows:

i). Computation of the switch duty cycles must be completed within one switching period.
ii). Accurate timing of the pulse-pattern output should be achieved, and
iii). The computational process must be synchronized with the input-voltage sinusoidal cycle.

For both modulation methods, a TMS320F30 digital signal processor was used for on-line calculation of the switch timings. The DSP is mounted on A PC-compatible card, the Evaluation Module (EVM) to facilitate the development process . An additional interface card was used for outputting the calculated

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switch timings. This comprises of seven programmable timers, 4MHz clock, a 2Kx8-bit EPROM, an 8-bit I/O port and a few logic gates and is configured in such a way that either Venturini or SVM control method may be selected. Both DSP and interface card are plugged in a PC which provides a convenient means for data communication and user interface.

During each sampling interval Ts, the DSP calculates six switch duty cycles $m_{ij}(tk)$ and converts them to integer time-counts using the on-board clock frequency. As the calculation is performed during the process of pulses-timing output and is completed within Ts, it has no effect on the real-time pulse signal generation. Once completed the calculated results are stored in the DSP memory and subsequently loaded into the timers. According to the output pulse pattern, two programmable timers are used for timing three switches. At the start of a switching period, two timers are loaded with T_{11} and $T_{11} + T_{12}$ respectively and begin the count-down process while their outputs are held 'LOW'. As soon as the first timer reaches a terminal count, its output goes 'HIGH', thus initiating the commutation of switches from S_{11} to S_{12}. At the terminal count of the second timer, commutation from S_{12} to S_{13} takes place. A third timer is required for timing out Ts which also determines the 'on' duration of switch S_{13}. On completion of a switching period, two times are re-loaded with the new integer counts and the procedure described is repeated. Loading of the timer is performed by a PC interrupt service routine. The outputs of the two timers can be converted to three switch control signals using a few gates, indicated as a 2-to-3 line logic decoder block. Since the other two groups of three switches are also controlled using this approach, seven programmable timers are, therefore, required in the Venturini control scheme.

The DSP computes the vector-time counts in the same manner as the Venturini method. An EPROM is used to store the selected sets of stationary and zero vectors. Each of the switching vectors, represented by nine control pulses, is coded as a 6-bit binary number to fit into an 8-bit EPROM. In retrieving, 2-to-4-line decoder IC's are used to recover the nine control signals. The 10-bit address of each memory of the output voltage vector, the sector number of the output voltage vector, the sector number of the input current and output of four timers is used. The input and output sector numbers are readily available from the DSP and hence can be directed to six address lines of the EPROM using the 6-bit latches. Four programmable timers can be similarly configured to those in the Venturini scheme but their outputs are directed to four address lines of the EPROM. The extra timer for controlling Ts is also required. When the sample period begins, four timers are loaded with T_1, T_1+T_2, $T_1+T_2+T_3$ and $T_1+T_2+T_3+T_4$ consecutively. The terminal count of each switch changes the pulse-pattern of the four-timer outputs and in turn updates the pointer of the look-up table. This effectively generates each of the five switching vectors for a specified time interval as required by the SVM technique. On the completion of Ts, four integer counts are updated and the process is then repeated.In comparison, the C30DSP takes 20 µs to complete the computation for the SVM scheme whereas 50 µs is needed for Venturini method. As Ts is usually set at the level of hundreds microseconds, during the majority of a sample period the DSP is idled and can be used for feedback control or other tasks. Both schemes require one interrupt routine for outputting the calculated results. Since this demands 50 µs to implement, the maximum sampling frequency of the modulator can be extended to 10kHz. Any control algorithm for a matrix converter must be synchronized with the input voltage cycle so that the calculation of switch timings can be correctly performed. This is achieved by using the software phase-lock-loop which detects the zero-crossing of the input phase voltage. An interrupt pulse generated at each zero-crossing will cause the DSP to initialize appropriate variables for calculation. The logic implementation is necessary to control the four-step commutation for the nine bi-directional switches requiring many resources, it was chosen to implement it in a XC95108 programmable logic device (Xilinx). This gives flexibility, as on board programming using the JTAG port, and allows for compact and good noise immunity design. The switching state for each bi-directional switch group, assigned to an output phase, is two-bit encoded, in order to minimize the interface terminals count and to avoid noise problems.

A DSP or a microcontroller, depending on requirements, is needed to produce the command signals: Enable, Clock, Reset and the switching states. A programmable logic device performs the logic control of the PEBB and also, controls the 4-step bi-directional switch commutation. Analog measurements, of the input phase voltages and the output currents, galvanic insulated, are accessible in the interface to the DSP micro-controller. The sign of the output currents is detected and used to control the 4-step commutation; an over-current on the output side will be detected, causing the matrix converter to shutdown. Even though the four-step commutation provides snubberless operation, a clamp circuit has to be employed. This protects the converter against over-voltage generated by excessive energy in the motor leakage inductance that may appear during shutdown due to an over-current. The diodes from the clamp circuit are sized according to the over-current level and are mounted on the Power Stage Board, in order to minimize the stray inductance. The capacitor should be externally mounted, the same as the input L-C filter, which gives some freedom to the user to change the parameters and configuration for the passive components. For evaluating the performance of the algorithm of proposed method following parameters are used.

4.1 Experimental Setup

The complete simulationmodel for induction motor fed by a three phase matrix converter through an indirect space vector modulation approach is shown in figure 4.

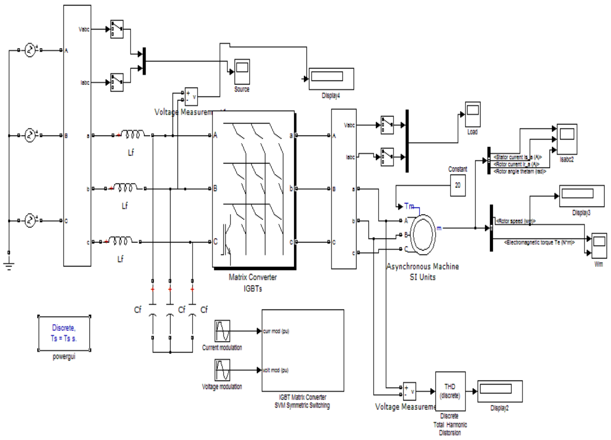

Fig. 4: SVM Based simulation model for induction motor fed by a three phase matrix converter

The MC is used to drive a standard induction motor having the following parameters shown in table 1.

Table 1: Motor Parameters

Voltage	400 V
Nominal Power	4 Kw
Frequency	50Hz
Pole Pair	2
Torque	20
Rotation Inertia .	0.0131 Kg·m²
Stator Resistance (Rs)	0.3578Ω
Rotor Resistance (R'r)	0.2861Ω
Stator Inductance (Ls)	0.03972H
Rotor Resistance (L'r)	0.03972H
Mutual Inductance (Lm)	0.03841H

The simulations have been carried out assuming a sampling frequency of 2μs and ideal switching devices. The dynamic behavior of the system has been tested with reference to a load step change response and impact speed response. Some simulation studies have been done using system parameters in Table 2.

Table 2: Input Parameters

Source voltage amplitude, Vin	220 V
Input frequency, fi	50 Hz
Input filter inductance, Lf	3 mH
Input filter capacitance, Cf	25 μF
Switching frequency, fs	6 kHz

The results found using MATLAB/SIMULINK are validated by performing experiments on available laboratory kit and are shown in the following section. The experimental setup of matrix converter prototype and the main circuit as well as power-control-isolation module of prototype with measuring instruments are shown in Figure 5.

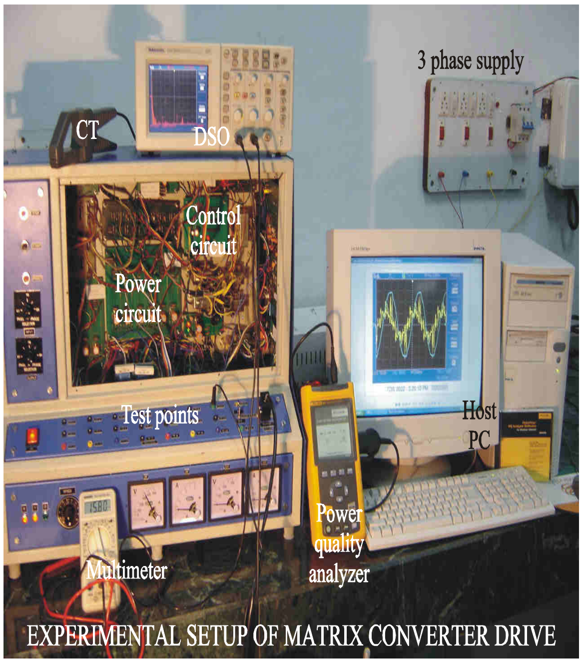

Fig. 5: Experimental set-up of the matrix converter drive system

For this, a 230V, 250VA three phase to three phase MC fed induction motor drive prototype is implemented using DSP based controller and tests have been carried out to evaluate and improve the stability of system under various typical abnormal input voltage conditions. Digital storage oscilloscope & power quality analyzer are used for experimental observations. For the purpose of generating various AC voltages, an AC source equipment-Elgar SW5253A is used which generates three phase output voltages with various amplitudes, various frequency and various waveforms. The equivalent circuit parameters of the test motor are obtained through light running and blocked rotor tests. Effect of saturation on magnetizing reactance has been found from zero slip tests.

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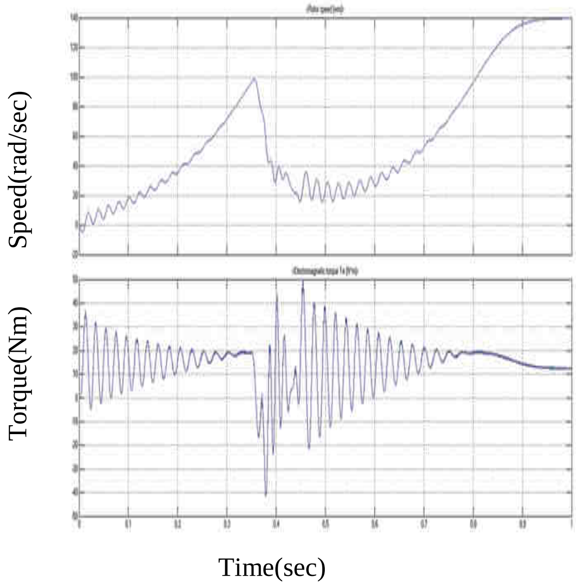
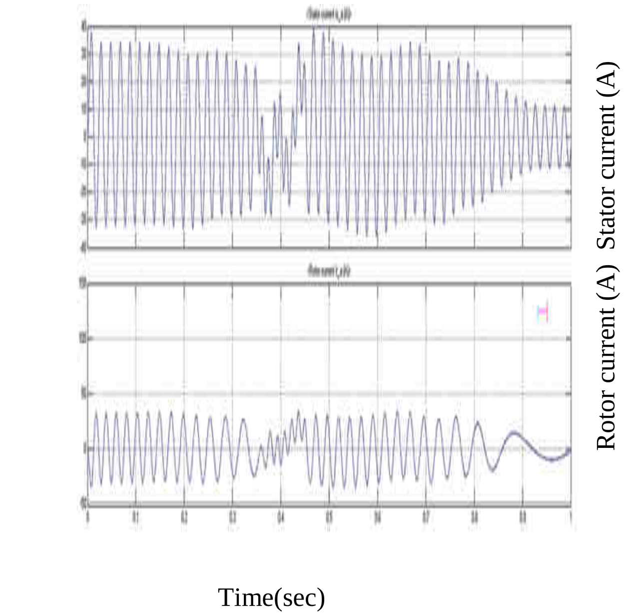
V. RESULTS AND DISCUSSION

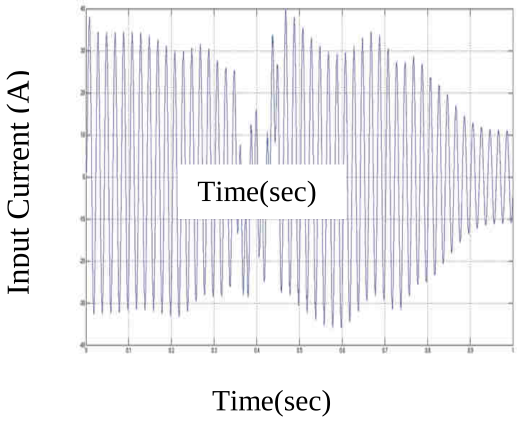
Performance of Matrix Converter fed induction motor drive under abnormal input frequency and voltage conditions of power supply is analyzed. These abnormal conditions of input power supply have a great influence on the input/output performance of induction drive. Fig. shows motor performance curves due to drop in supply frequency from 50 to 30 Hz for 1 sec. Sudden drop in frequency cause drop in speed of motor and reaches steady state speed at 0.95 secs shown in figure 6.



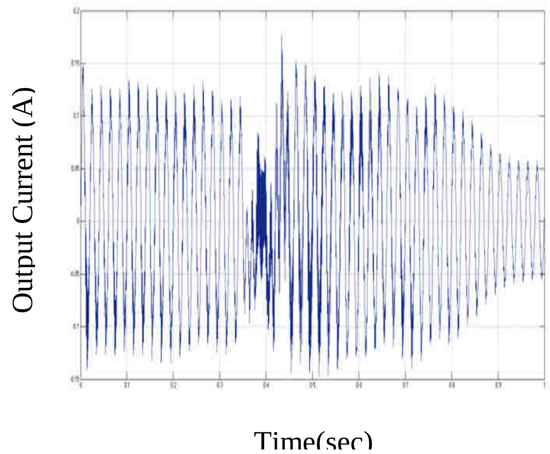
(a)



(b)



(c)



(d)

Fig. 6 (a) Speed and load Torque Response (b) Stator and Rotor Current (c) Input Current (d) Output Current at Abnormal input supply

The high performance matrix converter gives a very rapid response to sudden input frequency drop for few seconds. The rapid recovery of the stator and rotor current to this dynamic event is also clearly shown in figure 6(b). It first oscillates with the rapidly varying current before achieving steady-state. The speed of recovery is extremely fast, as stability is reached within few switching cycles.After evaluating the performance of the system under 20% step change in frequency using Simulink, it is validated by the experimental results.It is observed that the obtained experimental results are similar to the simulation results.

5.1 Results under Abnormal Input Voltage Conditions

Fig. 7 and 8 show the input/ output current & voltages, when system is operated with unbalanced power supply. The rms values of the input three-phase voltages are 72.6V, 109.8V and 128.2V respectively.

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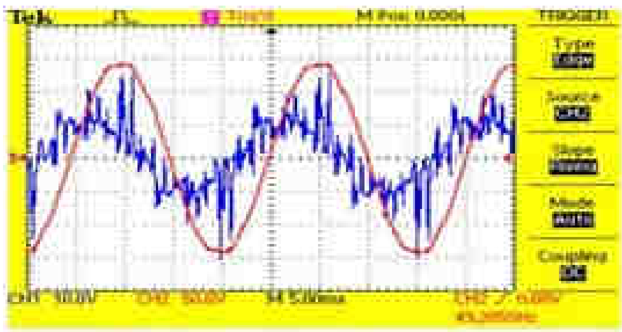

Fig. 7: Input & Output phase voltage at 30 Hz.

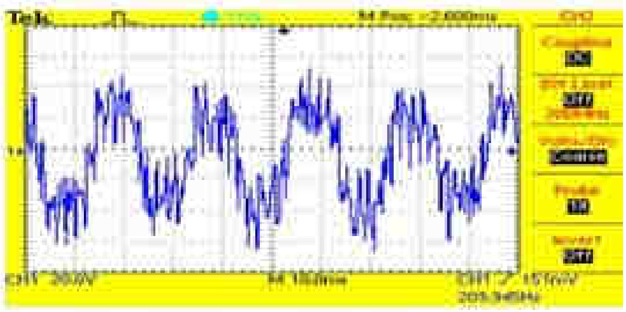

Fig. 8: Output line current at 30 Hz.

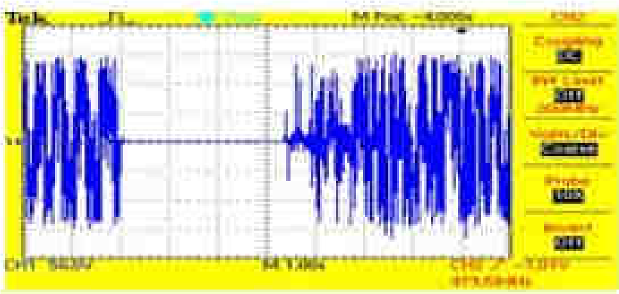

Fig. 9: Output line voltage.

AC source provides 450mS of blackout of the three phase voltages. Fig.9 shows the matrix converter output line voltage. It demonstrate rapid re-starting capability of matrix converter indicating that during the power interruption the power delivered to load is interrupted , however, following the line voltage restoration, the matrix converter rapidly resumes operation and delivers power quickly as compared to PWM converters.

VI. CONCLUSION

Modeling of the system is developed including modeling of induction motor and DSP controlled matrix converter structure.The paper presented indirect space vector modulation technique for three phase-to-three phase matrix converter. The resulting expressions of the modulation signals are simple and suitable for practical implementation. Besides, it is general that it can be used for unbalanced input voltages.

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