Direct Torque Control of Matrix Converter Fed Induction Motor Drive: A Review

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Abstract— **The direct torque control (DTC) scheme for a matrix-converter-fed induction motor drive system is a high performance motor control scheme with fast torque and flux responses. The main disadvantage of conventional DTC is electromagnetic torque ripple. Matrix converter is a single-stage ac-ac power conversion device without dc-link energy storage elements. Switching pattern of the different switches of matrix converter are generated by direct torque control scheme and by suitably selecting switching pattern, the electromagnetic torque ripple of the motor is effectively reduced. By this switching strategy, the advantages of the DTC schemes and the benefits of the matrix converters can be combined and as a result, a satisfactory servo drive can be achieved. This paper presents a literature survey on the direct torque control of matrix converter fed induction motor drive. Different techniques for DTCIMD are described and attempt is made to provide a guideline and quick reference for the researchers and practicing engineers those are working in the area of DTCIMD.**

Keywords— **Matrix converter, Direct torque controlled induction motor drive (DTCIMD), Switching Pattern.**

I. INTRODUCTION

Matrix converter offers an solution for AC-AC power conversion [1-5]. Figure.1 shows a typical three-phase to three phase matrix converter, with nine bi-directional switches. The switches allow any input phase to be connected to any output phase. The output voltage waveform is then created using a suitable PWM modulation pattern similar to a normal inverter, except that the input is a three-phase supply instead of a fixed DC voltage. This approach removes the need for the large reactive energy storage components used in conventional inverter based converters. The direct torque control (DTC) technique for induction motors has been proposed. The main advantages of DTC are robust and fast torque response, no requirements for coordinate transformation, no requirements for PWM pulse generation and current regulators.

Matrix Converters have received considerable attention in recent years. In fact the matrix converter provides bidirectional power flow, sinusoidal input/output waveforms, and controllable input power factor. It allows a compact design due to the lack of dc-link capacitors for energy storage. The ac/ac matrix converter has several advantages.

The capacitor can be a critical component because it is large and expensive. In addition, it has a high-power-factor

sinusoidal input current with a bi-directional power flow for the whole matrix converter drive system. Eupec Company has developed a new technology for integrating the whole matrix converter power devices in a single package and the integrated power modules are now available commercially. This type of packaging can minimize the stray inductance and the size of the power devices [1]. Yaskawa Company has implemented a commercial matrix converter and has shown that it has many advantages. It has less total current harmonic distortion, higher power factor at the input side when compared with the rectifier/dc-link/inverter and it requires small mounting place. As a result, one can predict that the applications of matrix converters will become more and more popular in the near future. The cost of matrix converters will be reduced and will compete with the traditional rectifier/dc-link/ inverter [2].
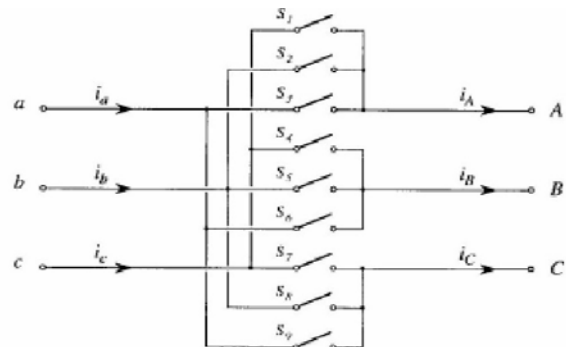

Figure 1. Three phase to three phase Matrix converter

II. MODELLING OF MATRIX CONVERTER

The three inputs of the matrix converter are the phase voltage Vi1, Vi2, Vi3, and its outputs are the voltage Vo1, Vo2, Vo3 (In equation 2 this notation is used for the first harmonic of the output voltages). The matrix components (S1.S2.....S9) represent nine bi-directional switches which are capable of blocking voltage in both directions and of switching without any delays. These are nine ideal switches. The matrix converter connects the three given inputs, with constant amplitude Vi and frequency $fi=\omega i/2\pi$, through the nine switches to the output terminals in accordance with precalculated switching angles. The three phase output voltages

obtained have controllable amplitudes Vo and frequency fo = $\omega_o/2\pi$.

The input three phase voltages of the converter are given by:

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

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

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

The problem at hand may be defined as follows: with input voltages as equation (1), the matrix converter switching angle equations will be formulated so that the first harmonic of the output voltages will be as equation (2).

The 3*3 switches gives 512 combinations of switching states, but only 27 permitted states remain if the two basic rules to operate this converter safely are applied:

(1) DO NOT connect two different input lines to the same output line (short-circuit of the main cause's overcurrent).

(2) DO NOT disconnect the output line currents.

The switching frequency is fs and its angular frequency ($\omega s = 2*pi*fs$) complies with $\omega s \gg \omega i$. In other words the switching frequency is much higher [fs $\cong$ 20 times max (fi, fo)] than the input and output frequencies.

Actually the output voltage vectors from matrix converter can be assigned to four groups:

Group 1: In this group, the output voltage vectors have the same magnitude as the input voltage vi , rotate in the same direction and have a displacement angle of 0°, 120° and 240°.

Group 2: In this group, the output voltage has the same magnitude but rotates in the opposite direction with a displacement angle of 0°, -120° and –240° respectively.

Group 3: In this group, the output vectors have a fixed position, but a magnitude varying with a line-to-line input voltage.

Group 4: In this group a zero vector is generated.

This control method uses only the switching combinations from groups 3 and 4 and than output voltage vectors of matrix converters are as given in Table I.

III. DIRECT TORQUE CONTROL

DTC is a high performance method of motor control systems. Since DTC had proposed for the inverter-fed motor drive systems [7], this control technique has already become an important technology now a days. In order to determine the switching strategies of inverter, the conventional DTC method controls the estimated electromagnetic torque and stator flux of the motor to maintain the errors of the torque and stator flux within the hysteresis bands as shown in Figure. 2.

The main advantages of DTC are fast torque and flux responses, no need for speed or position sensors, no requirements for coordinate transformation and no requirements for the voltages and currents decoupled processes. Therefore, the DTC schemes have attracted many researchers to study and investigate for a long time.

TABLE I.   OUTPUT VOLTAGE VECTORS OF MATRIX CONVERTER

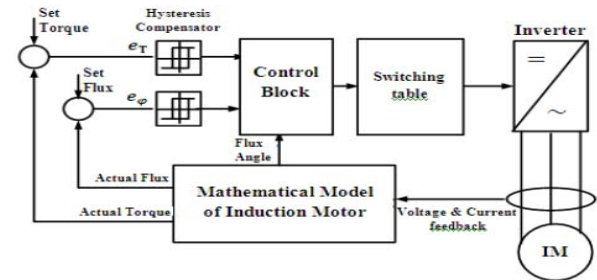|	A	B	C	Vo	A
+1	a	b	b	2/3 V_{ab}	0
-1	b	a	a	-2/3 V_{ab}	Π
+2	b	c	c	2/3 V_{bc}	0
-2	c	b	b	-2/3 V_{bc}	Π
+3	c	a	a	2/3 V_{ca}	0
-3	a	c	c	-2/3 V_{ca}	Π
+4	b	a	b	2/3 V_{ab}	$2\pi/3$
-4	a	b	a	-2/3 V_{ab}	$5\pi/3$
+5	c	b	c	2/3 V_{bc}	$2\pi/3$
-5	b	c	b	-2/3 V_{bc}	$5\pi/3$
+6	a	c	a	2/3 V_{ca}	$2\pi/3$
-6	c	a	c	-2/3 V_{ca}	$5\pi/3$
+7	b	b	a	2/3 V_{ab}	$4\pi/3$
-7	a	a	b	-2/3 V_{ab}	$\pi/3$
+8	c	c	b	2/3 V_{bc}	$4\pi/3$
-8	b	b	c	-2/3 V_{bc}	$\pi/3$
+9	a	a	c	2/3 V_{ca}	$4\pi/3$
-9	c	c	a	-2/3 V_{ca}	$\pi/3$
	a	a	a	-	-
	b	b	b	-	-
	c	c	c	-	-

Figure 2.   Basic DTC Scheme

In recent years, matrix converters and DTC schemes have all already become studied targets for many researchers. The control techniques and practical applications on those areas are more and more increasing importance for motor drive systems but the main drawback of the DTC scheme is the ripple of the electromagnetic torque. Many researchers had proposed the solutions that can reduce the ripple of the torque. In most of these literatures, the following methods are applied to improve the effects of the ripple on the torque output: fuzzy logical controller, multi-level inverter, the modulation methods of the SVM and so on. The DTC using a multi-level inverter can produce more sets of space vector to control torque and flux of a motor and gain more smooth electromagnetic torque of the

motor. However, the multi-level inverters need more power switch elements and cause more cost and complication to the whole system [8].

Using the basic switching table given in Table II, it is possible to implement DTC scheme having good performance. It should be noted that Table II is not the only possible DTC switching table. In general, modified switching table have been proposed in literature with the intention to improve the performance of the DTC scheme at very low and very high rotor speed [3], [7].

TABLE II.   BASIC DTC SWITCHING TABLE USING VSI

$C_\Psi=-1$			$C_\Psi=1$		
$C_t=-1$	$C_t=0$	$C_t=1$	$C_t=-1$	$C_t=0$	$C_t=1$
V2	V7	V6	V3	V0	V5
V3	V0	V1	V4	V7	V6
V4	V7	V2	V5	V0	V1
V5	V0	V3	V6	V7	V2
V6	V7	V4	V1	V0	V3
V1	V0	V5	V2	V7	V4

IV. DIRECT TORQUE CONTROL OF MATRIX CONVERTER FED INDUCTION MOTOR DRIVE

Matrix converter generates more number of output voltage vectors with respect to a VSI, the introduction of a third variable, which is the average value of sine of the displacement angle øi between the input line current vector and the input line to- neutral voltage vector, can be used to control the input power factor. This requirement is satisfied if third variable is kept close to zero. Although a new hysteresis controller is introduced, which controls this variable. The flux, torque and the average value of sin øi estimation requires knowledge of voltages and currents at the input and output side of the matrix converter. Nevertheless, only the input voltages and output currents are measured. The other quantities are calculated by the switching states of the matrix converter. The control algorithm will select the switching state of the matrix converter that generates a voltage vector as similar to that selected by the basic DTC control algorithm.

TABLE III.   MATRIX CONVERTER SWITCHING TABLE FOR DTC CONTROL

	1		*2*		*3*		*4*		*5*		*6*	
H ø	*+1*	*-1*	*+1*	*-1*	*+1*	*-1*	*+1*	*-1*	*+1*	*-1*	*+1*	*-1*
V1	*-3*	*1*	*2*	*-3*	*-1*	*2*	*3*	*-1*	*-2*	*3*	*1*	*-2*
V2	*9*	*-7*	*-8*	*9*	*7*	*-8*	*-9*	*7*	*8*	*-9*	*-7*	*8*
V3	*-6*	*4*	*5*	*-6*	*-4*	*5*	*6*	*-4*	*-5*	*6*	*4*	*-5*
V4	*3*	*-1*	*-2*	*3*	*1*	*-2*	*-3*	*1*	*2*	*-3*	*-1*	*2*
V5	*-9*	*7*	*8*	*-9*	*-7*	*8*	*9*	*-7*	*-8*	*9*	*7*	*-8*
V6	*6*	*-4*	*-5*	*6*	*4*	*-5*	*-6*	*4*	*5*	*-6*	*-4*	*5*

Due to the property of a matrix converter, there are more sets of space vectors can be applied to DTC. As a result, the drive systems fed by the matrix converter that need not any additional power switch element can attain the same performance as the multi-level inverter. To combine the

advantages of matrix converters with the advantages of DTC schemes, it is possible to select the space vector, the current deviations and the torque ripple of the motor can be effectively reduced.

Matrix Converter switching table for DTC control is shown in Table III. The first column on the left hand side in Table contains the voltage vectors selected by the basic DTC scheme in order to keep the stator flux and torque within the limits of the corresponding hysteresis bands. The other six columns are related to the sector of the matrix converter input current vector Ii. Depending on the output value of the Cø hysteresis comparator, the left or the right column has to be used in selecting the switching configuration of the matrix converter. when a zero voltage vector is required from Table II, the zero configuration of the matrix converter which minimizes the number of commutations is selected. The output of the hysteresis regulator Cø, together with the sector number of the input current vector and the voltage vector required by the DTC, are the input to the matrix converter switching configuration selection algorithm represented by Table III.
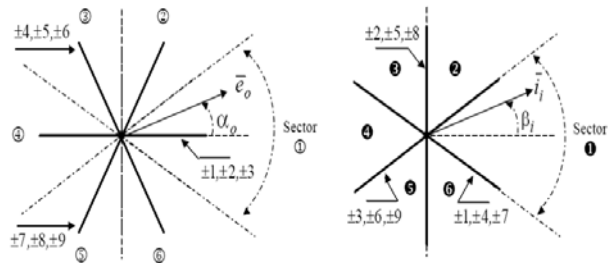

Figure 3.   (a) Output voltage vectors for active configuration and reference output voltage vector (b) Input current vectors for active configuration and reference input current vector

In recent trend, there is increased interest in direct torque control of matrix converter fed induction motor drive. In this paper a review on the different techniques based on the switching patterns of matrix converters are presented.

Guo qiangang" et al.[2] presents, which integrates MC and MCM into a single unit, solves the problem of low voltage transfer ratio of MC, reduces the cost and increases the overall efficiency and the equipment ability. The mathematical model of matrix converter fed motor drive system in the static plane based on the fictitious link concept was given. A novel control method for matrix converter fed motor drive system was proposed, which allows under the unity input power factor and the required voltage vectors to implement the direct torque control.

Hong-Hee Lee, et al.[1] presents direct torque control method (DTC) using matrix converter fed induction motor. The advantages of matrix converters are combined with the DTC technique under the constraint of unity input power factor, the required voltage vectors are generated to implement the conventional DTC method of induction motor. It describes the operation of induction motor under the DTC method in steady-state and transient conditions by the experimental results.

T. Satish, et al.[3] presents, a closed loop adaptive speed observer is proposed to improve the dynamic performance of a matrix converter (MC) fed stator flux oriented DTC induction motor drive. The speed observer uses estimated rotor fluxes to estimate the rotor speed. The advantages of using a full order Luenberger observer instead of a reduced order closed loop model with the proposed speed observer, for the estimation of the flux linkages, are demonstrated using experiments. Finally, the performance of the proposed observer is compared with a full order Luenberger observer that uses error between estimated and sensed stator dq axes currents for estimating the rotor speed. The superior dynamic performance of the proposed observer during sudden speed reversal command is demonstrated with experiments on a 3hp induction motor.

Hong-Hee Lee et al.[4] presents, experimental implementation with the DTC method using the matrix converter fed induction motor. This inherits the advantages of the DTC and the advantages of the matrix converter characteristics. The steady and transient results are shown to validate the stability and the robustness of the DTC method in the practical applications. With an improved hardware, the DTC method using the matrix converter may become the most appropriate solution to build a compact drive fed induction motor.

Ruzlaini ghoni et al. [5] presents, new control scheme based on hybrid particle swarm optimization (HPSO). The controller used the information provided by the torque and stator flux errors to modify the standard DTC voltage vector selection process. The voltage vector selected in the new HPSO scheme is the one producing the lowest possible start-up stator current and a reduced torque ripple hence improving the standard DTC scheme performance. Comparing with the DSP serial calculations of the DTC system for matrix converter induction motor, the control precision of DTC can be significantly improved by using the HPSO algorithm and the HPSO induction motor model allows the estimation of important parameters of motor such as speed, stator flux, rotor flux and torque without using the sensors. The results obtained show a better torque response for 0.9 power factor. The results are of good quality and robustness in the system dynamic response and reduction in the steady-state and transient motor ripple torque.

Hong-Hee Lee, et al.[6] presents, a new control strategy to improve efficiency, robustness and dynamic response for the matrix converter fed induction motor drive. It demonstrates a new modified method to improve the performance of motor, reduction of the load torque ripple and the flux ripple within its boundaries as compared with the conventional DTC method within each sample period, the time when actual flux comes to its boundaries is estimated and the actual torque is also calculated simultaneously. Therefore, we can produce the second space vector to correct the operation of load torque and flux. This new proposed method can be implemented quite easily.

J. Lettl et al. [7] presents, switching table based direct torque control (ST-DTC) in the matrix converter-fed induction motor drive. In order to improve the control of the matrix converter input power factor, the use of the simplified indirect

space vector modulation (ISVM) was proposed. It treats the matrix converter as a combination of an input virtual rectifier and an output virtual inverter stages, connected by a virtual DC link. The virtual rectifier stage SVM generates the input current vector with selected phase displacement with respect to the input voltage vector and at the same time generates the virtual DC link voltage. The virtual inverter stage then uses this virtual DC link voltage to generate the output voltage vector. This vector will then be generated by the simplified ISVM. In the simplified ISVM, the virtual rectifier stage will insure proper orientation of the input current vector and therefore will keep the reference power factor.

Kyo-Beum Lee et al.[9] presents, high performance control of induction motor drives fed by a matrix converter, a new DTC method for sensorless matrix converter drives have been proposed. The proposed method using SVM, flux deadbeat controller with simple non-linearity compensation using PQR power theory enables to minimize current and torque ripple, to obtain unity input power factor and to achieve good sensorless speed-control performance in the low speed operation, while maintaining constant switching frequency and torque dynamic response. It demonstrates that torque, flux, input power factor and speed control performance are improved with the proposed improved DTC.

Nabil Taib et al.[10] presents, a new constant switching frequency DTC of induction motor drives, in which a direct matrix converter is used for supplying the system, is proposed. The proposed scheme has been tested in the steady-state as well as in the dynamic transients. The torque, flux and current waveforms emphasize the effectiveness of the control scheme. The proposed technique using the fixed switching frequency DTC minimizes torque ripple. The results show that, during the regenerative braking, the drive system acts as a nearly sinusoidal unity input power factor generator.

Kai Sun et al. [12] presents, Nonlinear robust controller for matrix converter fed induction motor drives in which a nonlinear robust auto disturbance rejection controller (ADRC) is applied to the MC fed induction motor drive system, taking the place of proportional-integral (PI) regulator. In the drive system, the effects of external disturbance and model uncertainty are estimated and compensated by ADRC. Using this controller, the anti-disturbance capability of the drive system under abnormal input voltage conditions can be enhanced. In addition, the dynamic drive performances of induction motor are also improved, such as fast responses of speed change and load torque change.

J. Rodriguez et al. [13] presents a new control strategy for a matrix converter feeding an induction machine, in which a simple discrete model of the machine and the converter are used to predict the behavior of torque and flux. The switching state that optimizes the value of a quality function is selected. The proposed strategy considers the discrete nature of control processors and power converters, presenting a different approach to achieve control. Results confirm a very good motor performance with an extremely simple and versatile control method.

Zheng LI [14] presents matrix converter and direct torque control strategy of induction motor by using space vector

modulation algorithm. Based on the principles of the matrix converter and direct torque control, an incorporated combining control strategy presents, in which it can implement the real-time space vector modulation of converter and induction motor stator flux linkage oriented direct torque control. The steady state and transient state performance are simulated. It shows that under different conditions, the control system can derive quick and stable dynamic and static characteristics, with bidirectional power flow and advantages of matrix converter.

Binjun Cai et al.[15] presents a novel control strategy, which properly combines the space vector modulation (SVM) of MC with the DTC of induction machine through PI regulation of flux and torque. It improves the control performance of system, especially for the torque at low-speed. Results demonstrating the effectiveness of the torque control response and the input power factor correction. Furthermore, the novel control strategy makes the flux and torque small and stable.

V. Faraji et al.[17] presents the use of four step switching in rectifier bridge of indirect matrix converters to reduce the electromagnetic torque ripple, which appears when direct torque control technique is used in induction motors. By suitably selecting switching pattern, the electromagnetic torque ripple of the motor is effectively reduced. The advantages of this combination are: small size, fast response in torque control, near sinusoidal input current, adjustable input displacement power factor, regeneration capability and long life-time. The comparison of motor performance under the proposed control system with respect to those obtained under conventional DTC confirms its effectiveness and accuracy.

Vahid Faraji et al. [18] presents a high performance direct torque control (DTC) for the induction motor fed by indirect matrix converter has been investigated. Since the indirect matrix converter has an intermediate dc link, the control process can be separated into rectifier stage modulation and inverter stage modulation. Indirect space vector modulation (ISVM) for input current is applied on the rectifier bridge, while the inverter and motor can be seen as constant current load in DC link and ISVM for output voltage is applied on the inverter bridge. The modulation processes of rectifier stage and inverter stage are considered simultaneously. By suitably selecting switching pattern, the electromagnetic torque ripple of the motor is effectively reduced. The results of DTC system based on IMC and the comparison of motor performance under the proposed control system with respect to those obtained under conventional DTC confirm its effectiveness and accuracy.

H.F. Abdul Wahab et al. [19] presents direct torque control of induction machine which is considered as an alternative to the field oriented control (FOC) or vector control technique. They aim to control effectively the torque and flux. Torque control of an induction machine based on DTC strategy has been developed. The DTC allows the independent and decoupled control of torque and stator flux. In order to show the effectiveness of the model, a numerical simulation has been performed on a 7.5 kW induction machine fed by an IGBT PWM inverter. The feasibility and the validity of the developed DTC model, based on switching table technique, have been proved by simulation results obtained in the torque control mode.

Rene Vargas et al.[27] presents method for current control of an induction machine fed by an MC, effectively controls the output current from the MC to the machine and the reactive input current to the system. The proposed strategy allows the regulation of the input pf by means of a simple and straight forward technique, controlling the phase of the input current in a way that the converter can work with capacitive, unity, or inductive pf according to the requirements of the application. The proposed control method replaces a modulation stage carrier-based, SVM or others and the current controller in a classic control scheme. Joint with FOC, the strategy allows for an excellent control of an induction machine together with the input currents from the mains. The method was tested on speed reversals, different load conditions and regenerating, revealing good performance in all cases. Moreover, the strategy was tested under unbalanced mains, presenting a satisfactory behavior without any further modification. Output variables, as currents to the machine and speed, remained unchanged when the unbalance is introduced to the grid. The current control strategy can also be applied to other loads that fulfill or can be represented by the proposed model. The method can be easily implemented, taking advantage of the present technologies available in digital signal processors. The high sampling frequency required should not be a problem now a day. This control strategy uses in a convenient way, the discrete nature of power converters and microprocessors used in their control. These results show that predictive control is a very powerful tool, with a conceptually different approach that opens new possibilities in the control of power converters.

Yaohua Li et al. [21] presents two-stage matrix converter (TSMC), which has many advantages as bidirectional power flow, high quality input/output waveform, simply clamp circuit and compact power circuit. TSMC has a low immunity to the ac line disturbances, which can degrade its performance and reliability. A novel direct torque control method for induction motor drive system fed by TSMC considers as the combination of an AC/DC and a DC/AC without DC-link capacitor and controls AC/DC and DC/AC separately. As the angle of output voltage vectors of TSMC is fixed, DTC can be applied on DC/AC of TSMC. To control AC/DC is to provide the positive dc-bus voltage for DC/AC and improve the steady and dynamic performance of the drive system. Results verify the performance and strong robustness for input voltage of the proposed control method and demonstrate that this method is very suitable for industry application supplied by non-ideal grid.

Der-Fa Chen et al. [22] presents a direct torque control (DTC) scheme for a matrix-converter-fed induction motor drive system. Due to the properties of the matrix converter, the pseudo dc-link will provide with three different types of voltage: the high, middle and low voltages. Therefore, based on space vector modulation generated by a matrix converter, there are three states on each space vector location. By suitably selecting switching pattern, the electromagnetic torque ripple of the motor is effectively reduced.

Kyo-Beum Lee et al. [26] presents a simple direct torque control (DTC) method for sensorless matrix converter drives was proposed, which characterizes by a simple structure, minimal torque ripple and unity input power factor. It is possible to combine the advantages of matrix converters with the advantages of the DTC strategy using space vector modulation and a deadbeat algorithm in the stator flux reference frame. The flux and torque error are geometrically put together in a new flux leakage vector to make a stator command voltage vector in a deadbeat manner. To overcome the degrading of dynamic torque response compared to the basic DTC method, an over modulation strategy presents in the proposed control scheme. A nonlinearity compensation strategy has been developed to make better the speed control performance in the low speed region. A supply voltage unbalance compensation technique that improves the input power quality has been presented. The experimental results have shown that the speed control performance, current waveforms and input power quality have been improved. Experimental results are shown to illustrate the feasibility of the proposed strategy.

Bhim Singh et al.[23] presents a torque ripple minimization technique with constant switching frequency is proposed for direct torque control (DTC) of a matrix converter fed squirrel cage induction motor drive in which, an optimal switching instant during one switching cycle is calculated for torque ripple minimization, which is derived from torque ripple based on an instantaneous torque. It has been tested in steady-state and transient conditions in the low and high speed ranges and compared with the matrix converter fed conventional DTCIMD. The dynamic behavior has been tested with both step change in torque and step change in speed from the motor in regenerative braking operating condition. The results verify the feasibility of the modified DTC method for matrix converter and also show that the Modified DTC improves the torque control characteristic with the THD of the AC source current.

R. R. Joshi et al. [24] presents a fuzzy logic controller for a direct torque control of matrix converter fed induction machine. A response faster than conventional DTC during startup and during a step change in torque is achieved and also a fuzzy resistance estimator has been proposed to correct the stator resistance used by the controller to match the actual stator resistance of the machine. The stator resistance used by the controller follows the actual stator resistance of the machine. The current implementation of the stator resistance estimator has been found to give trouble at low torque levels. Under low torque levels, resistance estimates were found to vary irradically causing the controller to produce improper torque and flux. It is necessary to turn off the estimator at low torque levels to ensure proper operation. Rigorous investigation is being undertaken to improve the controller performance. As a result, it is likely to play major role in future converter designs both as a motor drive at low and high powers and as a power converter linking two electrical power systems having different voltages and frequencies.

Brahim Metidji et al. presents, a modified fuzzy direct torque control scheme of induction motor fed by matrix converter to reduce the electromagnetic torque ripple which is one of the most important drawbacks of direct torque control. This DTC scheme based fuzzy logic regulation of the virtual DC voltage in the virtual rectifier stage output. A comparison between the classical direct torque control using matrix converters and the proposed method is carried out. It introduces a novel fuzzy logic based direct torque control with direct matrix converters which uses a classic direct torque control in inverter stage and controlled modulation index in rectifier stage to reduce the electromagnetic torque ripple. Results show that by using the proposed direct torque scheme with direct matrix converter, the torque ripple is significantly reduced.

Brahim Metidji, et al. [8] presents, a new approach for direct torque control of three phase induction motor fed by indirect matrix converter using fuzzy logic technique. It develops a fuzzy logic based DTC-SVM methodology for AC drive systems which is proposed for an efficient torque and flux control without changing the motor parameters. A direct torque fuzzy control of SVM indirect matrix converter fed induction motor drive system has been described. The system was analyzed, designed and its performances were studied extensively. The results show that the proposed method procures high performance in presence of load disturbances. The control of speed gives fast dynamic response with no overshoot. This technique can be applied for AC drives where high dynamic performance is required. The proposed method combines the direct torque control method and the indirect matrix converter, the advantages of this combination are fast torque response, near sinusoidal input current and adjustable input displacement power factor.

Chitra Venugopal [16] presents the fuzzy inference system for selecting the switch states of matrix converter using direct torque control technique to control the speed of induction motor. In this system, two fuzzy controllers are used. One fuzzy controller estimates the voltage and the other fuzzy controller is used to select the switching vector based on the voltage vector selected by the first fuzzy controller. DTC using fuzzy controller is designed and implemented for matrix converter fed induction motor and results are compared with the conventional DTC controller fed Matrix Converter drive. The speed and torque response of both the controllers are analyzed under various operating conditions. It is observed that the fuzzy controller performance is better than the conventional controller.

R.Toufouti et al. [20] presents DTC based on fuzzy logic technique switching table, is described and compared with conventional direct torque control (DTC). The FLDTC of induction machine can achieve precise control of the stator flux and torque compared to conventional DTC. This method is easily implemented, and the steady performances of ripples of both torque and flux are considerably improved. The main improvements shown are: reduction of torque and current ripples, no flux droppings caused by sector changes circular trajectory, fast torque response and zero-steady-state torque and flux.

Phon quoc Dzung et al. [25] presents a new complete artificial neural network based direct torque control (ANN-DTC) scheme for a matrix converter fed three phase induction motor. Based on the understanding of DTC complexity

(dynamic, recurrent and nonlinear), the fixed weight and supervised methods with the training individually strategy are implemented for the controller design. Complete ANN system for MC-IM consists 12 layers and 134 neurons. Compared with the DSP based DTC, the proposed ANN-DTC scheme for matrix converter–induction motor incurs much shorter execution times (about one third of execution time of DSP controller) and hence the flux and torque errors caused by control time delays are minimized.

V.   CONCLUSION

In this paper, a review of previous research in Direct Torque Control of Matrix Converter Fed Induction Motor Drive has been presented. The fundamentals of various methods have been introduced as a useful reference for preliminary investigation of conventional methods. The recent advancements in the fuzzy logic and neural network were also discussed.

As the performance of the DTCIMD drive schemes has the advantages are: small size, fast response in torque control, near sinusoidal input current, adjustable input displacement power factor and long life-time. Different new control techniques like the fuzzy logic and neural network are becoming interesting perspective for the future research. At present, these new techniques are alternative solution to the conventional control techniques. A detailed survey of the literature available in this topic has been given to provide a comprehensive insight into this subject.

VI.   REFERENCES

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