Matrix Converter fed Induction motor Drive using Fuzzy Logic based Direct Torque Control

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Abstract : This paper presents the fuzzy logic based direct torque control (DTC) of induction motor fed by matrix converter. Using the proposed system the advantage of both DTC and the matrix converter can be achieved together. The use of fuzzy logic controller reduces the ripple content in electromagnetic torque. The comparative results in case of steady state and transient conditions are analyzed to test the effectiveness of the proposed controller. The proposed system simulated in MATLAB Simulink environment. The results shows that the ripple contents in electromagnetic torque are significantly reduced using the proposed fuzzy logic based controller.

***Index Terms* – Direct Torque Control, Fuzzy Logic, Torque.**

I. INTRODUCTION

Variable speed drives are generally used to control the speed with high efficiency and performance. These drives make extensive use of different controllers and switching techniques. The pulse width modulation (PWM) and space vector pulse width modulation (SVPWM) switching techniques are used to control and regulate the frequency and output voltage of the drive. These switching techniques have the ability to reduce harmonic content, low switching losses and more output power with satisfactory performance. To reduce complex online computation, ANN, ANFIS and FLC based SVPWM are also used (Durgasukumar, 2012, Agarwal, 2014, Sathish Kumar, 2017). Apart from the conventional controllers (PID, PD and PI), the microcontrollers, DSPs, FPGAs, dSPACE and other integrated circuits are used as controller platform to design the IM controllers to regulate the motor variables like flux, voltage, torque, and speed with quick response (Reza, 2015, Gdaim, 2015, Liu, 2018).
With vector control method for induction motor operation, the magnitude and the phase of stator voltage can be controlled. The advantage of the direct torque control method is that it has very fast response and simple structure which makes it to be more popular used in industrial world. For the induction motor direct torque control initially proposed as direct self control by Depenbrok in 1988, and as direct torque control proposed by Takahashi in 1986. This method of control implies a comparative control of the torque and the stator flux which must fall into two separate certain bands to be applicable. The simple objective is to control two quantities which are the stator flux vector and the electromagnetic torque. Those quantities are directly controlled by selecting the proper converter state with a combination of sense, command and control feedback loops and by power electronics drive control in the inverter stage. Various research papers are published on DTC scheme with matrix converter with PSMS (Ortega, 2010) and induction motor (Chen, 2007, Lettl, 2010).

This paper proposed a fuzzy logic based direct torque control of induction motor fed by matrix converter. Unlike AC-DC-AC power converters the matrix converter does not require any energy storage element as it is direct AC-AC converter resulting it has less weight and size. The combined advantage of both DTC and matrix converter can be achieved using DTC with matrix converter

II. DTC FOR MATRX CONVERTER

The direct torque control for matrix converter is developed from the conventional DTC for VSI. There are six switching configuration for any selected VSI output vector, and these six switching configuration can be applied to the matrix converter to generate the same output voltage vector, as shown in Fig. 1(a), and six input current vectors for every sector having different directions as shown in fig. 1(b).

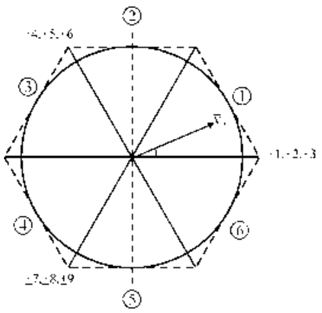

Fig. 1 (a) : Output Voltage Vector

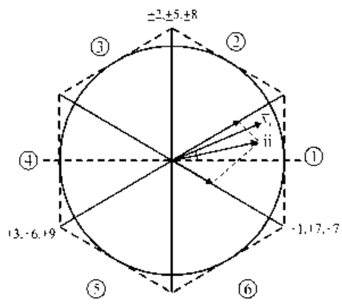

Fig. 1(b) : Input Current Vector

The possible switching configurations(SCs) in 3x3 matrix converter are 27, out of these in first six SCs each output phase is connected to a different input phase, in next 18 SCs the two output phase among three are shorted and in the rest three SCs a the three output phases are short-circuited. Twenty one out of these twenty seven SCs are useful.

From fig. 1 it is observed that the switching configuration ±1, ±2. ±3 can be applied to the matrix converter to generate the voltage vector V_1 and V_4, the switching configuration ±4, ±5, ±6 can be applied to the matrix converter to generate the voltage vector V_2 and V_5 and ±7, ±8. ±9 can be applied to the matrix converter to generate the voltage vector V_3 and V_6. The magnitude and direction of the matrix converter output vector depends upon the input vector at any instance.

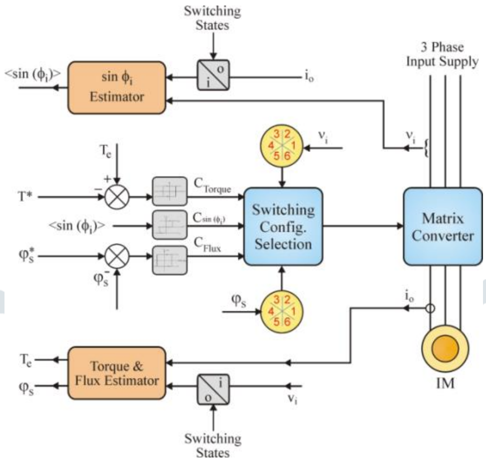

Fig. 2 Direct Torque Control Scheme for the Matrix Converter Block Diagram

When stator flux vector is in sector 1 and flux error at the lower end of the flux hysteresis i.e. -1, then voltage vector V_2 and V_6 is selected in order to increase the flux and vector V_3 and V_5 is selected in order to decrease the flux.

Table 1 Switching Configurations for DTC based Matrix Converter

Sectors of Input Voltage Vector		**I**		**II**		**III**		**IV**		**V**		**VI**	
$C_{sin(\phi_i)}$		+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1
O/p VECTOR (INVERTER STAGE OF MC)	**V_1**	-3	+1	+2	-3	-1	+2	+3	-1	-2	+3	+1	-2
	V_2	+9	-7	-8	+9	+7	-8	-9	+7	+8	-9	-7	+8
	V_3	-6	+4	+5	-6	-4	+5	+6	-4	-5	+6	+4	-5
	V_4	+3	-1	-2	+3	+1	-2	-3	+1	+2	-3	-1	+2
	V_5	-9	+7	+8	-9	-7	+8	+9	-7	-8	+9	+7	-8
	V_6	+6	-4	-5	+6	+4	-5	-6	+4	+5	-6	-4	+5

Fig. 2 shows the block diagram of the direct torque control for matrix converter. Only the input voltage and output current are measured rest are calculated. A two level hysteresis comparator is used for flux error and for electromagnetic torque error a three level hysteresis comparator is used. The sine of the input displacement angle ϕ_i is considered as a third controlling component for the switching configuration in proposed DTC control. ϕ_i is the angle between input voltages vector and input current vector. The average value of sin ϕ_i is maintained near to zero in order to maintain the input power factor unity.

III. ESTIMATION OF FLUX AND ELECTROMAGNETIC TORQUE

The stator flux linkage can be estimated by integrating the stator voltage

$$\varphi_{ds} = \int (v_{ds} - i_{ds} R_s) dt \qquad ...(1)$$

$$\varphi_{qs} = \int (v_{qs} - i_{qs} R_s) dt \qquad ...(2)$$

$$\varphi_s = \sqrt{\varphi_{ds}^2 + \varphi_{qs}^2} \qquad ...(3)$$

The electromagnetic torque can be estimated using the stator flux linkage and motor current vector.

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}\right) \qquad ...(4)$$

IV. DEVELOPMET OF FUZZY LOGIC CONTROLLER

The direct torque control method is simple to implement and it gives fast response. In addition to these advantages there are some drawbacks of DTC scheme i.e. higher the electromagnetic torque and stator flux ripples. The proposed fuzzy logic based DTC overcome these drawbacks. The Mamdani-type Fuzzy Logic Controller is used to adjust the torque hysteresis band to reduce the ripples in the torque.

The change in torque hysteresis band is considered as the output of the fuzzy logic controller. therefore the upper band and lower band of torque hysteresis controller are adjusted with output of the fuzzy logic controller such that the ripples in electromagnetic torque is being minimum, resulting the ripples in the motor speed can be minimized in order to get the smooth speed of the induction motor over a wide range of the speed load within the rated limits. The input and output membership function of the proposed fuzzy logic is shown in fig. 3- fig. 5.

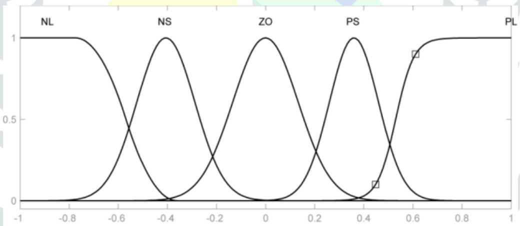

Fig. 3 : Membership Function for Input Variables (ΔT_e) of Fuzzy Logic Controller

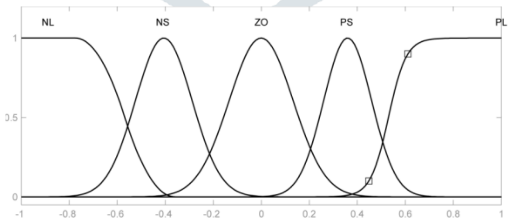

Fig. 4 : Membership Function for Input Variables (ΔI)of Fuzzy Logic Controller

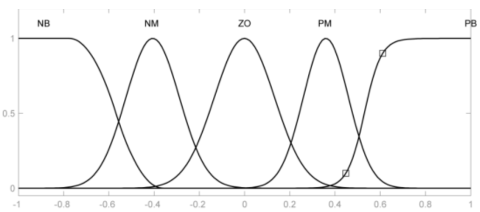

Fig. 5 : Membership Function for Output Variables of Fuzzy Logic Controller

V. RESULT AND DISCUSSION

a. Response of System at Constant Reference Speed

The desired speed is considered 100 rad/sec and at no load condition to test the steady state performance of the proposed system at no load and the comparison is shown between the conventional DTC and the proposed fuzzy logic DTC based IM drive.

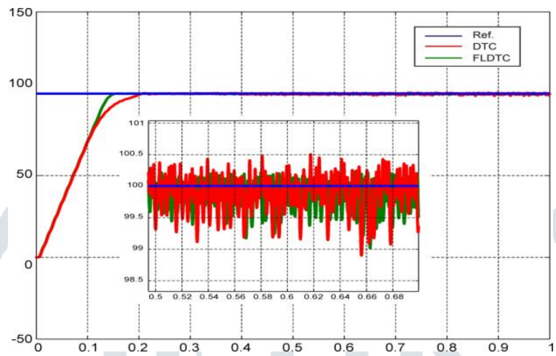

Fig. 6 : Simulated comparative Speed Response of Induction Motor Drive at No Load Condition

Figures 6 show the comparative speed response of the induction motor drive with and without fuzzy logic control. It is observed that the proposed fuzzy logic DTC based system reaches its steady state condition in 0.18 sec. while the conventional DTC based system settle down in 0.21 sec. The proposed controller yields faster response. The maximum variation in speed is 1.2 rad/sec. in case of conventional DTC whereas the maximum variation in speed is 0.8 rad/sec. in proposed system. The variations in speed less in proposed FLDTC based IM drive resulting lower vibrations in motor.

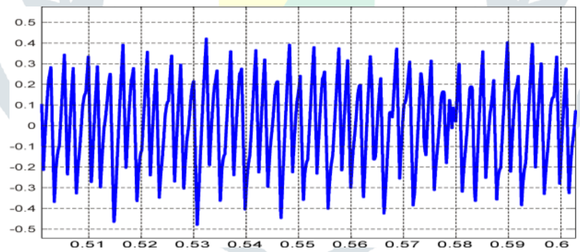

Fig. 7 :Electromagnetic Torque Ripple with Conventional DTC

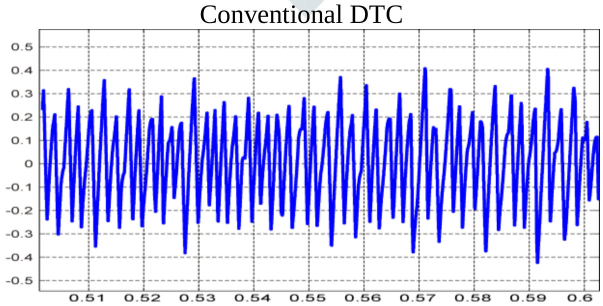

Fig. 8 Electromagnetic Torque Ripple with Proposed Fuzzy Logic DTC based Controller

It is seen from fig. 7 and fig. 8 that the maximum ripple using the proposed controller is 0.41 N-m whereas the ripple in electromagnetic torque using conventional DTC based IM drive is 0.48 N-m. The fuzzy logic based DTC minimized the ripple content in the electromagnetic torque.

b. Response of the IM Drive with Step Change in Reference Speed at No Load Condition

In this section the performance of the proposed controller is tested with a step change in desired speed to test the dynamic performance of the system at no load the reference speed is changed from 80 to 100 rad/sec at the instant of 0.3 sec and again speed is changed from 100 to 80 at the instant of 0.6 sec. At the above mention conditions the response of the proposed system is compared with the conventional DTC based IM Drive.

The response of speed of the IM drive with proposed fuzzy logic based controller and the conventional DTC based controller are with step change in load torque is shown in figure 7(a). The IM achieved the steady state speed faster in the case of proposed fuzzy logic DTC controlled IM drive.

The speed of IM with proposed fuzzy logic DTC controller settle down at 0.35 sec. whereas the speed of IM with conventional DTC is settle down at 0.37 sec. resulting the settling time of the IM with proposed controller (0.05 sec.) is less than the settling time with conventional DTC (0.07 sec.).Similarly when a step change in reference speed of induction motor is done by decreasing the speed from 100 rps to 80 rps, it is also observe that the settling time is less for the proposed system when a sudden change in speed is applied. By analyzing the simulated results with applying sudden change in desired speed it is seen that the dynamic performance of the IM with proposed controller is better than that of conventional DTC without fuzzy logic controller.

Figure 7(b) shows the comparison in electromagnetic torque response of the proposed IM drive system and conventional IM drive system with step change in reference speed.

The maximum positive torque is applied at time t=0.3 sec. in order to increase the speed from 80 rps to 100 rps and the electromagnetic torque reaches again to its previous value as the speed settle down to the desired value at time t=0.37 sec. in case of conventional DTC whereas time t=0.35 sec. with proposed controller. Similarly when the speed need to decrease, a maximum negative torque is applied at time t=0.6 sec. and the torque reaches its previous value as the speed settle at new desired value at time t=0.63 sec. in case of conventional DTC whereas time t=0.62 sec. with proposed controller.

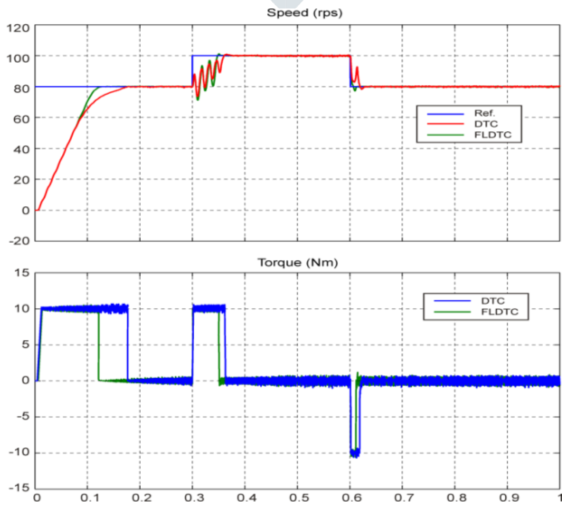

Fig. 7 : (a) Comparison of Speed and (b)Electromagnetic Torque with Step Change in Reference Speed and No Load Condition

VI. CONCLOSON

This paper introduces a fuzzy logic based direct torque control of the induction motor fed by matrix converter. The performance of the system tested in steady state condition and with step change in load torque found good. The system yields fast dynamic response with the proposed controller. It is seen that ripple contents in electromagnetic torque is reduced. The simulation results demonstrate the superior performance of the proposed system as compared to the conventional DTC controller.

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