Comparative Study of Direct Torque Control in Four Switch and Six Switch Three Phase Inverter

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Abstract— The present paper investigates the performance of four switch three phase inverter (FSTPI) and six switch three phase inverter (SSTPI) fed induction motor drive. Direct torque control of induction motor drives are done mainly using six switch three phase inverter. In low power applications, six switch three phase inverter can be replaced by four switch three phase inverter. FSTPI helps reduction in switching losses, gate drive requirements, circuit cost and computational time. Four unbalanced voltage vector produced by this four switch inverter is used for synthesis of six balanced voltage vectors having same magnitude as that of six switch three phase inverter by using a suitable lookup table. A comparative simulation study is done between four switch three phase inverter and six switch three phase inverter fed induction motor drives and verified using MATLAB/SIMULINK.

Key words: Direct torque control (DTC), Four Switch Three Phase Inverter (FSTPI), Six Switch Three Phase inverter (SSTPI), Induction motor

I. INTRODUCTION

Induction motor is widely used in industrial or general applications due to its robustness, low cost, the better performance and the ease of maintenance. IM drive demands precise and quick torque and flux responses. Mostly, six switch three phase inverter is used as a voltage source inverter for induction motor. But we can provide an alternate strategy to control IM by using four switch three phase inverter [1]. At low power application, FSTPI fed IM drives are more suitable than SSTPI. Also reconfiguration of these three leg inverter to FSTPI, in case of switch or leg failure can be done.

Several researches were going on based on implementing of four switch three phase inverter (FSTPI) in low power industrial applications [2-4]. This reduces the overall cost of the IM drive by reducing number of switching components and its driver circuit. By using two leg inverters instead of three leg inverters the switching losses, total harmonic injection and also electromagnetic interference can also reduce. Direct torque control is used here to implement four switch topology in induction motor DTC of IM drives has been widely used due its possible rapid real time application as compared with other control methods in induction motors [5]. DTC has following merits such as very simple control scheme and low computational time and reduced parameter sensitivity [6]. By using DTC we can estimate torque and magnetic flux of motor by measuring current and voltage of the motor [7].

DTC strategy based on FSTPI generates four unbalanced voltage vectors and they are aligned in four sectors in Clarke's plane. In SSTPI six balanced active vectors having equal magnitude are generated and they lie on six sectors in Clarke's plane. This difference between the basic space vectors of FSTPI and SSTPI pay less achievement in field of FSTPI topology. The method of direct torque control of FSTPI and SSTPI are similar instead of their voltage vectors and sectors. In this paper by using a desired switching technique for FSTPI, the Clarke's plane is divided in to six sectors and six balanced voltage vectors equivalent to SSTPI topology were produced by applying mean vectors of FSTPI [8]. This method increases the efficiency of induction motor drive.

II. FOUR SWITCH THREE PHASE INVERTER

A. Theory

The four switch three phase inverter is configured by using four switches as shown in fig.1. The open and closed condition of switches S_1, S_2, S_3 and S_4 are represented as either by '1' or '0'.

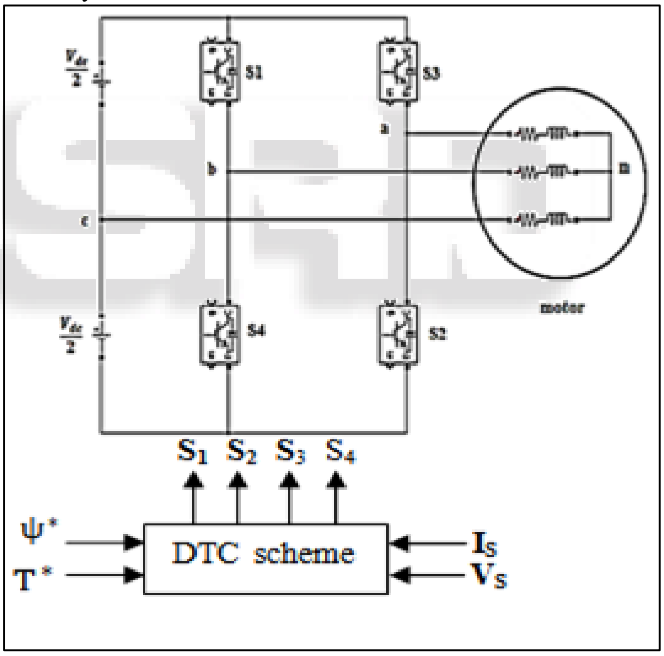

Fig. 1: DTC system for FSTPI

The states of upper switches and lower switches are complimentary to each other. That means,

$$S_1 + S_3 = 1 \quad (1.1)$$

$$S_2 + S_4 = 1 \quad (1.2)$$

The output terminal voltages of inverter V_{as} , V_{bs}, V_{cs} are given to the three phase terminal of star connected induction motor drive and are represented as given below,

$$V_{as} = \frac{V_C}{3}(4S_1 - 2S_2 - 1) \quad (1.3)$$

$$V_{bs} = \frac{V_C}{3}(-2S_1 + 4S_2 - 1) \quad (1.4)$$

$$V_{cs} = \frac{V_C}{3}(-2S_1 - 2S_2 + 2) \quad (1.5)$$

Usually, FSTPI configuration produce four unbalanced output voltage vectors V_1, V_2, V_3 and V_4 and no non zero vector as shown in fig.2. They have unequal magnitude. The angle between adjacent vectors is 90° that means these vectors divide αβ plane in to four sectors as shown in figure. By suitably selecting the switching states, desired three phase output voltage can be obtained at terminals of induction motor drive.

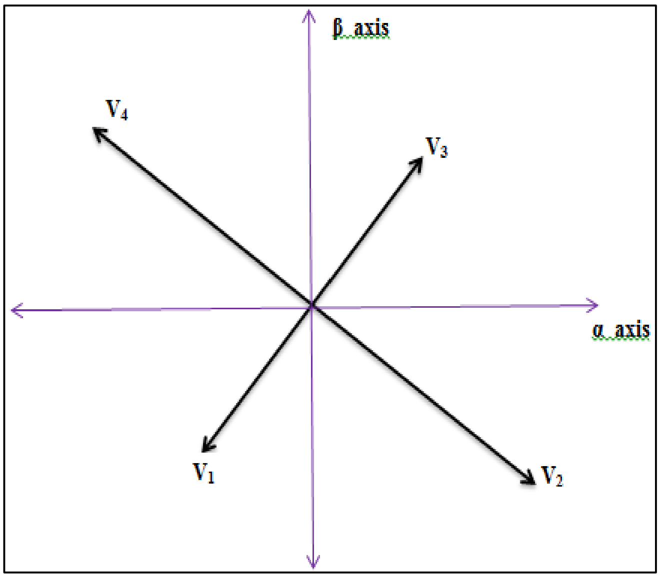

Fig. 2: Unbalanced voltage vectors of basic FSTPI

B. *Basic DTC for FSTPI*

The main aim of direct torque control strategy isto control directly the stator flux linkage or magnetizing flux linkage or rotor flux linkage and electromagnetic torque by the proper selection of inverter's switching selection table.The switching state selection is made to restrict the flux and torque within the respective flux and torque hysteresis bands, to get low inverter switching loss, fast dynamic response and harmonic distortion in stator currents. The selection of vectors depends on the output$\Delta\psi$ of the fluxhysteresis controller, the output$\Delta T$of the torque hysteresis controller, and the angular displacement θ_s of the stator flux vector ψ_s in the Clarke plane.

By Clark's transformation, stator voltages and currents can be obtained as,

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \quad (1.6)$$

$$\begin{bmatrix} I_{ds} \\ I_{qs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (1.7)$$

Since flux and torque calculations remain the same, stator flux is estimated as follows:

$$\psi_{ds} = \int (V_{ds} - R_s I_{ds})dt \quad (1.8)$$

$$\psi_{qs} = \int (V_{qs} - R_s I_{qs})dt \quad (1.9)$$

From the d and q axis component of stator flux ψ_{ds}andψ_{qs} resultant flux (ψ_s) and its angular displacement (θ_s) are obtained as follows:

$$\psi_s = \sqrt{\psi_{ds}^2 + \psi_{qs}^2} \quad (1.10)$$

$$\theta_s = tan^{-1}\left(\frac{\psi_{qs}}{\psi_{ds}}\right) \quad (1.11)$$

The electromagnetic torque is given by the equation,

$$T_e = \frac{3P}{4}(\psi_{ds} I_{qs} - \psi_{qs} I_{ds}) \quad (1.12)$$

Where, *P* is number of poles

R_S is the stator resistance

The main difference between the DTC system based on SSTPI and FSTPI is the optimum look up table. The other steps (motor terminal voltages reconstruction, flux, and torque calculations) are the same. The lookup table I represent the vectors in each switching period for basic DTC of FSTPI. There are no zero vectors, so a two-level torque hysteresis controller is used instead of three level hysteresis controllers.

Δψ	ΔT	Sectors			
		I	II	III	IV
1	1	V_3	V_4	V_1	V_2
	-1	V_2	V_3	V_4	V_1
-1	1	V_4	V_1	V_2	V_3
	-1	V_1	V_2	V_3	V_4

Table 1: Vector selection table for basic DTC of FSTPI

III. PROPOSED DTC IN FSTPIFOR SIX VECTOR GENERATION

The four active vectors generated in FSTPI is used to synthesis six voltage vectors by modifying the basic vector selection table shown in Table.II.

Δψ	ΔT	T_S	Sectors					
			I	II	III	IV	V	VI
1	1	1^{st}	V_3	V_3	V_4	V_1	V_1	V_2
		2^{nd}		V_4	V_1		V_2	V_3
	1	1^{st}	V_1	V_2	V_3	V_3	V_4	V_1
		2^{nd}	V_2	V_3		V_4	V_1	
-1	1	1^{st}	V_3	V_4	V_1	V_1	V_2	V_3
		2^{nd}	V_4	V_1		V_2	V_3	
	-1	1^{st}	V_1	V_1	V_2	V_3	V_3	V_4
		2^{nd}		V_2	V_3		V_4	V_1

Table 2: Vector selection table for proposed DTC

The six voltage vectors of four switch three phase inverters produced using the switching table are V_{11}, V_{12}, V_{23}, V_{33}, V_{34} and V_{41}.The vectors V_{11} and V_{33} can be produced by application of V_1 and V_3 twice within the sampling period of 'T_s' respectively. Here no zero vectors have been taken. Zero vectors can be generated by application of oppositely acting vectors in FSTPI V_1 and V_3 in same sampling period.V_{12} can be generated by successively giving the voltage vectors V_1 and V_2 at 50% of the duty cycle (in the time period T_s) and similarly all the remaining vectors V_{23}, V_{34} and V_{41} can be produced by corresponding voltage vectors used in basic FSTPI topology. In fig.3 resultant vectors generated from the modified vector selection table are shown.

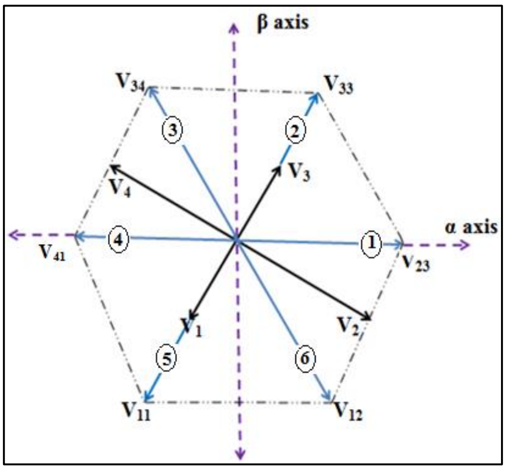

Fig. 3: Six vectors of FSTPI similar to SSTPI

IV. DTC OF SIX SWITCH THREE PHASE INVERTER (SSTPI)

The flux and torque can be maintained within the limits by controlling the voltage vectors given in the Table III.

Δψ	ΔT	SECTORS					
		I	II	III	IV	V	VI
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	-1	V_6	V_1	V_2	V_3	V_4	V_5
-1	1	V_3	V_4	V_5	V_6	V_1	V_2
	-1	V_5	V_6	V_1	V_2	V_3	V_4

Table 3: Vector selection table for SSTPI

The dtc control of SSTPI are done by using two level torque and flux hysterisis controllers. The conventional six switch three phase inverter configuration have eight switching states. The zero voltage states produce zero output voltage and at this instant line current phase to freewheel through either upper or lower components. The state's 1 to 6 produces non zero ac output voltages. So the voltage vectors V_1 to V_6 are called active vectors. The zero vectors V_0 and $V_7$are neglected in vector selection table. The inverter moves from one state to another in order to generate the desired quasi square waveform at its output terminal. The fig.4 represents all the eight vectors and sectors with 60° displacement with each other. The six voltage vectors forms the axes of a regular hexagon as shown. Angle between any adjacent vectors is 60°.

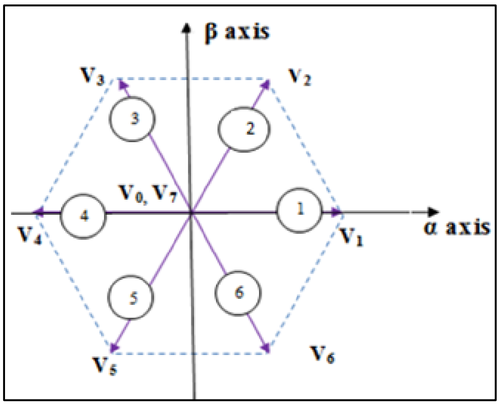

Fig. 4: voltage vectors and sectors of SSTPI

Voltage vectors used in SSTPI	Voltage vectors used in SSTPI
V_1	V_{23}
V_2	V_3
V_3	V_{43}
V_4	V_{14}
V_5	V_1
V_6	V_{12}

Table 4: Similar voltage vectors of SSTPI and FSTPI

V. SIMULATION

A Simulink/Matlab is used to validate the DTC method for FSTPI and SSTPI fed induction motor drive. The ripple content in the resulting torque in both FSTPI and SSTPI can be minimized by further refining the tuning of the input membership functions.

The induction motor model for the simulation studies has the follows parameters:

Type: Three-phase, squirrel-cage induction motor 415 V, 1.3KW, 1480r/min, R_s = 8.43Ω, R_r=4Ω, L_s=4.514(mH), L_r=4.514(mH), L_m=71.54(mH),

Pole pairs = 2, J_m=0.015(kgm^2)

The torque controller has two levels: -1, 1; the flux controller has 2 levels: -1, 1.

The parameters used in simulation are given below:

- V_{dc} = 400V
- Torque hysteresis band= 10%
- Flux hysteresis band= 1%
- Reference flux = 0.9Wb.
- Sample time: T_s= 1e-5s
- Load torque T_L= 10Nm
- Time of simulation t =0.5s.

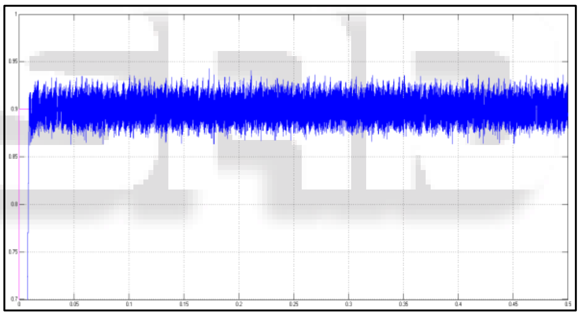

Fig. 5: Stator flux response of proposed FSTPI (x axis=0.05sec/div; y axis= 0.05Wb/div)

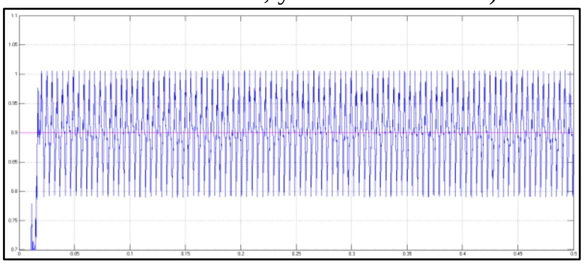

Fig. 6: Stator flux response of SSTPI (xaxis=0.05sec/div;y axis= 0.05Wb/div)

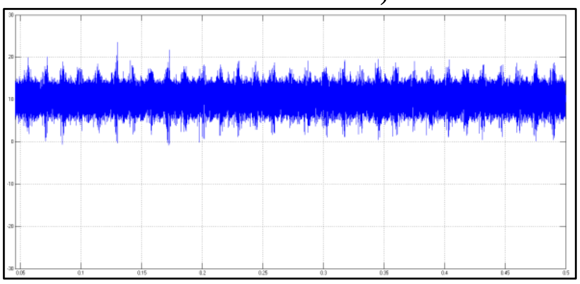

Fig. 7: Torque response of proposed FSTPI (x axis=0.05sec/div; y axis= 10Nm/div)

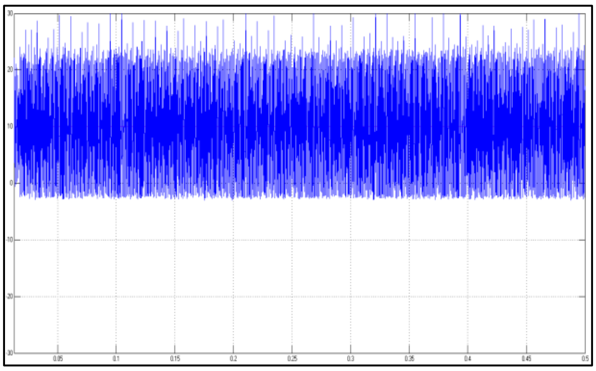

Fig. 8: Torque response of SSTPI (x axis=0.05sec/div; y axis= 10Nm/div)

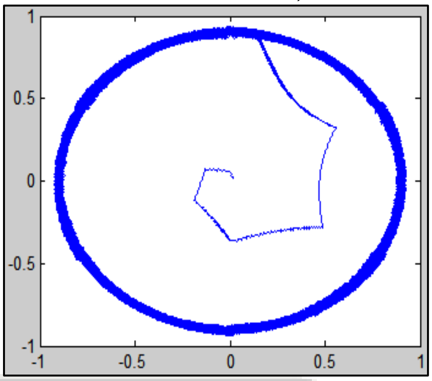

Fig. 9: Stator flux locus of proposed FSTPI

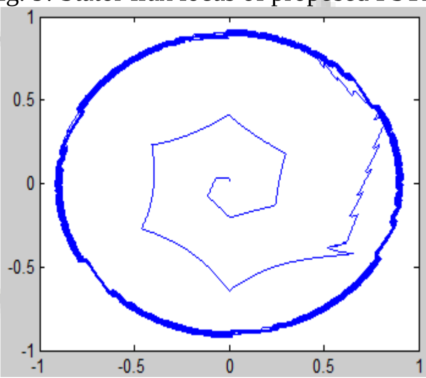

Fig. 10: Stator flux locus of SSTPI

VI. CONCLUSION

This paper deal with comparison and study about four switch three phase inverter and six switch three phase inverter fed Induction motor DTC scheme. The switching table used in FSTPI-DTC scheme is based on the principle of similarity between FSTPI and SSTPI (Six-Switch Three Phase Inverter), where the Clarke's plan is divided into six sectors and the formation of the voltage space vector is done in the same way as for SSTPI by using effective (mean) vectors. The validity of both techniques was verified using Matlab/Simulink. Simulation and experimental results demonstrate the good performance of the DTC for FSTPI-IM. So we can conclude that FSTPI can be used as an alternate method for SSTPI fed induction motor in low power applications.

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