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DIRECT TORQUE CONTROLLED INDUCTION MOTOR DRIVE FOR TORQUE RIPPLE REDUCTION

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ABSTRACT

This paper presents the performance analysis of direct torque control (DTC) and DTC based space vector modulation (SVM) technique controlled induction motor drive. DTC drive utilizes hysteresis comparators and suffers from high torque ripple and variable switching frequency. While the SVM-DTC reduces torque ripple preserving DTC merits. SVM-DTC calculates the required voltage vector to compensate the flux and torque errors generating SVM for each sampling period. The simulation is performed using PSIM and shows the better performance of SVM-DTC over basic DTC.

KEYWORDS: Direct torque control, induction motor, space vector modulation

INTRODUCTION

The DTC has wider industrial application due to several features i.e. quick torque response and robustness against motor parameters variation [1-4]. Unlike, field oriented control (FOC), DTC has less complexity in its implementation due to non dependence of machine parameter. E.g. DTC only use the stator resistance to estimate the stator flux and torque [3].

In the basic conventional DTC, flux and electromagnetic torque are controlled by selecting optimum inverter switching states. The DTC scheme consists torque and flux hysteresis bands, swithing table, flux and torque estimation block. Less parameter dependency makes DTC more robust and easy to implement. However, difficulty in controlling flux and torque at low speed , high distortion in current and torque during sector alteration, variable switching frequency are some disadvantages of DTC. Also higher torque ripple generates noise and vibration, causing error in sensorless drive.

The reasons behind high torque and current ripple in DTC is due to the presence of hysteresis comparators and limited number of available voltage vectors. The solution to minimize the torque ripple is using SVPWM technique in DTC scheme. Since, SVM techinque generates a reference stator voltage vector with a constant frequency at every sampling time, inverter produce a voltage vector in any direction of any magnitude, giving the smooth change in torque.

DIRECT TORQUE CONTROL SCHEME

Fig.1 shows the block diagram of the basic DTC scheme. A constant DC voltage is applied to the inverter. The output of inverter are connected to the induction motor. DTC of induction motor is divided in three steps;

Torque and Flux Estimation

The feedback flux and torque are calculated from the machine terminal voltages and currents. This estimation block also calculates the sector number in which the flux vector lies.

Three phase voltage and currents are transformed to stationary frame using Clarks transformation as given below.

$$i_{s\alpha} = i_a \, , \; i_{s\beta} = \frac{-1}{\sqrt{3}}\left(i_a + 2i_b\right) \quad (1)$$

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$v_{s\alpha} = v_a$, $v_{s\beta} = \frac{-1}{\sqrt{3}}(v_a + 2v_b)$. (2)

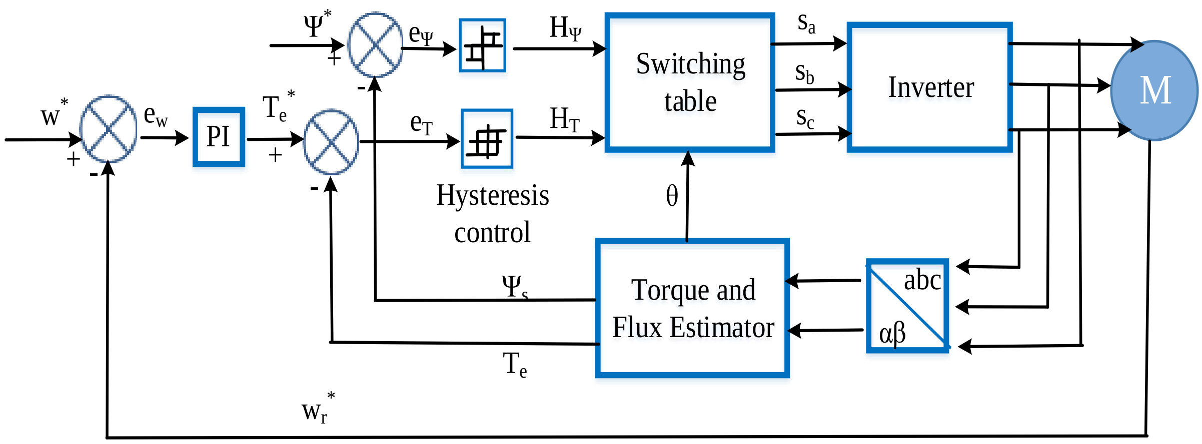

Fig. 1. The block diagram of basic DTC

The flux and torque are calculated by stator current and voltage.

The stator flux is given as

$$\psi_{s\alpha} = \int (v_{s\alpha} - R_s i_{s\alpha}) dt \ . \quad (3)$$

$$\psi_{s\beta} = \int (v_{s\beta} - R_s i_{s\beta}) dt \ . \quad (4)$$

The magnitude of stator flux is given as

$$\psi_s = \sqrt{\psi_{s\alpha}^2 + \psi_{s\beta}^2} \quad (5)$$

Sector number for flux vector is estimated by

$$\theta = \tan^{-1}(\psi_{s\beta} / \psi_{s\alpha}) \quad (6)$$

The electromagnetic torque can be calculated using flux, current and number of poles.

$$T_e = 1.5P(\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha}) \quad (7)$$

Torque and Flux Control

The reference ψ^* and T_e^* are compared with respective estimate value and error are processed by hysteresis band controllers.

The flux controller and torque controller are according to following,

$$H_\psi = 1 \text{ for } e_\psi > +HB_\psi \quad (8)$$

$$H_\psi = \text{-}1 \text{ for } e_\psi > \ \text{-}HB_\psi \quad (9)$$

$$H_T = 1 \text{ for } e_T > \ +HB_T \quad (10)$$

$$H_T = \text{-}1 \text{ for } e_T > \ -HB_T \quad (11)$$

$$H_T = 0 \text{ for } \text{-}HB_T < e_T \ > \ +HB_T \quad (12)$$

Switching table

The switching selection block as shown in Fig.1 receives the input signals HT, Hψ and θ, generates the desired control voltage vector as given in look-up table shown in Table 1.

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Table 1. Switching table of inverter voltage vector

H_ψ	H_T	I	II	III	IV	V	VI
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-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
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_5	V_6	V_1	V_2	V_3	V_4

Fig. 2 shows the relationship of inverter voltage vector and flux (ψs). Neglecting the stator resistance Rs of the machine, we can write

$$v_s = \frac{d}{dt}(\psi_s) \qquad (13)$$
$$\Delta\psi_s = v_s \Delta t$$

Equation (13) shows that the flux can be changed incrementally by applying stator voltage vector for an increment time. The flux can be increased by the vectors and it can be decreased by the vectors. Similarly, torque is increased by the vectors and decreased by the vectors. Meanwhile, zero vector short circuits the machine terminals and keeps the flux and torque unaltered.

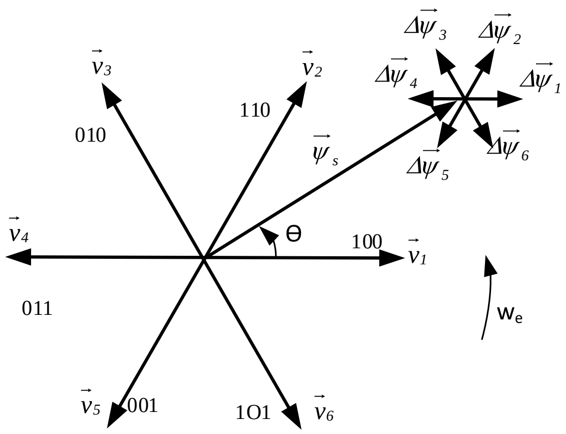

Fig. 2 Inverter Voltage vectors and corresponding stator flux variation

SVM-DTC SCHEME

The block diagram of the SVM-DTC scheme is shown in Fig. 3. Here the torque and flux estimator are used to find the flux and the torque . Numeric calculation and PI controllers are used instead of switching table and hysteresis controllers. PI regulates flux and torque error giving reference voltage vector in d-q coordiante. And voltage vector in α-β coordinates are delivered to SVM block.

Space Vector PWM (SVPWM) refers to a special technique of determining the switching sequence of the upper three power transistors of a three-phase voltage source inverter (VSI). It has been shown to generate less

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harmonic distortion in the output voltages or current in the windings of the motor load. SVPWM provides more efficient use of the dc bus voltage, incomparison with the direct sinusoidal modulation technique.

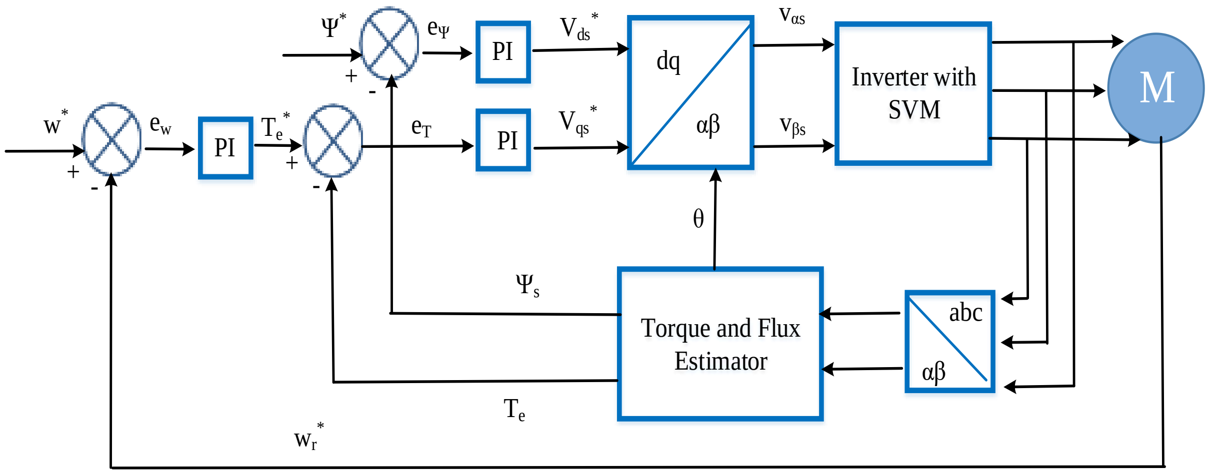

Fig. 3. The block diagram of SVM-DTC

The dwell time calculation is achieved by volt-second balancing equation, as

$$\vec{v}_{ref} T_s = \vec{v}_1 T_a + \vec{v}_2 T_b + \vec{v}_0 T_0 \quad (14)$$

For kth sector

$$T_a = \frac{\sqrt{3} T_s V_{ref}}{V_d} \sin\left(k\frac{\pi}{3} - \alpha\right)$$

$$T_b = \frac{\sqrt{3} T_s V_{ref}}{V_d} \sin\left(\alpha - \frac{(k-1)\pi}{3}\right) \quad (15)$$

$$T_s = T_a + T_b + T_0$$

SIMULATION RESULTS

The simulated results for basic DTC and SVM-DTC are shown in Fig. 4. for the similar speed reference. In both the cases the sinusoidal stator currents waveform is achieved. For no load cases, the DTC scheme contains larger amount of torque ripple which is also reflected in the current waveform. This can be seen in Fig. 4, that the ripple is reduced from ± 1.9 N-m to ± 0.51 N-m.

Also the flux trajectory is nice and smooth in the case of SVM-DTC scheme compared to basic DTC. Since the flux is smooth, the torque calculated is also smoothed. Thus, it is clear from the simulation results, the torque and current ripple has been reduced.

Fig. 5. Shows the simulated results for the dynamic performance of the SVM-DTC. Fast dynamic performance of the DTC scheme is preserved giving smooth rotor speed response. Unlike from the conventional DTC, SVM-DTC use the flux angle to calculate rotor voltage. angle to calculate voltage reference for SVM is also shown in the simulation result.

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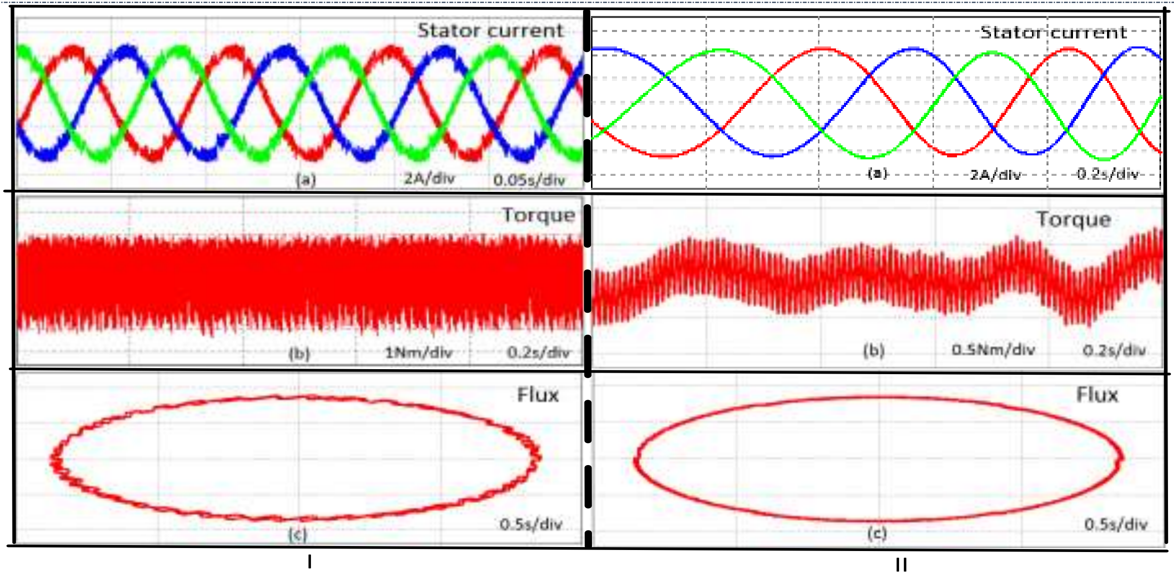

Fig.4. Simulated results with (I) Basic DTC scheme (II) SVM-DTC scheme with no load and speed reference 800 rpm: (a) three phase stator current, (b) torque ripple, (c) excitation reference frame flux trajectory

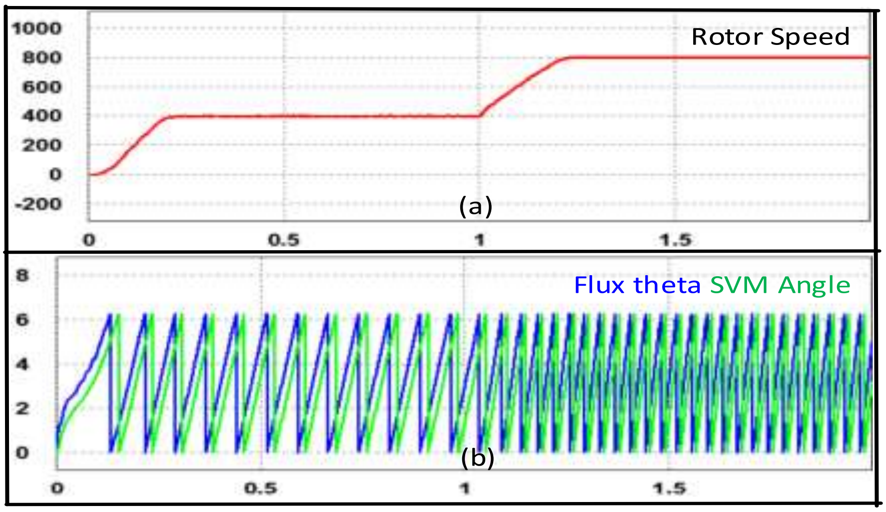

Fig.5. Simulated results with (a) Speed response of speed reference 400-800 rpm (b) flux theta and SVPWM voltage angle.

CONCLUSION

This paper has reviewed the basic Direct Torque Control scheme and SVPWM inverter fed DTC for induction motor drives. SVM-DTC operated by three-phase ac voltage with variable magnitude and frequency scheme improves the drive performance in terms of reduced torque ripple and flux pulsation.

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