

## Analysis of Direct Torque Control of Industrial Drives using Zone-Shifting SVM

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### ABSTRACT

Direct Torque Control of Induction Motor has gained popularity in industrial applications mainly due to its simple control structure from its first introduction in 1986. Here the direct torque control (DTC) of induction motor with zone shifting space vector modulation (SVM) has been done. It uses a simple phase current re-construction algorithm for three phase induction motor (IM). The phase current re-construction algorithm is done by using information from the current that is from the phases between the inverter and the induction motor. The proposed algorithm is robust and very simple. It uses the AC current to get the stator current for estimating the motor flux and the electromagnetic torque. By evaluating through the torque value and the current the controlling of induction motor is done. The simulation results are also given which supports the direct torque control strategy of the induction motor (IM).

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## 1. INTRODUCTION

The concept of direct torque control of the induction motor (IM) has been started and gained popularity in the field of industrial sector. The DTC method is having similarities with the field-oriented control despite a simple structure. In fact the DTC control is having the closed loop control of the electromagnetic torque and the flux without using the current loop or the shaft sensors.

In DTC method the information about stator current and DC-link voltage which is used with the inverter switches states to get the values of flux and electromagnetic torque. The paper "Direct Torque Control of IPM synchronous motor using back stepping approach" by G.Foo and M.F.Rahaman, and the paper "Incorporating control trajectories with the direct torque control scheme of interior permanent magnet synchronous motor drive" by M.E.Haque and M.F.Rahaman explains current sensing by the use of galvanically isolated current sensor and the Hall effect sensor. The current measurement is done by using these sensors but the disadvantage is the cost, encumbrance and non-linearity. Another paper by D.W.williams and T.C.Green "Derivation of motor line-current waveforms from the dc-link current of an inverter" here single current sensor operation has been proposed to reconstruct the phase current from dc link current sensor. Another main approach is based on estimation of phase using prediction-correction algorithms by T.M.Wolbank and P.Machiener "An improved observer-based current controller for inverter fed AC machines with single DC-link current measurement". Having the defect of additional computational burden

to drive system. The paper's by M. Bertoluzzo, G. Buja, and R. Menis, "Direct torque control of an induction motor using a single current sensor," and E. Peralta-Sanchez, F. Al-rifai, and N. Schofield, "Direct torque Control of permanent magnet motors using a single current sensor," is only dealing with the DTC method of IM and PMSM.

In this paper the phase current is measured from the phases. And based on the sensed phase current DTC method is done and switching happened. DTC method is mainly based on the switching. The switching table gives the optimal inverter switching state for the inverter. By the use of voltage and the current obtained from the current and voltage sensing parts is used to deduce flux and electromagnetic torque. The voltage and current hysteresis controller determine voltage required to drive the flux and torque for the particular time. The basic block diagram is given below as Figure 1.

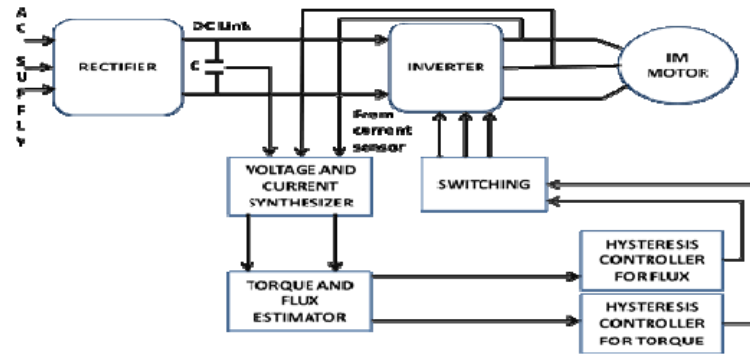


Figure 1. Basic DTC

From the voltage and current appropriate magnitude current and voltage are to be obtained. From these electromagnetic torque and flux are estimated, a hysteresis control is done and voltage vectors to be applied are obtained from the switching table. The torque and flux can be deduced from the following equations,

$$\phi_s = \int (V_s - R_s I_s) dt \quad (1)$$

$$T_{em} = \frac{3}{2} P (\phi_s - I_s) \quad (2)$$

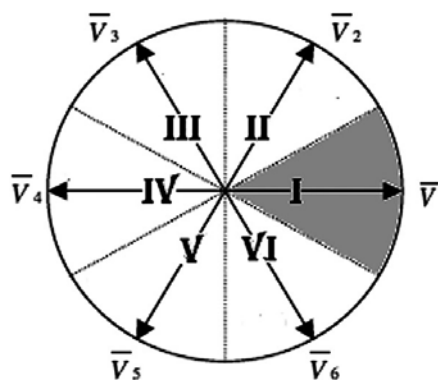


Figure 2. DTC sectors and inverter voltage vectors

Table 1. Basic DTC switching table

$b_0$	$b_r$	Sec I	Sec II	Sec III	Sec IV	Sec V	Sec VI
1	1	V5	V6	V1	V2	V3	V4
	0	V3	V4	V5	V6	V1	V2
	1	V6	V1	V2	V3	V4	V5
0	0	V2	V3	V4	V5	V6	V1

## 2. DIRECT TORQUE CONTROL STRATEGY

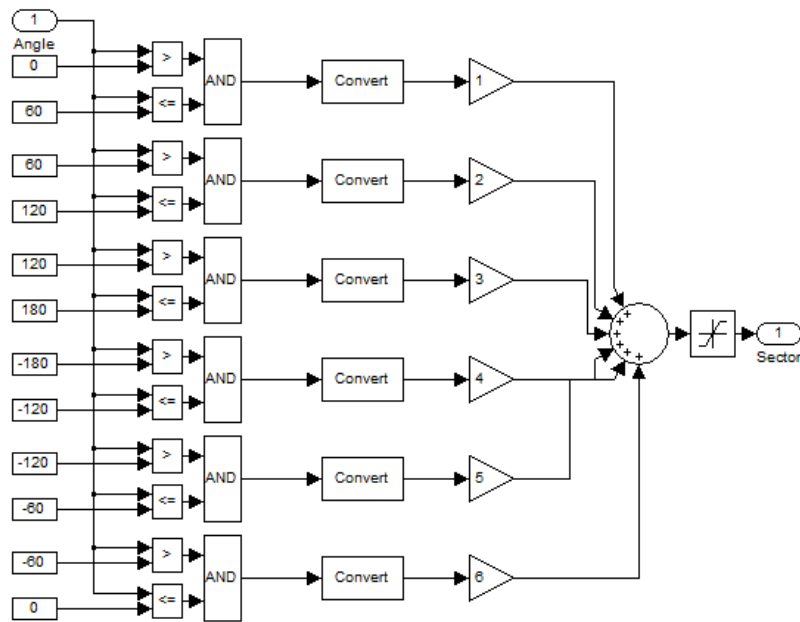


Figure 3. Sector selection

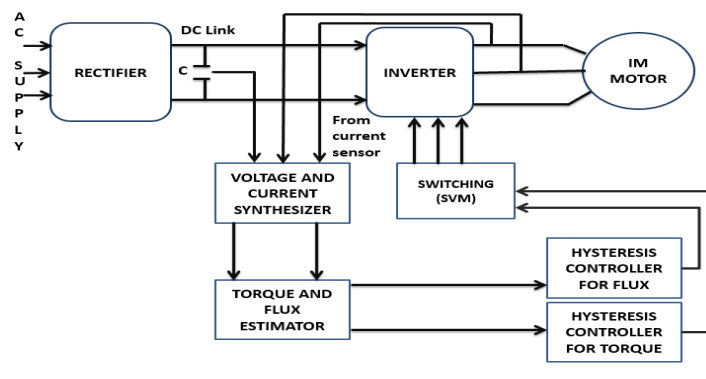


Figure 4. Proposed model

DTC strategy is quite different from that of the field orientation control (FOC) or vector control, which does not need complicated coordination transformations and decoupling calculation. Here a simple current re-construction algorithm is done by using current sensor. The stator currents and the dc-link voltages

are sampled and based on the sampled voltage and current torque and flux are created. These torque and flux are again undergone transformations to form voltage and current that is used for switching. The switching is done by using space vector switching method. On the first implementation the control system should be able to generate more voltage vectors; this could be achieved by applying at each cycle period voltage vectors at specified interval of time. This leads to a space vector modulation (SVM). In improving the DTC method look up table and adjusting the stator flux sector which is taken from  $0^0$  to  $60^0$  (given in Figure 3) (by zone shifting strategy) instead of  $-30$  and  $+30$  degree as of basic DTC schemes. The proposed DTC method is given in the Figure 4.

$$V_{sd} = \frac{2}{3} V_{dc} \left( S_a - \frac{S_b + S_c}{2} \right) \dots\dots\dots 3$$

$$V_{sd} = \frac{1}{\sqrt{3}} V_{dc} (S_a - S_c) \dots\dots\dots 4$$

$$T_e = \frac{2}{3} P (\varphi_{sd} i_{sq} - \varphi_{sq} i_{sd}) \dots\dots\dots 5$$

$$\varphi_{sd} = \int (V_{sd} - R_s i_{sd}) dt \dots\dots\dots 6$$

$$\varphi_{sq} = \int (V_{sq} - R_s i_{sq}) dt \dots\dots\dots 7$$

The switching table and the voltage vector are given in Table 2, and Figure 5.

Table 2. Switching table

Flux error position	Torque error position	Sec I	Sec II	Sec III	Sec IV	Sec V	Sec VI
1	1	V2	V3	V4	V5	V6	V1
	0	V7	V0	V7	V0	V7	V0
	-1	V6	V1	V2	V3	V4	V5
	1	V3	V4	V5	V6	V1	V2
0	0	V0	V7	V0	V7	V0	V7
	-1	V5	V6	V1	V2	V3	V4

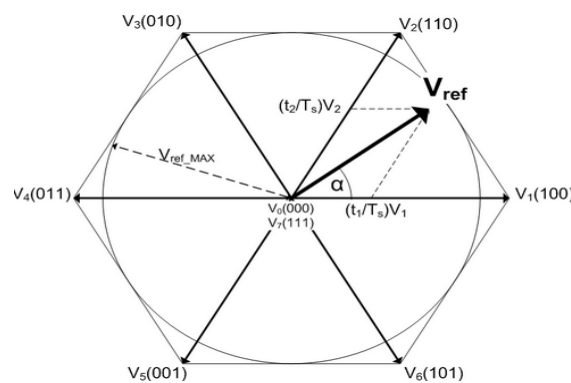


Figure 5. Voltage Vector

SVM techniques have several advantages that are offering better DC bus utilization, lower torque ripple, lower Total Harmonic Distortion (THD) in the AC motor current, lower switching losses, and easier to implement in the digital systems. At each cycle period, a preview technique is used to obtain the voltage

space vector required to exactly compensate the flux and torque errors. The torque ripple for this SVM-DTC is significantly improved and switching frequency is maintained constant. The two switching states (SA and SB) are named active switching states. SA indicates the inverter switching states (001), (100), or (010) and SB indicates the inverter switching states (101), (110) or (011). In DTC, with the space vector PWM technique, the DTC transient performance and robustness are preserved and the steady state torque ripple is reduced. Moreover, the inverter switching frequency is constant and totally controllable.

### 3. SIMULATION RESULTS & DISCUSSIONS

The simulation for the proposed DTC method is done by the MATLAB/SIMULINK model based on power system toolbox. Based on the simulation outcome the behavior of the proposed DTC method is analyzed and concluded. The specifications of the induction motor in this study are as follows.

$$P_n = 1.1 \text{ kW}, u_n = 415 \text{ V}, f = 50 \text{ Hz}, \Omega_n = 1415 \text{ rpm}, R_s = 6.03 \Omega, R_r = 6.085 \Omega,$$

$$L_{ls} = 29.9 \text{ mH}, L_{lr} = 29.9 \text{ mH}, L_m = 489.3 \text{ mH}, J = 0.011787 \text{ Kg.m}^2$$

Figure 6 shows the variations of the motor torque in the proposed control scheme. First, the machine is fluxed with a zero reference torque, then at 0.25s, we set the torque reference to 3.5 Nm (50% of the rated torque) and a torque inversion is made at 1s.

Torque Reference	: 0    3.5    -3.5
Time	: 0    0.25    1 (sec)

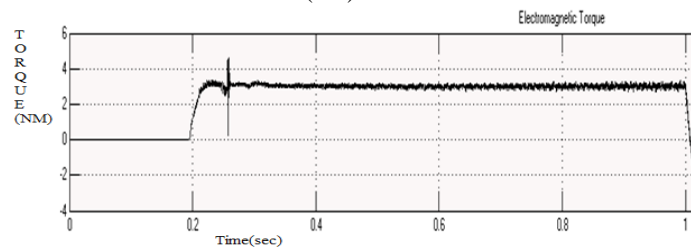


Figure 6. Torque dynamic

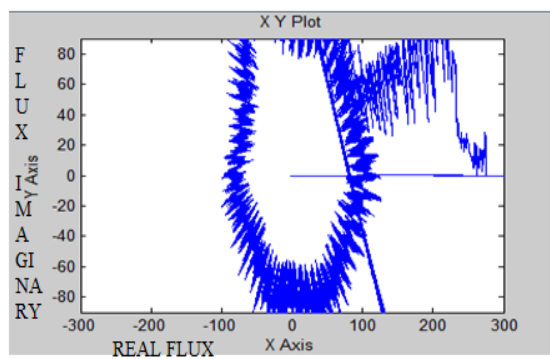


Figure 7. Circular flux trajectory

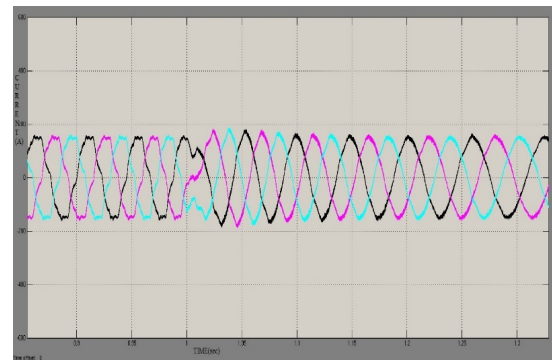


Figure 8. Phase currents dynamic during torque reversal

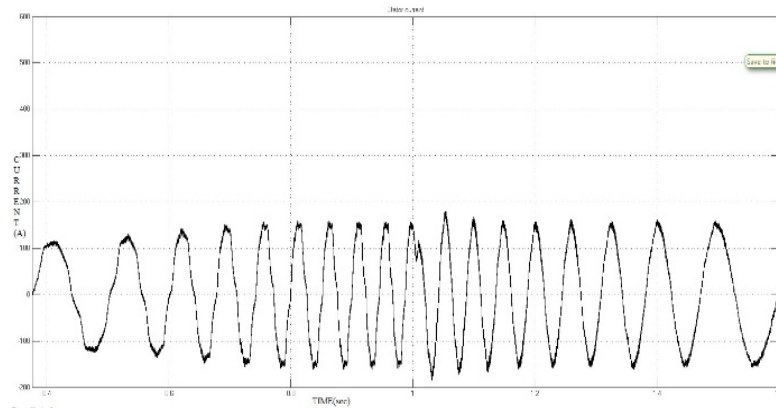


Figure. 9 Stator current of Induction motor

The above Figures represents the simulation results of the phase current dynamics during torque reversal. We can see that the change in the three currents  $I_a$ ,  $I_b$ , and  $I_c$  caused by the torque reversal is very fast. And when the torque reversal is happened at the time instant of 1sec then the three phase output current and the stator current are having the phase reversal.

#### 4. CONCLUSION

The direct torque control of induction motor is done and, the torque is in the controlled range. Since there are losses the torque is in controlled by using the discrete space vector modulation technique. Simulation of the system is done by using MATLAB/Simulink and the output waveforms are obtained. And from the waveforms the inferences are made which gives positive result regarding the control strategy of the induction motor.

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