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# DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVE BASED ON RANDOM POSITION SVPWM FOR REDUCTION OF ACOUSTICAL NOISE

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## ABSTRACT

Direct Torque Control (DTC) is known to produce fast and robust response in induction motors. However, during steady state, notable torque, flux and current pulsations will occur which are reflected in speed estimation, speed response and also in increased acoustical noise. This paper introduces a new direct torque control method based on random position space vector pulse width modulation (RPSVPWM). In the proposed method each of the three phase pulses is located randomly in each switching sequence interval without corrupting the switching sequences for space vector modulation. Simulation studies have been carried out for different operating conditions of the drive system and compared with those of the conventional method.

**Keywords:** torque, control, induction, motor, pulse, space, vector, modulation, noise.

## I. INTRODUCTION

In the recent years direct torque control (DTC) [1] has proven to be a powerful method for controlling induction motor drives. Despite being simple, DTC is able to produce very fast torque and flux control and also robust with respect to motor parameters and perturbations .however, during steady state operation notable torque, flux and current pulsations occur which are reflected in speed estimation and in increased acoustical noise. To overcome these and also for full utilization of dc bus Space Vector PWM technique has been introduced [2-3]. Besides preserving the fast response and robustness merits of conventional DTC it has the advantages of 1) In SVPWM DTC a sequence of six vectors is applied during a sampling period while for classical DTC a single voltage vector is applied during the same time and 2) The switching frequency is constant and controllable and ensures reduction in torque and flux ripples. The problem with conventional SVPWM is that the pulses are located at the centre of a switching interval and hence less is the degree of freedom in pulse location which hinders the decrement of acoustical noise .To reduce audible switching noise this paper presents a new DTC scheme based on random pulse position space vector pulse width modulation[4].In the proposed RPSVPWM ,each three phase pulse can be located at any place in each switching interval so long as it does not corrupt the switching sequences for space vector modulation and hence flatter and wider power spectrum causing reduction in acoustical noise.

## II. MODELING OF INDUCTION MOTOR

The induction motor model can be developed from its fundamental electrical and mechanical equations. In stationary reference frame the voltage equations are given by:

$$\begin{aligned} v_{ds} &= R_s i_{ds} + p\,\lambda_{ds} \\ v_{qs} &= R_s i_{qs} + p\,\lambda_{qs} \\ 0 &= R_r i_{dr} + \omega_r \lambda_{qr} + p\,\lambda_{dr} \\ 0 &= R_r i_{qr} - \omega_r \lambda_{dr} + p\,\lambda_{qr} \end{aligned} \qquad \text{(I)}$$

Where $p$ indicates the differential operator (d/dt). The stator and rotor flux linkages are defined using their respective self leakage inductances and mutual inductance is as given below:

$$\begin{aligned} \lambda_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \lambda_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \lambda_{dr} &= L_r i_{dr} + L_m i_{ds} \\ \lambda_{qr} &= L_r i_{qr} + L_m i_{qs} \end{aligned} \qquad \text{(II)}$$

The electromagnetic torque in the stationary reference frame is given as:

$$T_e = \frac{3}{2}\frac{P}{2}\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \qquad \text{(III)}$$

## III. PRINCIPLE OF CONVENTIONAL DTC

The relationship between the voltage vectors and flux variation when stator resistance drop neglected is given by:

$$v_s = \frac{d\lambda_s}{dt} \qquad \text{(IV)}$$

The above equation shows that the applied voltage space vector produces a stator flux variation which has the same direction of the voltage space vector and amplitude which is proportional to the voltage and time interval for which the voltage vector is applied. Based on the voltage demands and the sector where the stator flux vector is positioned, an appropriate inverter voltage vector is selected from the

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switching table. The selected voltage vector is applied fro the whole sampling period.

## IV. CONVENTIONAL SVPWM BASED DTC

In this approach the actual stator flux vector is determined by using the stator currents and voltage measurements .The calculated one is compared with the reference and an error signal in flux is generated which when divided by the sampling period gives a reference voltage vector. As shown in Fig.1. The reference vector can be synthesized into $U_1$ and $U_2$. If α is the angle of vector $U_{ref}$, then the times $T_1$, T2 and $T_0$ for which $U_1$, U2and Uo (the duration of zero vector) act respectively can be expressed as

$$T_1 = T.M.\frac{\sin(60^0 - \alpha)}{\sin 60^0}$$
$$T_2 = T.M.\frac{\sin \alpha}{\sin 60^0} \qquad (V)$$
$$T_0 = T - T_1 - T_2$$

Where $T_1$ = the duration of vector $U_1$, $T_2$ = the duration of vector$U_2$ and $T_0$ = the duration of zero vector $U_0$.

Where M is the modulation index, is given by $\frac{3V_{ref}}{2V_{dc}}$.

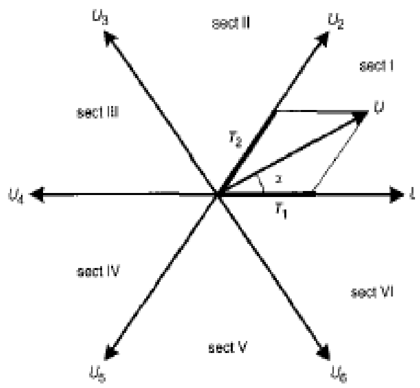


**Figure-1.** Voltage Space Vectors for SVPWM.

The block diagram for SVWPM based DTC is as shown in Figure-2.

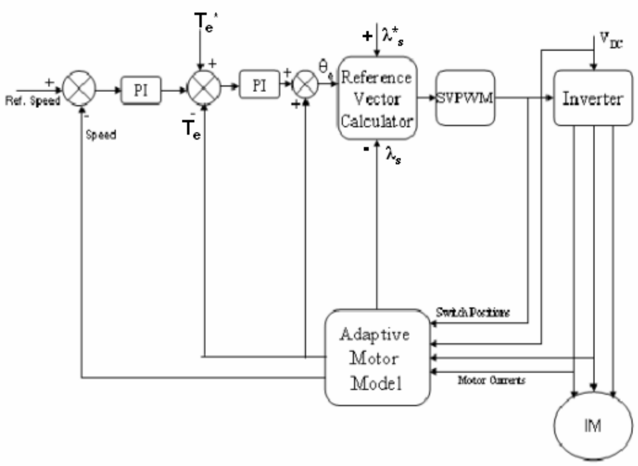


**Figure-2.** SVPWM based DTC scheme.

## V. RPSVPWM BASED DTC

The proposed random position space vector PWM (RPSVPWM) technique is similar to the conventional SVPWM technique, but in the proposed technique a pulse can be placed any where with in the switching interval as long as it does not corrupt the switching sequences for space vector modulation. The relative positions of the pulses associated with each phase are shown in Figure-3. To randomize the pulse position, a random function is used, which is given in [4].

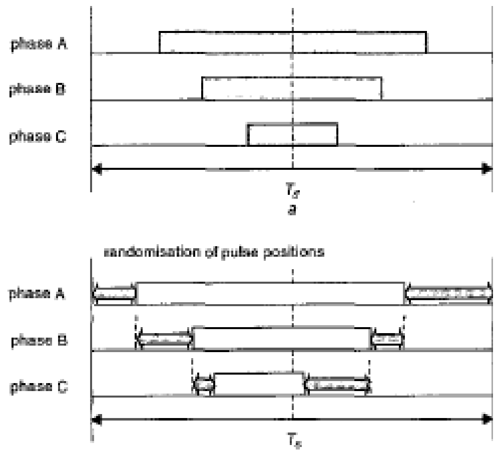


**Figure-3.** PWM Pulse Positions.
a) Conventional SVPWM b)RPSVPWM

## VI. SIMULATION RESULTS AND DISCUSSION

To verify the proposed scheme, a numerical simulation has been carried out by using Matlab/Simulink. Sampling time of 125µs and ode 4 (Runge-Kutta) methods are used for a fixed step size of 10µs. For the simulation, reference flux is taken as 1wb and starting torque is limited to 40N-m. Various conditions such as starting, steady state, step change in load and speed reversal are simulated. The results for conventional DTC (CDTC) are shown in Figures 4, 5 and 6.

From the simulation results of conventional DTC, it can be observed that, the ripple in current, torque and flux is high for conventional DTC scheme. To reduce ripples and to get fixed switching frequency, conventional SVPWM scheme is used in [2-3]. The results for conventional SVPWM are given in Figures 7, 8 and 9.

Though the ripples are reduced with conventional sequence, to reduce acoustical noise and THD in phase current a RPSVPWM is proposed in [4]. The results for RPSVPWM based DTC are given in Figures 10, 11 and 12. Also the phase current spectra for conventional SVPWM and RPSVPWM are given in Figures 13 and 14 along with THD values.

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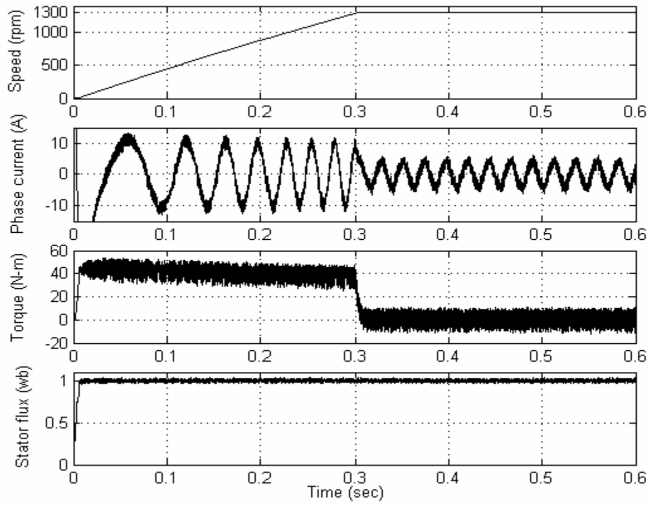

**Figure-4.** Simulation results of CDTC during starting and steady state.

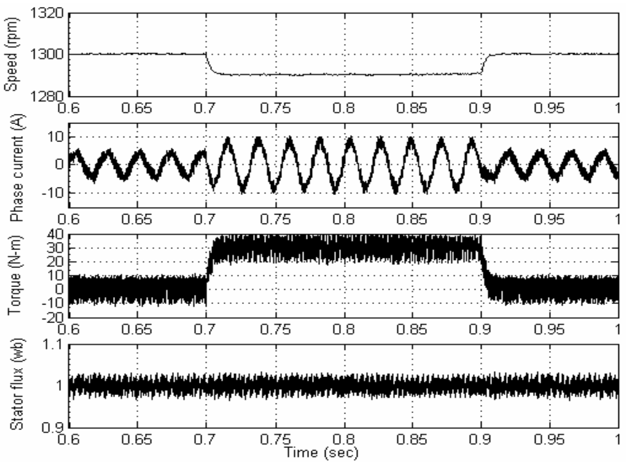

**Figure-5.** Simulation results of CDTC; a 30 N-m load is applied at 0.7 sec and removed at 0.9 sec.

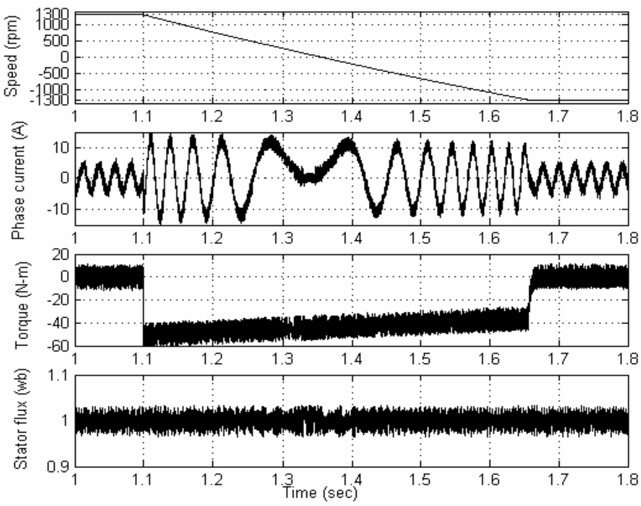

**Figure-6.** Transient responses during speed reversal for CDTC; Speed is changed from +1300rpm to -1300rpm.

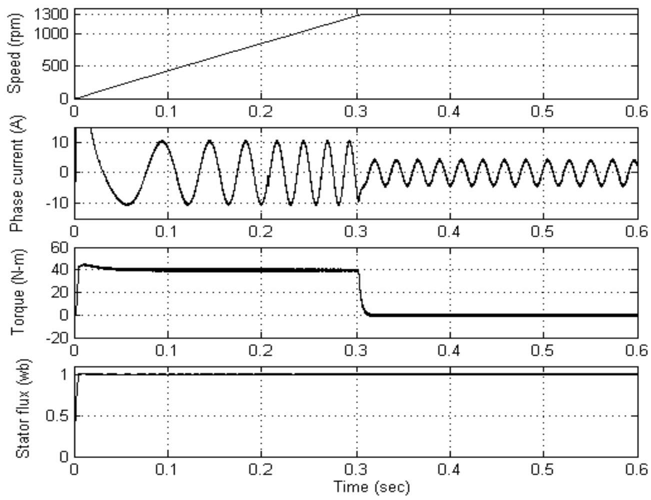

**Figure-7.** Simulation results of SVPWM based DTC during starting and steady state.

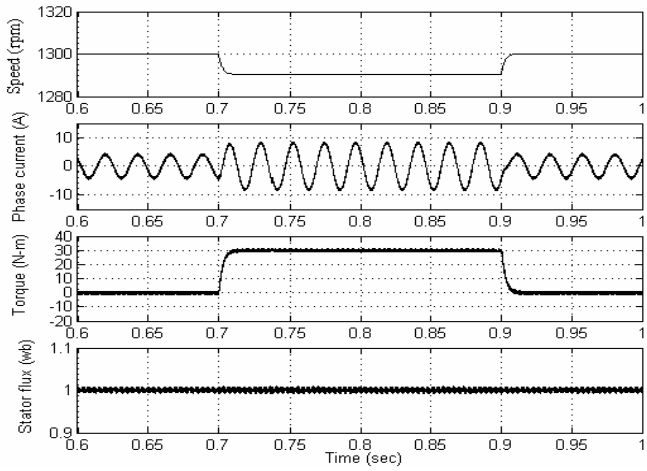

**Figure-8.** Simulation results of SVPWM based DTC; a 30 N-m load is applied at 0.7 sec and removed at 0.9 sec.

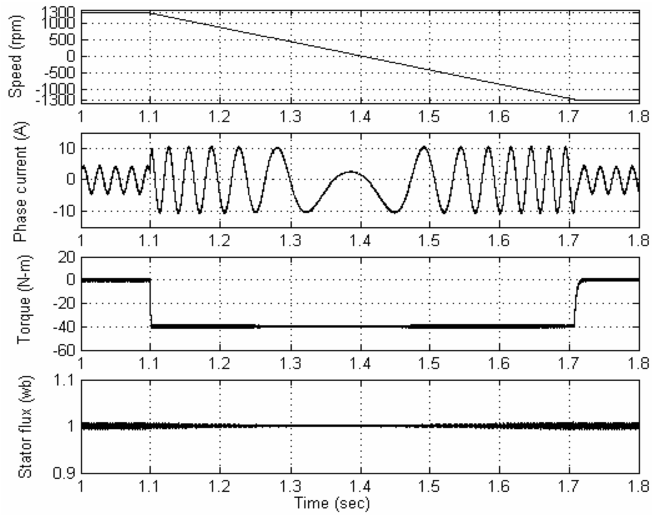

**Figure-9.** Transient responses during speed reversal for SVPWM based DTC; Speed is changed from +1300rpm to -1300rpm.

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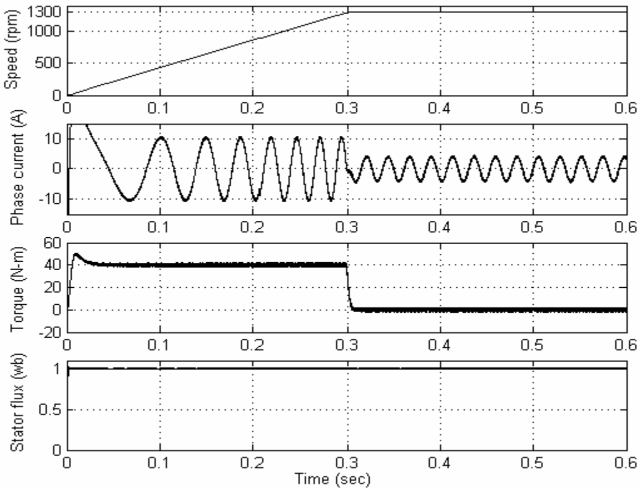

**Figure-10.** Simulation results of RPSVPWM based DTC during starting and steady state.

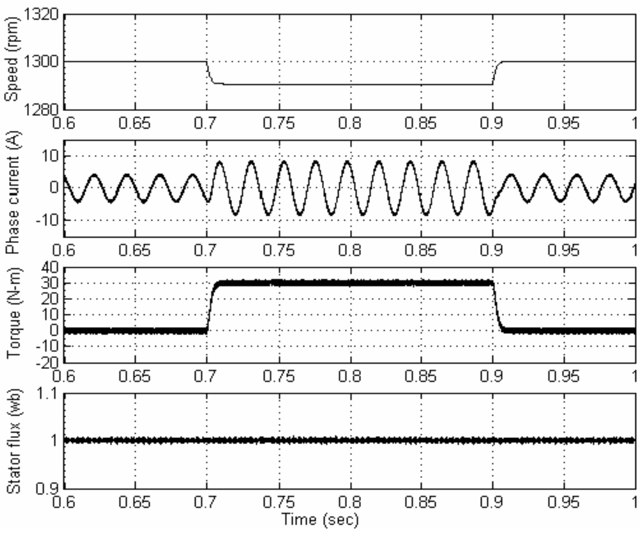

**Figure-11.** Simulation results of RPSVPWM based DTC; a 30 N-m load is applied at 0.7 sec and removed at 0.9 sec.

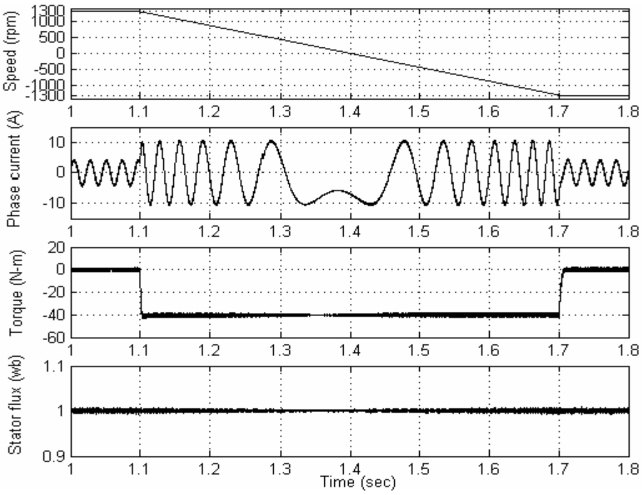

**Figure-12.** Transient responses during speed reversal for RPSVPWM based DTC; Speed is changed from +1300rpm to -1300rpm.

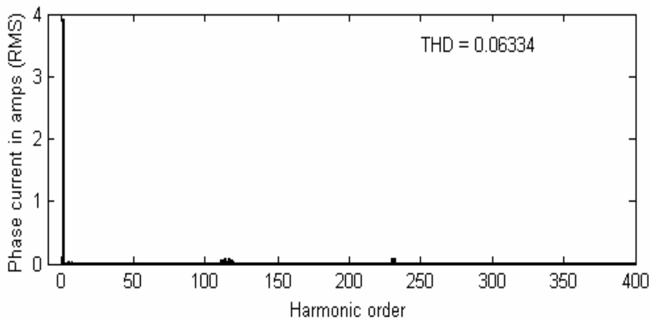

**Figure-13.** Spectra along with THD value for phase current in SVPWM based DTC.

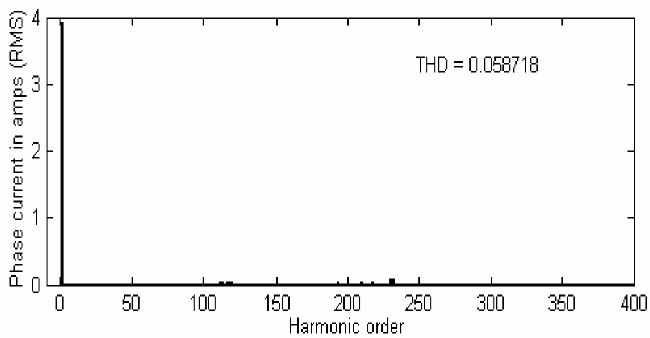

**Figure-14.** Spectra along with THD value for phase current in RPSVPWM based DTC.

## VII. CONCLUSION

In this paper RPSVPWM based DTC is proposed for induction motor and the results show that a reduction in torque, flux ripples and acoustical noise.

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## *Nomenclature*

| | |
|---|---|
| $v_{ds}, v_{qs}$ | d and q axes stator voltages, V |
| $v_{dr}, v_{qr}$ | d and q axes rotor voltages, V |
| $i_{ds}, i_{qs}$ | d and q axes stator currents, A |
| $i_{dr}, i_{qr}$ | d and q axes rotor currents, A |
| $R_s$ | Stator resistance, ohms |
| $R_r$ | Rotor resistance, ohms |
| $L_s$, $L_r$ | Stator and rotor inductances, H |
| $L_m$ | Mutual inductance, H |
| $\omega_r$ | Electrical rotor speed, rad/sec |
| $T_e$ | Electromagnetic torque, N-m |
| $\lambda_{ds}$, $\lambda_{qs}$ | Stator flux linkages in d and q axes, V-sec |
| $\lambda_{dr}$, $\lambda_{qr}$ | Rotor flux linkages in d and q axes, V-sec |