

## Space Vector Based Random Pwm Algorithms Based Direct Torque Controlled Induction Motor Drive

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### ABSTRACT

In this proposed paper, to get fast transient response, DTC algorithm has to be developed for an /induction motor. Then, to get constant frequency, hysteresis controllers have to be replaced with space vector PWM (SVPWM) modulator. However, the SVPWM algorithm gives more harmonic distortion. Hence, to reduce the complexity involved in classical SVPWM algorithm and acoustical noise, various spread spectrum modulation methods which are also known as random pulse width modulation algorithms, have to be developed by using the instantaneous phase voltages only. The proposed paper mainly focuses on the generation of a family of spread spectrum modulation methods by using both space vector approach. To validate the proposed algorithms, several numerical simulation studies have been developed by using Matlab-Simulink. Finally the simulation results are compared with the existing methods.

**Keywords:** Induction Motor, Total Harmonic Distortion, Direct Torque Control, Space Vector PWM, Random PWM

### I. INTRODUCTION

Nowadays, Induction Motors drives are popular in industries, because of their advantages over the DC drives. The variable speed induction motor drives need a better transient performance compared with steady state operation. In high performance speed control applications, the direct torque control (DTC) is very popular. Almost three decades ago, In 1985 Takahashi presented the first paper on DTC for induction motors. Since that time the technique was completely developed and several papers have been published on DTC. Using DTC, it has been possible to combine the induction motor structural robustness with the control simplicity and efficiency of a direct current (DC) motor. This evolution resulted to a replacement of the DC machines by induction motor in many applications in the last few years. DTC is method to control machine with utilizing torque and flux of motor controlled. The basic DTC scheme consists of two comparators having different features, switching table, Voltage Source Inverter (VSI), flux and torque estimation block and IM. A classical DTC drive system, which is based on a fixed hysteresis bands for both torque and flux controllers, suffers from a varying switching frequency, which is a function of the motor speed, stator/rotor fluxes, and stator voltage; it is also not constant in steady state. Variable switching frequency is undesirable. At low speed, an appreciable level of acoustic noise is present, which is mainly due to the low inverter switching frequency. The high frequency is limited by the switching characteristics of the power devices. Therefore, there will be large torque ripples and distorted waveforms in currents and fluxes. In recent

years, the space vector PWM (SVPWM) algorithm is attracting many researchers to overcome these anomalies.

### II. DIRECT TORQUE CONTROL OF INDUCTION MOTOR

#### Principle of DTC:

The electromagnetic torque of a three-phase induction motor can be written as

$$T_e = \frac{3}{2} \frac{P}{\sigma} \frac{L_m}{L_s L_r} |\psi_r| |\psi_s| \sin \eta \quad \text{-(1)}$$

where  $\eta$  is the angle between the stator flux linkage space vector ( $\psi_s$ ) and rotor flux linkage space vector ( $\psi_r$ ), as shown in Fig. 1 and  $\sigma$  is the leakage coefficient given by

$$\sigma = 1 - \left( \frac{L_m^2}{L_s L_r} \right)$$

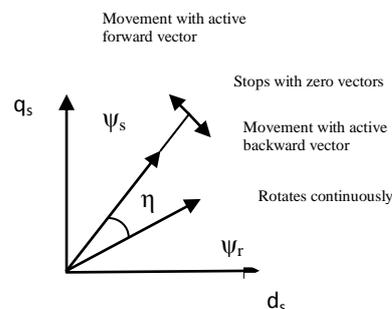


Fig.1  $\psi_s$  movement relative to  $\psi_r$  under influence of voltage vectors:

The expression given in (1) is valid for both the steady state and transient state conditions. In steady state both the stator flux and rotor flux moves with the same angular velocity. The rotor flux lags the stator flux by torque angle. But during transients these two vectors do not have the same velocity. From (1), it is clear that the motor torque can be varied by varying the rotor or stator flux linkage vectors. The magnitude of the stator flux is normally kept constant. The rotor time constant of a standard squirrel-cage induction machine is very large, thus the rotor flux linkage changes very slowly compared to the stator flux linkage. So assuming both to be constant, it follows from (1) that torque can be rapidly changed by changing 'η□' in the required direction. This is the essence of "Direct Torque Control".

### III. SPACE VECTOR PULSE WIDTH MODULATION

A Three-phase voltage source inverter has eight switching states as shown in Fig 2

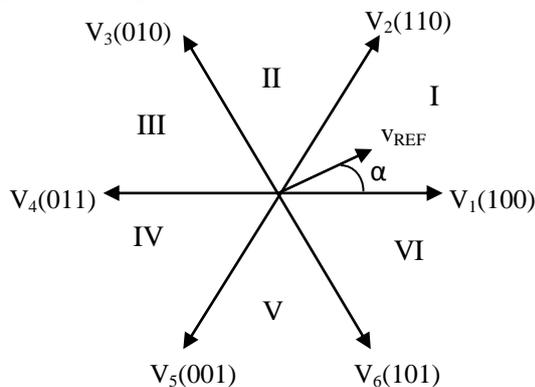


Fig.2 Inverter states o get and voltage vectors of three-phase inverter

Three phase voltage inverter has two zero states (- - - and + + +) which short the motor terminals and produce a voltage vector of zero magnitude. The other six states are active states produces an active voltage vector each. These active vectors divide the space vector plane into six sectors and are of equal magnitude as shown in Fig 2. The active voltage vectors or active states can be represented as

$$V_k = \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}} \text{ Where } k=1,2,\dots,6 \quad (2)$$

#### 3.1 Switching Sequences

In space vector-based PWM, the voltage reference, is provided by revolving reference vector (Fig 2), which is sampled once in every sub cycle  $T_s$ . Given a sampled reference vector of magnitude  $V_{REF}$  and angle  $\alpha$  in sector I as shown in fig. 2, the dwell times of active vector 1, active vector 2 and zero vector in the subcycle are given by  $T_1$ ,  $T_2$ , and  $T_Z$  respectively. In CSVPWM divides  $T_Z$  equally between

0 and 7, and employs the switching sequence 0-1-2-7 or 7-2-1-0 in a subcycle in sector I

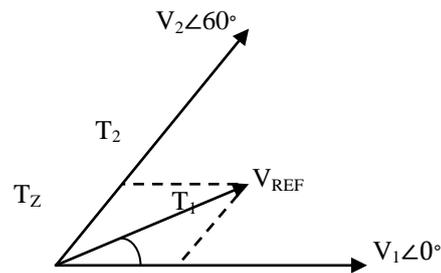


Fig-3. Switching times of Sector I

From Fig 3 principle of volt-time balance  $T_1$ ,  $T_2$  and  $T_Z$  can be calculated as:

$$T_1 = M \frac{\sin(60^\circ - \alpha)}{\sin 60^\circ} * T_s \quad (3)$$

$$T_2 = M \frac{\sin \alpha}{\sin 60^\circ} * T_s \quad (4)$$

$$T_Z = T_s - T_1 - T_2 \quad (5)$$

Where 'M' is the modulation index  $M = \frac{3 V_{REF}}{2 V_{dc}}$

In the SVPWM algorithm, the total zero voltage vector time is equally distributed between  $V_0$  and  $V_7$ . Also, the zero voltage Vector time is distributed symmetrically at the start and end of the sub cycle in a Symmetrical manner. Thus CSVPWM uses  $V_0, V_K, V_{K+1}, V_7, V_{K+1}, V_K, V_0$  sequences for odd sectors and  $V_0, V_{K+1}, V_K, V_7, V_K, V_{K+1}, V_0$  for even sectors. Moreover, to minimize the switching frequency of the inverter, it is desirable that switching should take place in one phase of the inverter only for a transition from one state to another.

The conditions to be satisfied by a valid sequence in sector I are as follows

1. The active state 1 and the active state 2 must be applied at least once in a sub cycle.
2. Either the zero state 0 or the zero state 7 must be applied at least once in a sub cycle.
3. In case of multiple application of an active state, the total duration for which the active state is applied in a sub cycle must satisfy (1).
4. The total duration for which the zero vectors (either using the zero state 0 or the zero state 7) is applied in a sub cycle must satisfy (1).
5. Only one phase must switch for a state transition.
6. The total number of switching's in a subcycle must be less than or equal to three.

Conditions 1 to 4 ensure volt-second balance. Condition 5 avoids unwanted switching's to keep the switching losses low. Condition 6 ensures that the average switching frequency is less than or equal to that of CSVPWM for a given sampling Frequency.

A typical switching sequence when the sample is situated in sector-I

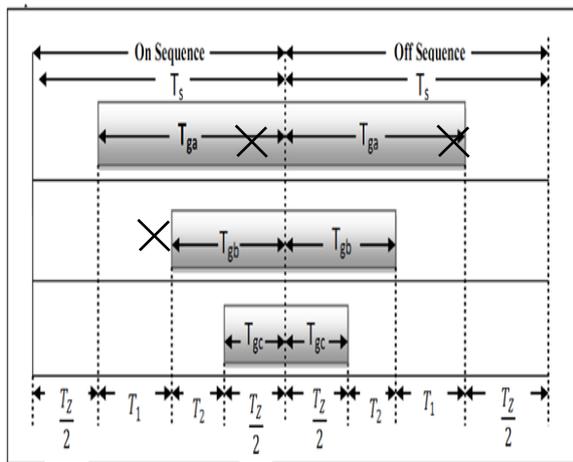


Fig-4. Gating signal generation using SVPWM scheme in sector-I

#### IV. RANDOM PULSE WIDTH MODULATION

The SVPWM algorithm uses the equal distribution of total zero state time among the two available zero Voltage vectors and gives constant switching frequency operation. Though, the standard SVPWM algorithm gives good performance, it gives more acoustical noise and harmonic distortion due to the switching frequency. The audible switching noise radiated from the drive can be decreased by increasing the PWM switching frequency of the inverter. Nowadays, to reduce the acoustical noise and harmonic distortion, many researchers have concentrated on random PWM (RPWM) algorithms. The content of the higher harmonics voltage (current) and electromagnetic interference generated in the inverter fed drive depends on the modulation technique. Therefore, PWM methods are investigated from this point of view. To reduce these disadvantages several methods have been proposed. One of these methods is random modulation (RPWM). The classical carrier based method or space vector modulation method are named deterministic (DEPWM), because these methods work with constant switching frequency. In opposite to the deterministic

methods, the random modulation methods work with variable frequency, or with randomly changed pulse position.

#### 4.1 Principle of RPWM:

In the Random pulse width modulator for voltage source inverters, random modified factor  $k_0$  is used. The sampling rate is maintained at a constant level, required by the desired dynamic characteristics of the drive system incorporating the inverter. The factor  $k_0$  is dithered in a random manner to disperse the harmonic power in the voltage spectrum. be less than 100% to modify the durations of zero state times. The zero state time durations can be modified as given in (6)-(7).

$$T_0 = k_0 T_z \tag{6}$$

$$T_7 = (1 - k_0) T_z \tag{7}$$

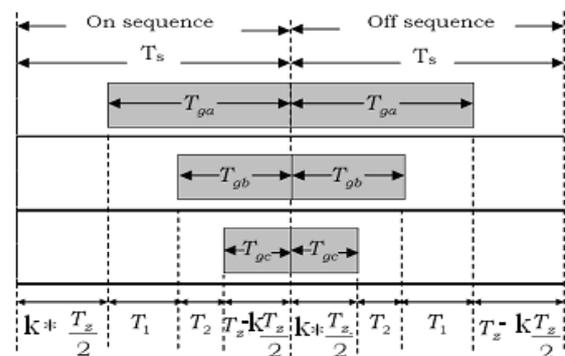


Fig-5. Gating signal generation using RPWM scheme in sector-I

#### V. PROPOSED RPWM BASED DTC-IM DRIVE

The block diagram of the proposed VDRPWM algorithm based DTC is as shown in Fig. 4,

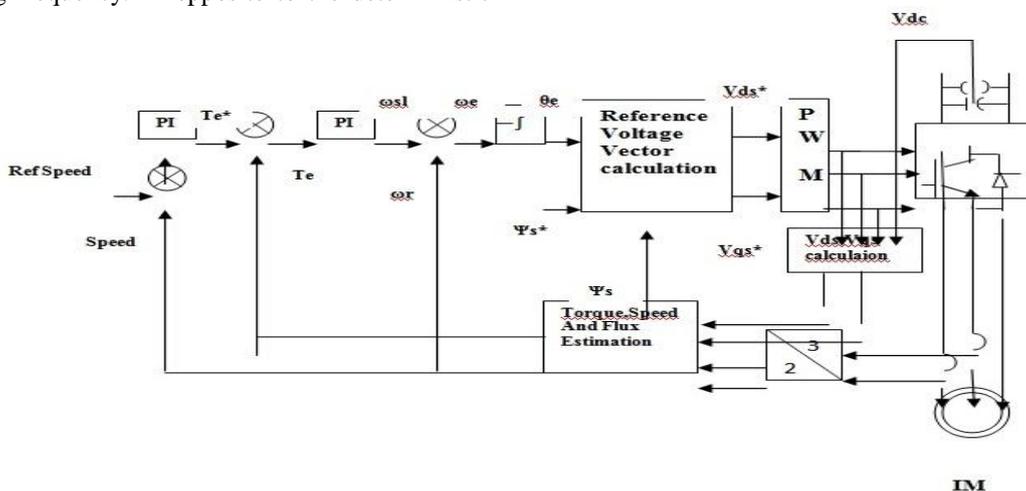


Fig-6 Block Diagram of RPWM based DTC

From which it can be observed that this scheme retains all the advantages of the conventional direct torque control, such as no coordinate transformation and robust motor parameters.

However a PWM modulator is used to generate the pulses for the inverter control, therefore the Complexity is increased in comparison with the CDTC method. In the proposed method, by adding the slip speed and actual rotor speed of the drive the position of the reference stator flux vector  $\psi_s^*$  is obtained and by using the flux estimator the actual synchronous speed of the stator flux vector  $\omega_s$  is evaluated. After each sampling interval, actual stator flux vector  $\psi_s$  is corrected by the error signal and it tries to reach the reference flux space vector  $\psi_s^*$ . Thus the flux error is reduced in each sampling interval. The reference values of the d-axis and q-axis stator fluxes and actual values of the d-axis and q-axis stator fluxes are compared in the reference voltage vector calculator block and then the errors in the d-axis and q-axis stator flux vectors are obtained as in(8),(9),(10),(11)

$$\Delta\psi_{ds} = \psi_{ds}^* - \psi_{ds} \quad - (8)$$

$$\Delta\psi_{qs} = \psi_{qs}^* - \psi_{qs} \quad - (9)$$

$$V_{ds}^* = R_s i_{ds} + \Delta\psi_{ds} / T_s \quad - (10)$$

$$V_{qs}^* = R_s i_{qs} + \Delta\psi_{qs} / T_s \quad - (11)$$

These derived d-q components of the reference voltage vectors are passed to the PWM block. In PWM block, these two-phase voltages are then converted into three-phase voltages. Later, the switching times are calculated as explained in the earlier sections for RPWM control

## VI. SIMULATION RESULTS

To verify the proposed conventional VDRPWM based drive, simulation studies have been carried out on direct torque controlled induction motor drive by using MATLAB/SIMULINK. For the simulation analysis, the reference flux is considered as 1wb and starting torque is limited to 15 N-m. The induction motor used in this case study is a 3-phase, 4-pole, 1.5 kW, 1440 rpm and having the parameters as  $R_s = 7.83 \Omega$ ,  $R_r = 7.55 \Omega$ ,  $L_s = 0.4751H$ ,  $L_r = 0.4751H$ ,  $L_m = 0.4535 H$  and  $J = 0.06 \text{ Kg.m}^2$ . The steady state results of conventional DTC and SVPWM algorithm based DTC are shown. From the results it is clear that SVPWM algorithm based drive gives superior performance and reduced harmonic distortion when compared with conventional DTC, but it gives considerable acoustical noise. Hence, to minimize the acoustical noise and THD of the drive, this paper presents conventional VDRPWM algorithm based control. The simulation results of VDRPWM algorithm based induction motor drive are shown. From the simulation results, it is clear that the proposed VDRPWM algorithm gives reduced THD and less acoustical noise when

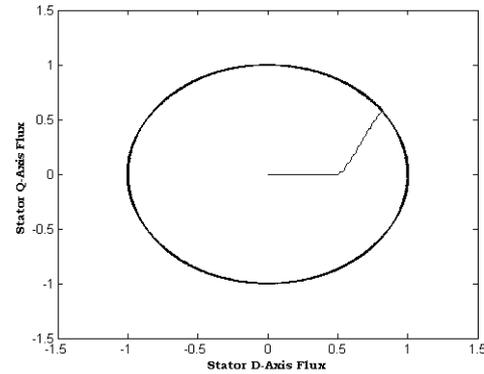


Fig.1 Locus of Stator flux in SVPWM based DTC Drive

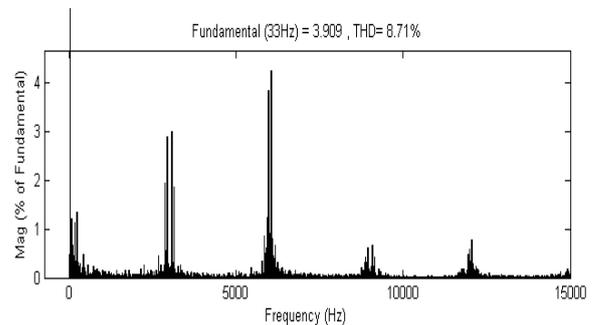


Fig.2 Harmonic Spectra of line Current in SVPWM based DTC drive

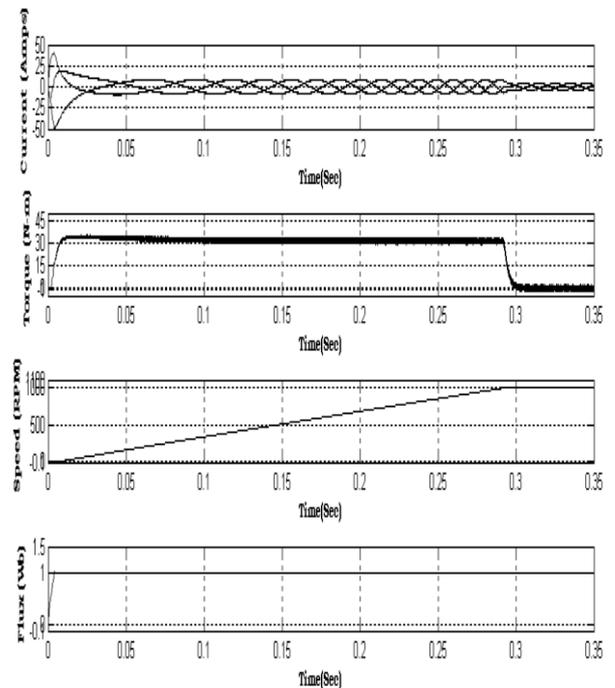
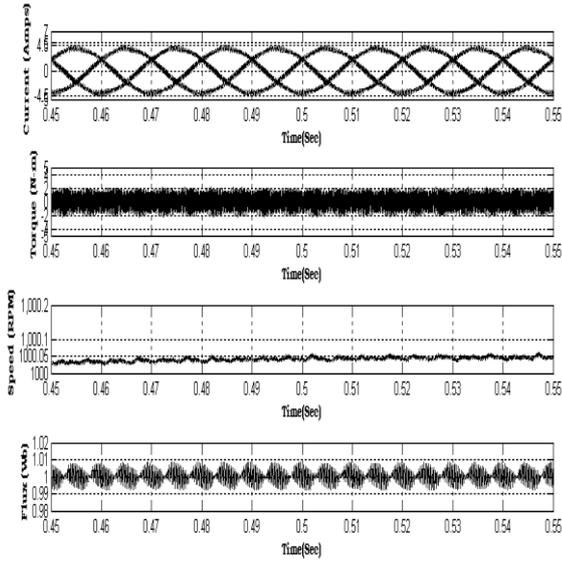
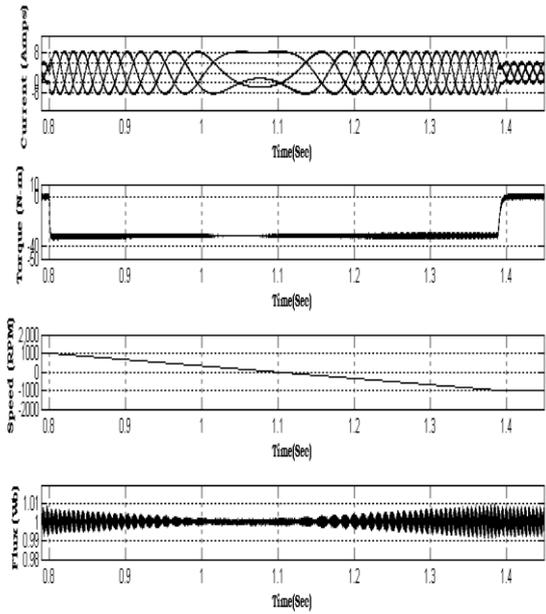


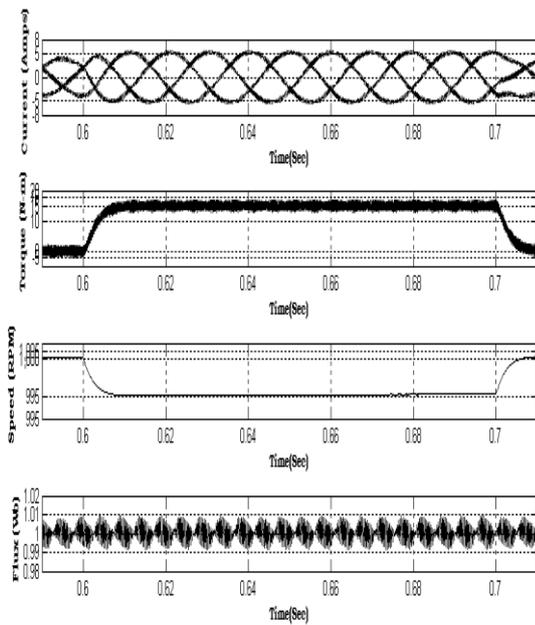
Fig.3 Starting transients of SVPWM based DTC drive



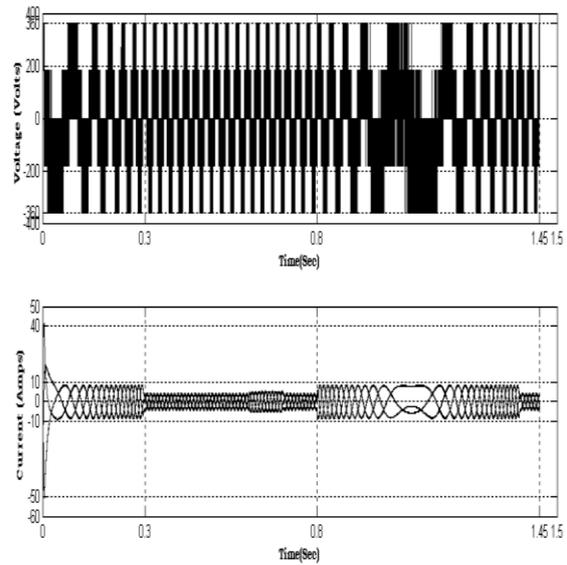
**Fig.4 Steady State Plots of SVPWM based DTC drive**



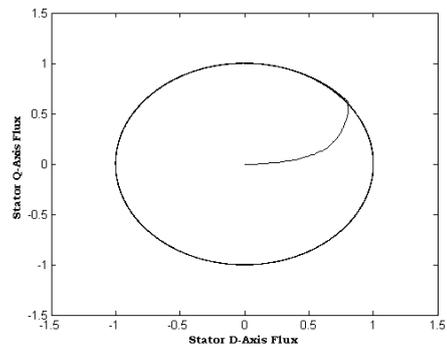
**Fig.6 Transients during speed reversal condition for SVPWM based DTC drive**



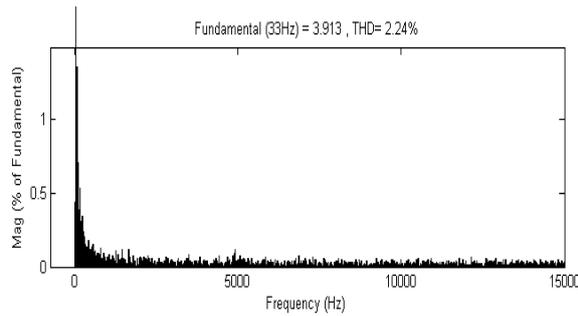
**Fig.5 Transients during step change in load for SVPWM based DTC drive**



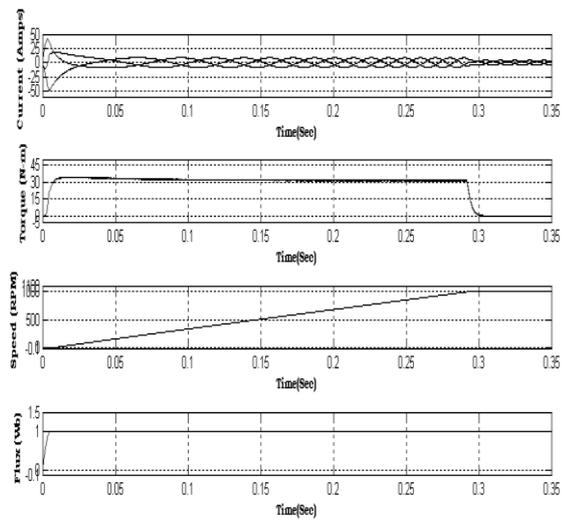
**Fig.7 Voltage and Current Plots for SVPWM based DTC drive**



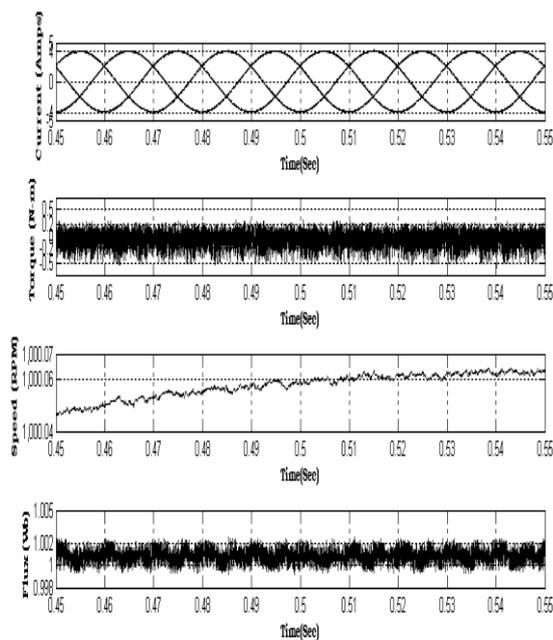
**Fig.8 Locus of Stator flux in proposed RPWM based DTC Drive**



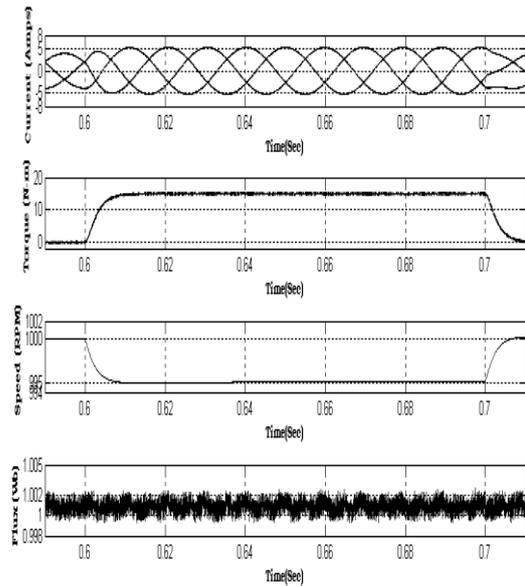
**Fig.9 Harmonic Spectra of line Current in Proposed RPWM based DTC drive**



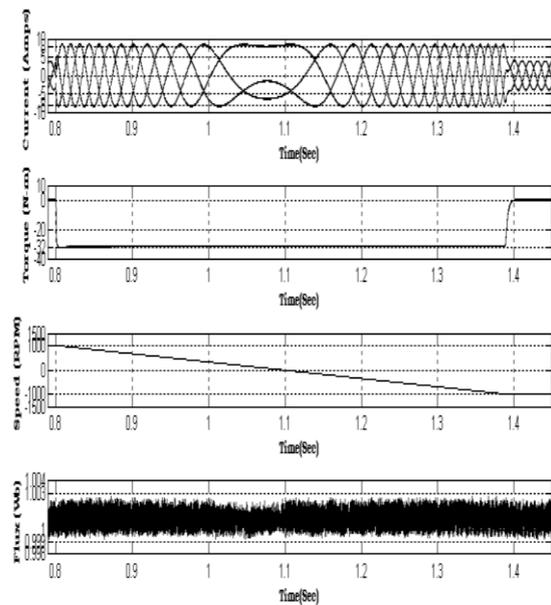
**Fig.10 Starting transients of Proposed RPWM based DTC drive**



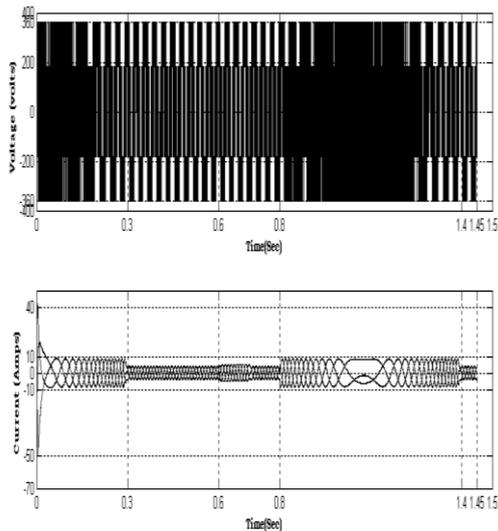
**Fig.11 Steady State Plots of Proposed RPWM based DTC drive**



**Fig.12 Transients during step change in load for Proposed RPWM based DTC drive**



**Fig.13 Transients during speed reversal condition for Proposed RPWM based DTC drive**



**Fig.14 Voltage and Current Plots for Proposed RPWM based DTC drive**

## VII. CONCLUSIONS

To overcome the drawbacks of conventional DTC and SVPWM algorithm based drive, a novel RPWM algorithm is presented in this paper for direct torque control of induction motor. From the simulation results, it can be observed that the proposed RPWM algorithm gives reduced harmonic distortion. Hence, the proposed RPWM algorithm gives distributed spectra and gives reduced amplitude of harmonics when compared with the SVPWM algorithm. The simulation results confirm the superiority of proposed VDRPWM algorithm when compared with the SVPWM algorithm based DTC drive.

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