SPACE VECTOR BASED VARIABLE DELAY RANDOM PWM ALGORITHM FOR DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVE FOR HARMONIC REDUCTION

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ABSTRACT

The conventional SVPWM algorithm gives good performance for control of induction motor drive, but it produces more acoustical noise resulting in increased total harmonics distortion. The random pulse width modulation (RPWM) techniques has become an established means for mitigation of undesirable side effects in PWM converters, the use of voltage source inverters in adjustable speed ac drives in particular. Hence, to minimize these anomalies of the drive, this paper presents a novel variable delay random pulse width modulation (VDRPWM) algorithm with constant switching frequency for direct torque controlled induction motor drive. The Simplicity of this technique is its easy implementation and requires only low-end processors. The conventional VDRPWM preserves both the quality switching of the conventional space-vector PWM (SVPWM) method and minimized harmonic mitigation of the variable switching frequency PWM technique. To validate the proposed conventional VDRPWM algorithm for the considered drive, simulation studies have been carried out and results are presented. The simulation results confirmed the feasibility of proposed VDRPWM algorithm strategy in terms of acoustical noise and harmonic distortion as compared with conventional DTC and SVPWM based induction motor drive.

KEYWORDS: *Total Harmonic Distortion, sampling period, acoustic noise, SVPWM, constant switching times, Variable Delay Random Pulse Width Modulation (VDRPWM).*

I. INTRODUCTION

Variable frequency AC drives are increasingly used for various industrial applications. The direct torque control (DTC) technique has been recognized as the viable solution to achieve the requirements of various industrial drives. Despite being simple, DTC is able to produce very fast torque and flux control and also robust with respect to drive parameters [1]-[2]. However, during steady state operation, a notable torque, flux and current pulsations will occur which are reflected in speed estimation and in increased acoustical noise. To overcome these anomalies and also for full utilization of dc bus, Space Vector PWM technique has been introduced [3]-[4]. Due to the improvement of fast-switching power semiconductor devices, voltage source inverters with pulse width- modulated (PWM) control growing interest which increases the performance of DTC drive Systems [5]-[6] . In recent years, the space vector PWM (SVPWM) algorithm is gaining importance by many researchers. In the SVPWM algorithm, the reference is given as a voltage space vector, which is sampled in every sub-cycle and an average voltage vector equal to the sampled reference is generated by different voltage vectors produced by the inverter. The SVPWM based PWM technique for inverter operated induction motor drive has major advantages compared to other techniques. It has lower current harmonics, a possible higher modulation index compared with sinusoidal modulation technique and ease of implementation. Though, the SVPWM algorithm has good performance, it produces acoustical noise and harmonic distortion due to its nature of pulse durations. To overcome the anomalies CSVPWM, the PWM controlled inverter is used which is operated at a constant switching frequency. When the carrier frequency increases, the current harmonics shift to higher frequencies. As the PWM switching done at high frequencies higher harmonic distortion and switching noise will results. Among various PWM techniques, the random pulse width modulation (RPWM) techniques are attracted by many researchers for application to various drive systems. The principle of RPWM is that, either the position of the pulse or the switching frequency is varied randomly then the power spectrum of the output voltage acquires a continuous part, while the harmonic part is significantly reduced. The detailed review of the RPWM approach is given in [7]-[9]. However, a novel algorithm known as variable delay RPWM (VDRPWM) which is characterized by a constant switching frequency and a varying switching period (Ts) is gaining importance recently [10]-[11]. This paper presents a novel variable delay random PWM based direct torque controlled induction motor drive to reduce acoustical noise and harmonic distortion. The results of this drive are compared with that of the conventional DTC and SVPWM based induction motor drive.

II. SPACE VECTOR PWM ALGORITHM

The three-phase, two-level voltage source inverter (VSI) has a quite simple design and generates a low-frequency output voltage with controlled amplitude and frequency by programming gating pulses at high-frequency. For a 3-phase, two-level VSI, there are eight possible voltage vectors, which can be represented in the space as shown in Fig. 1.

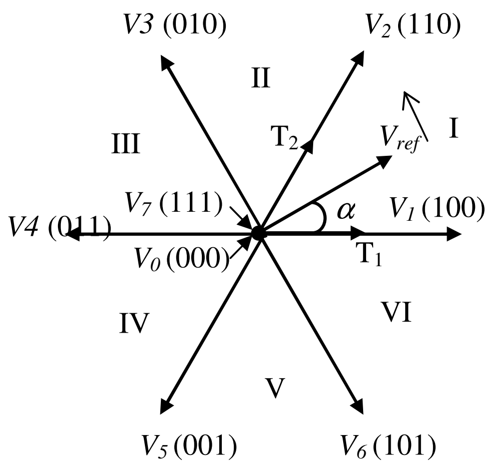

Fig 1 Possible voltage space vectors and sector definition

The voltage vectors V_1 and V_7 are known as zero voltage vectors or null vectors and the remaining voltage vectors V_1 to V_6 vectors are known as active voltage vectors or active states. The reference voltage space vector or sample as shown in Fig.1 represents the corresponding required value of the fundamental components for the output voltages. In the space vector algorithm this is constructed in an average sense. V_{ref} is sampled at equal intervals of time, T_s . Different voltage vectors that are produced will be applied over different time durations with in a sampling time period such that the average vector produced over the sampling time period is equal to the sampled value of the V_{ref}, both in terms of magnitude and angle. Any two active voltage vectors and one zero voltage vectors forming the boundary of the sector in which the sample lies be considered to generate reference sample vector. For the required reference voltage vector, the active and zero voltage vectors times are calculated as given in (1)-(3).

$$T_1 = \frac{2\sqrt{3}}{\pi} M_i \sin(60^o - \alpha) T_s \quad (1)$$

$$T_2 = \frac{2\sqrt{3}}{\pi} M_i \sin(\alpha) T_s \quad (2)$$

$$T_z = T_s - T_1 - T_2 \quad (3)$$

where M_i is the modulation index and defined as $M_i = \pi V_{ref} / 2V_{dc}$.

III. PROPOSED VDRPWM ALGORITHM

A fixed sampling technique allows optimal use of the processor computational capability. Several papers by various researchers have investigated different methods for maintaining fixed sampling rate while introducing RPWM techniques [12]–[13]. In [13], three different fixed sampling rate techniques are illustrated, which maintains synchronous sample and PWM period but it suffers some form of limitation. Random zero vector and random centre displacement (RCD) has less effectiveness at high-modulation indexes. The Random lead–lag (RLL) does not offer a very good performance with respect to the reduction of acoustical noise and suffers in increased current ripple. In addition, RLL and RCD introduce an error in the fundamental component due to average value of the switching ripple. For the listed reasons, the variable-delay random pulse width modulation (VDRPWM) method was selected for this application.

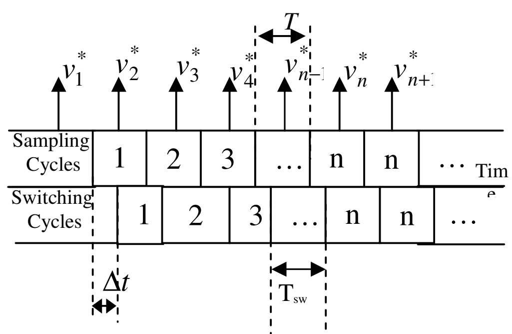

Fig 2 sampling and switching cycles in the proposed VDRPWM algorithm

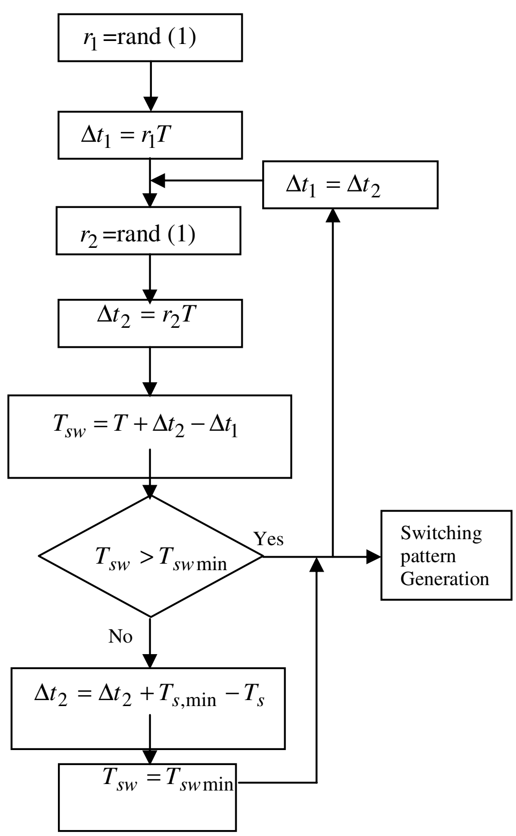

Fig 3 flowchart of proposed variable delay random PWM algorithm

The novel approach to dithering the switching periods, referred to as a variable-delay random pulse width modulation (VDRPWM) technique, is characterized by a constant sampling frequency. The Sampling and switching cycles in the VDRPWM technique is shown in figure 2. As described in the above figure, the individual switching periods are varied in a random manner by randomizing the switching cycle delays with respect to their corresponding sampling cycles. The random delay, Δt, can be varied with uniform distribution between zero and the sampling period, τ[14]-[16]. The resulting switching period will turn out to be too short if a long delay in one sampling cycle is followed by a short delay in the next subsequent cycle, that is, shorter than its minimum allowable value T_{sw} minimum. In such case, the switching period is set to that value which results the length of the switching cycle varies between T_{sw} minimum and 2τ. A flow chart of the VDRPWM technique for control of induction motor drive is shown in Fig. 3 from which it is clear that, the number of switching cycles is same as that of sampling cycles, that is, the average switching frequency equals the fixed sampling frequency.

IV. PROPOSED VDRPWM BASED DTC-IM DRIVE

The block diagram of the proposed VDRPWM algorithm based DTC is as shown in Fig. 4, from which it can be observed that this scheme retains all the advantages of the conventional direct torque control, such as no co-ordinate transformation and robust motor parameters.

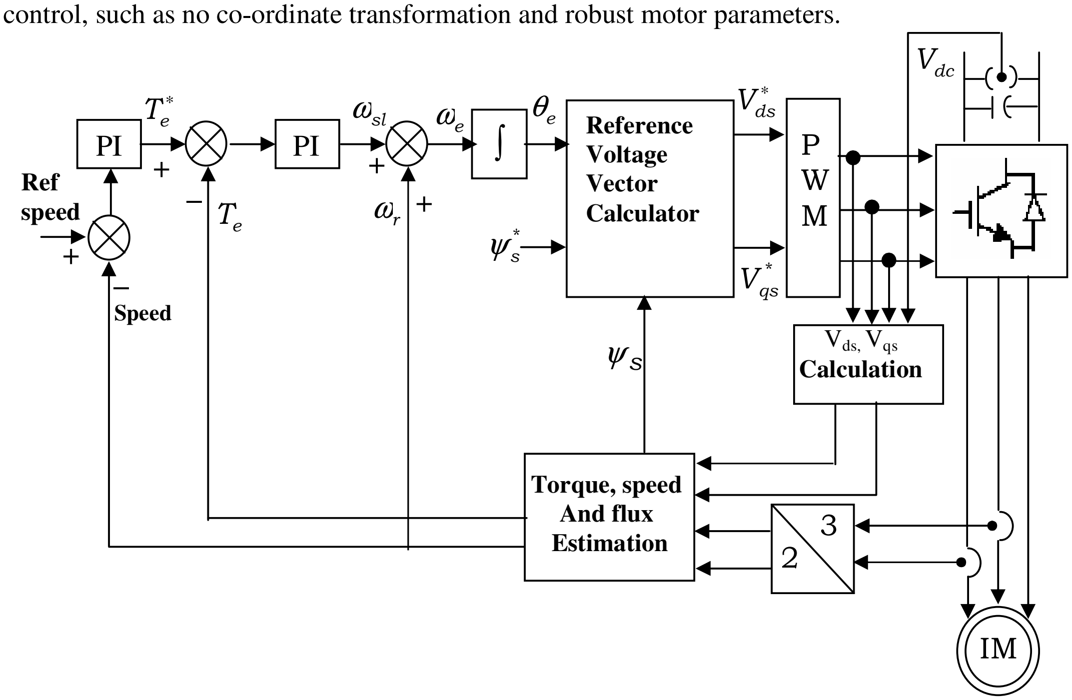

Fig 4 Block diagram of proposed VDRPWM based Direct Torque Control

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 $\bar{\psi}_s^*$ is obtained and by using the flux estimator the actual synchronous speed of the stator flux vector $\bar{\psi}_s$ is evaluated. After each sampling interval, actual stator flux vector $\bar{\psi}_s$ is corrected by the error signal and it tries to reach the reference flux space vector $\bar{\psi}_s^*$. 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 (4)-(5).

$$\Delta\psi_{ds} = \psi_{ds}^* - \psi_{ds} \qquad (4)$$

$$\Delta\psi_{qs} = \psi_{qs}^* - \psi_{qs} \qquad (5)$$

The knowledge of flux error is then can be used to get the appropriate reference voltages as in (6)–(7).

$$V_{ds}^{*} = R_s i_{ds} + \frac{\Delta \psi_{ds}}{T_s} \quad (6)$$

$$V_{qs}^{*} = R_s i_{qs} + \frac{\Delta \psi_{qs}}{T_s} \quad (7)$$

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 VDRPWM control.

V. Simulation Results and Discussion

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 = 7.83Ω, R_r = 7.55 Ω, L_s = 0.4751H, L_r = 0.4751H, L_m = 0.4535 H and J = 0.06 Kg.m^2. The steady state results of conventional DTC and SVPWM algorithm based DTC are shown in Fig.5-Fig.10. 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 in Fig. 11- Fig.16. From the simulation results, it is clear that the proposed VDRPWM algorithm gives reduced THD and less acoustical noise when compared with the SVPWM algorithm based drive.

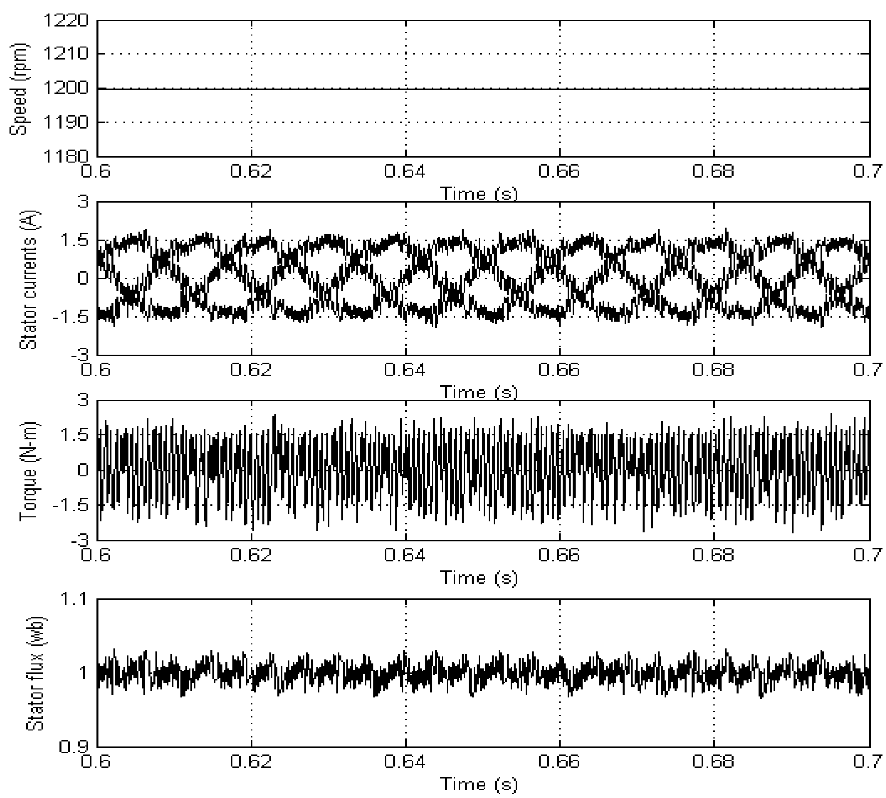

Fig 5 steady state plots of conventional DTC

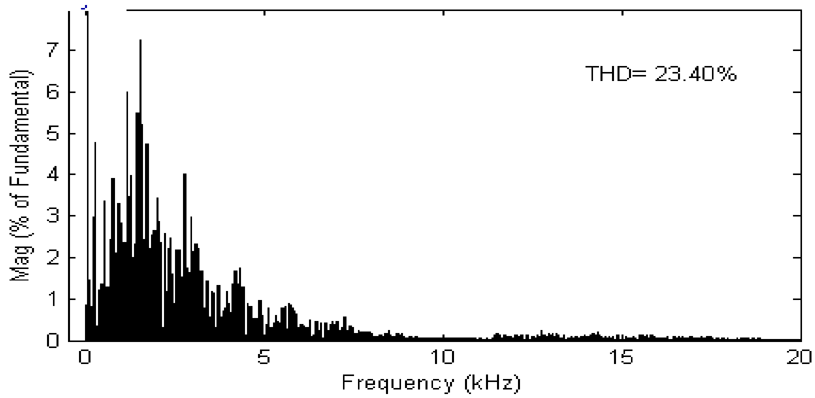

Fig 6 Harmonic spectra of line current in conventional DTC

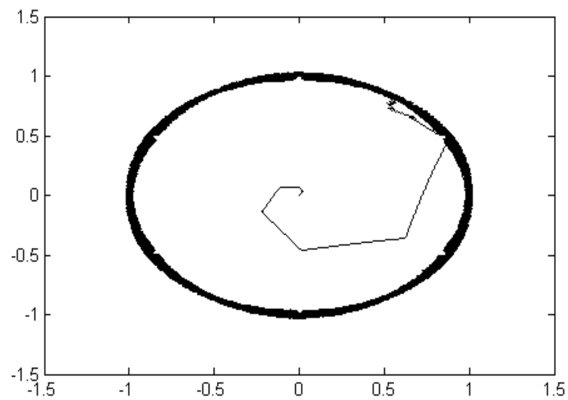

Fig 7 Locus of stator flux in conventional DTC drive

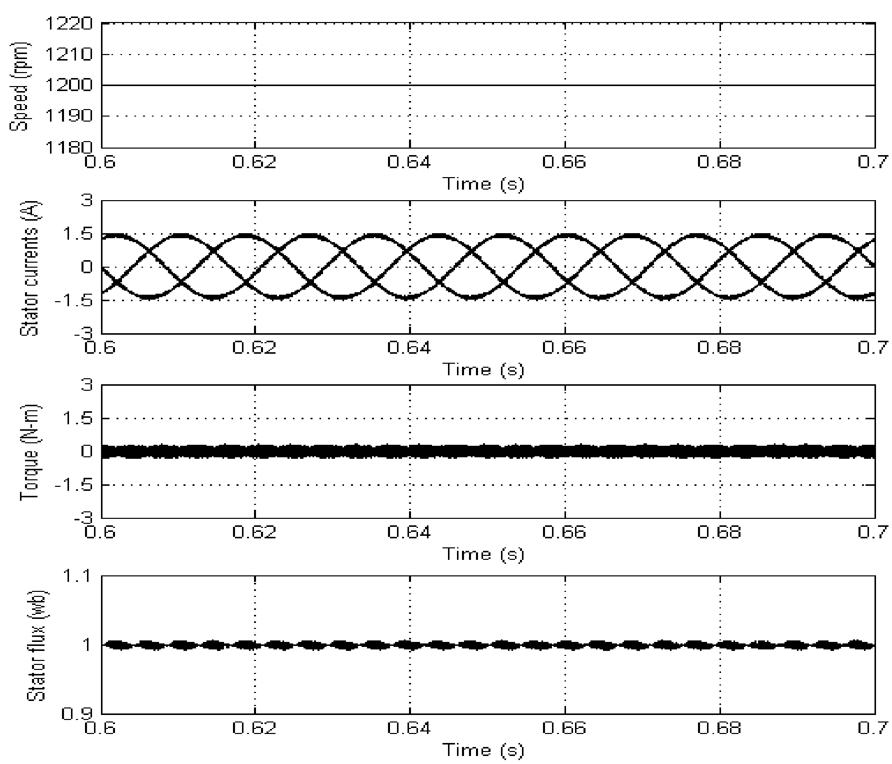

Fig 8 steady state plots of SVPWM algorithm based DTC

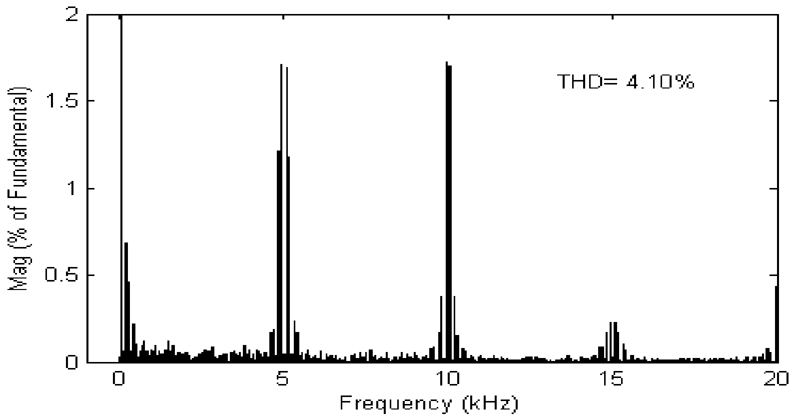

Fig 9 Harmonic spectra of line current in SVPWM based DTC drive

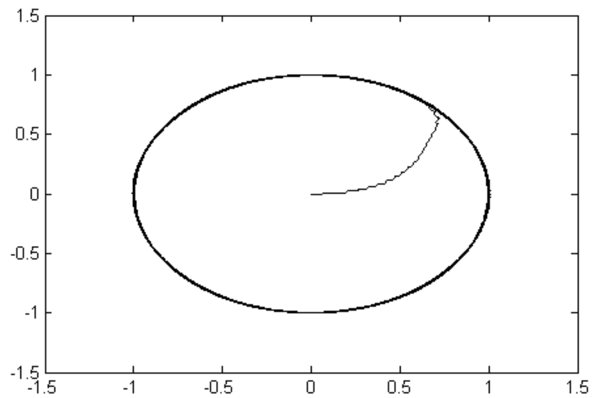

Fig 10 Locus of stator flux in SVPWM based DTC drive

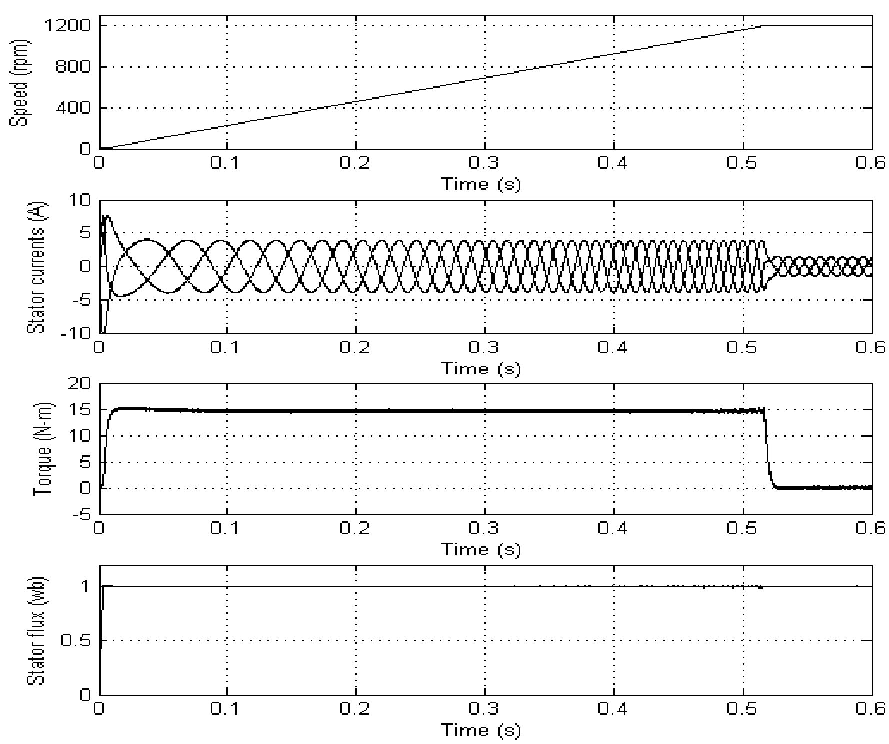

Fig 11 starting transients of proposed VDRPWM based DTC drive

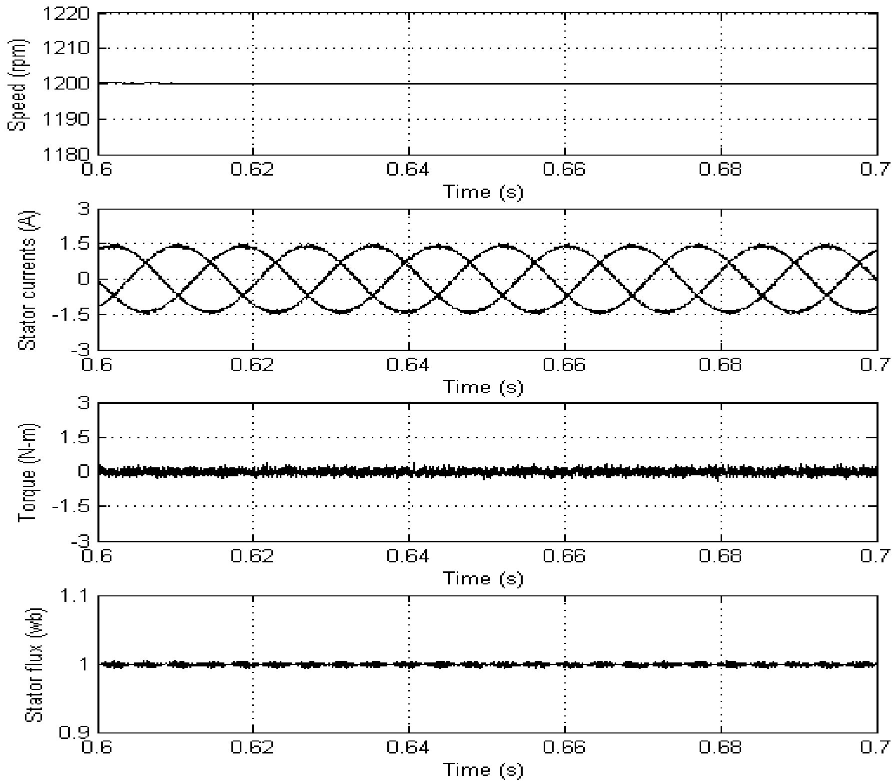

Fig 12 Steady state plots of proposed VDRPWM based DTC drive

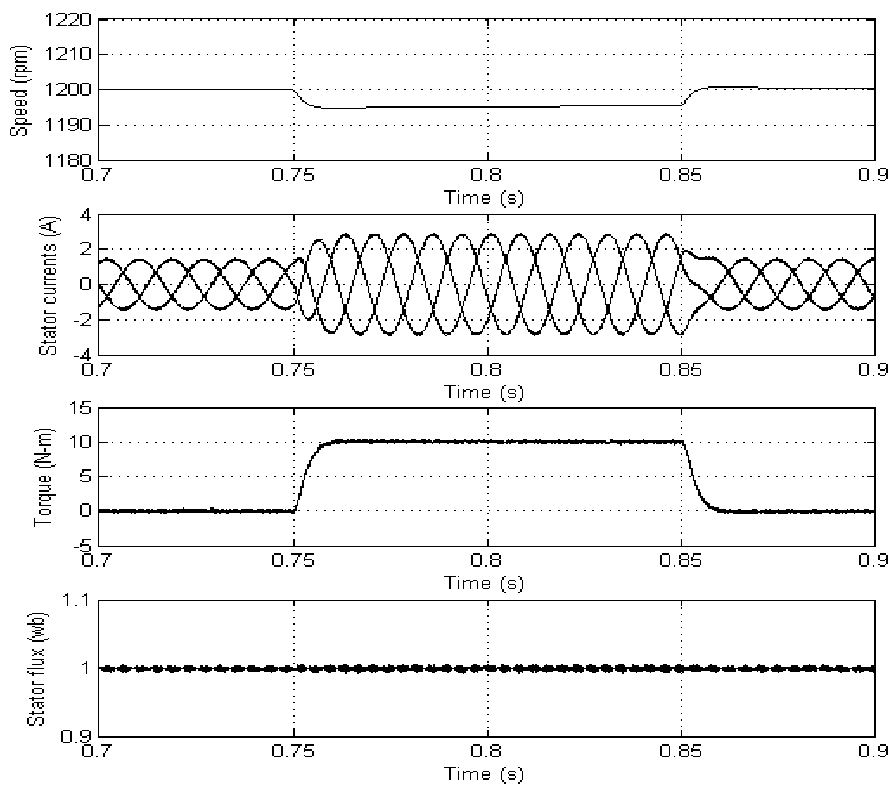

Fig 13 Transients during step change in load for proposed VDRPWM algorithm based DTC drive (a load torque of 10 N-m is applied at 0.75 s and removed at 0.85s)

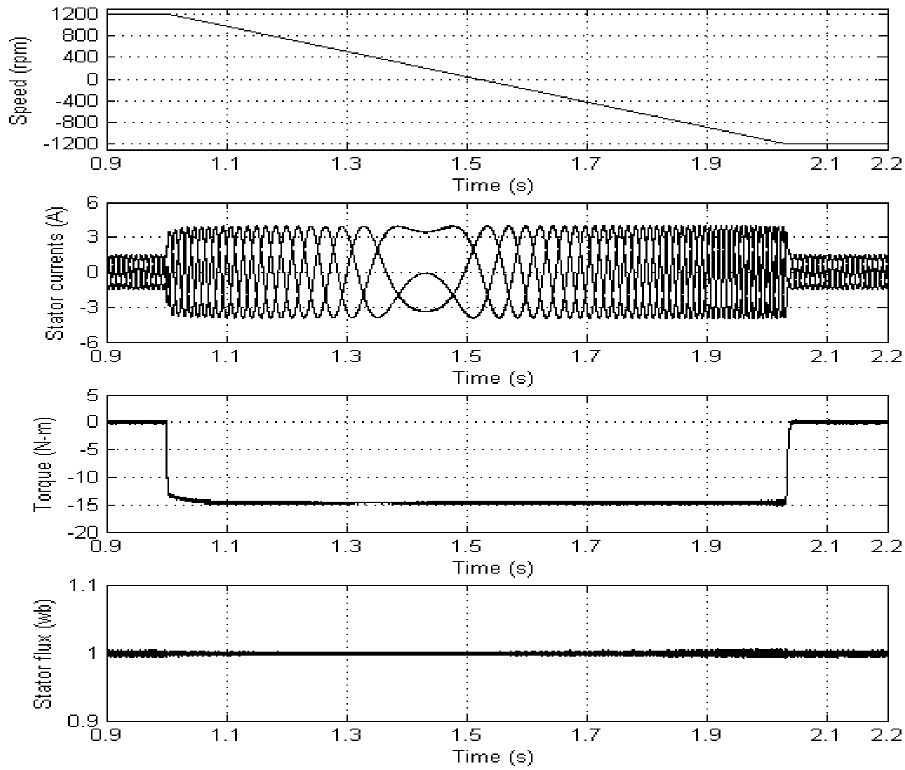

Fig. 14 Transients during speed reversal condition for proposed VDRPWM algorithm based DTC drive (speed changed from +1200 rpm to -1200 rpm)

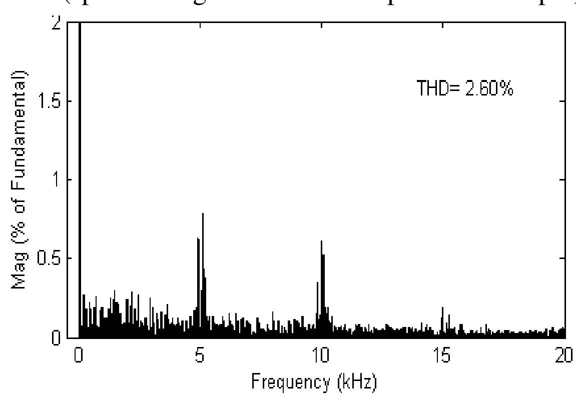

Fig 15 Harmonic spectra of line current in proposed VDRPWM based DTC drive

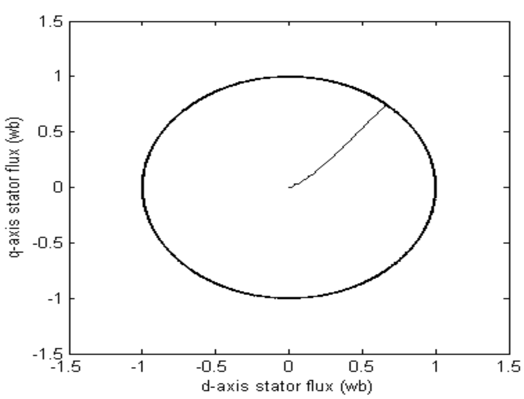

Fig 16 Locus of stator flux in proposed VDRPWM based DTC drive

VI. CONCLUSION

To overcome the drawbacks of conventional DTC and SVPWM algorithm based drive, a novel VDRPWM algorithm is presented in this paper for direct torque control of induction motor. From the simulation results, it can be observed that the proposed VDRPWM algorithm gives reduced harmonic distortion. Hence, the proposed VDRPWM 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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