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Space Vector Based Dual Zero Random Distribution PWM Algorithm for Direct Torque Control of Induction Motor Drive

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Abstract— The basic direct torque control algorithm gives large ripples in torque, flux and current in steady state, which results in acoustical noise and incorrect speed estimations. 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 have become an established means for mitigation of undesirable side effects in adjustable speed ac drives in particular. Hence, to minimize these anomalies of the drive, this paper presents a random zero vector distribution (RZVDPWM) algorithm for direct torque controlled induction motor drive. The proposed random zero vector distribution PWM (RZVDPWM) algorithm distributes the zero state time between the two zero voltage vectors. To validate the proposed PWM algorithm, simulation studies have been carried out and results are presented and compared. From the results, it can be observed that the proposed RZVDPWM algorithm gives reduced acoustical noise when compared with space vector pulse width modulation (SVPWM) algorithm.

Key Words: DTC, RZVDRPWM, RPWM, stator flux ripple, SVPWM, Harmonic Distortion, Acoustical noise.

I. INTRODUCTION

In the middle of 1980s, a new technique for the torque control of induction motors was developed and presented by I.Takahashi as direct torque control (DTC) [1], which is preferable for low and medium power range applications. 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. In recent years, the space vector PWM (SVPWM) algorithm is attracting many researchers to overcome these anomalies [3]-[4]. In the SVPWM algorithm, the reference is provided as a voltage space vector, which is sampled in every sub cycle and an average voltage vector equal to the sampled reference voltage vector is generated by time-averaging of the different voltage vectors produced by the inverter.The SVPWM is a superior PWM technique for three phase inverter drives compared to the traditional regularly sampled triangular comparison technique. The SVPWM algorithm results in higher line side voltage and less line current harmonic distortion than sine PWM algorithm with constant switching frequency [5]. To reduce the steady state ripple and to get constant switching frequency operation of the inverter, SVPWM algorithm is applied to DTC in [6-7]. Though, the SVPWM algorithm gives good performance, it gives more acoustical noise and harmonic distortion. To overcome these drawbacks, random PWM (RPWM) algorithms are attracting many researchers. Various RPWM algorithms are reported in the literature [8-10]. Among various algorithms, random zero vector distribution PWM (RZVDPWM) algorithm is simple and ease of implementation. [9-10].This paper presents a conventional RZVDPWM algorithm for direct torque controlled induction motor drive to reduce the acoustical noise.

II.SPACE VECTOR PULSE WIDTH MODULATION

Space Vector Modulation (SVM) was originally developed as vector approach to Pulse Width Modulation (PWM) for three phase inverters. It is a more sophisticated technique for generating sine wave that provides a higher voltage to the motor with lower total harmonic distortion. The main aim of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application.
The space vector concept, which is derived from the rotating field of induction motor, is used for modulating the inverter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent two-phase quantity either in synchronously rotating frame (or) stationary frame. From these two-phase components, the reference vector magnitude can be found and used for modulating the inverter output. The process of obtaining the rotating space vector is explained in the following section, considering the stationary reference frame. SVM is a digital Power Converter PWM technique where the duty cycles of inverter switches are calculated directly by using mathematical transformations. The three-phase, two-level VSI has a simple structure and generates a low-frequency output voltage with controllable amplitude and frequency by programming high-frequency gating pulses. For a 3-phase, two-level VSI, there are eight possible voltage vectors, which can be represented as shown in Figure 1.

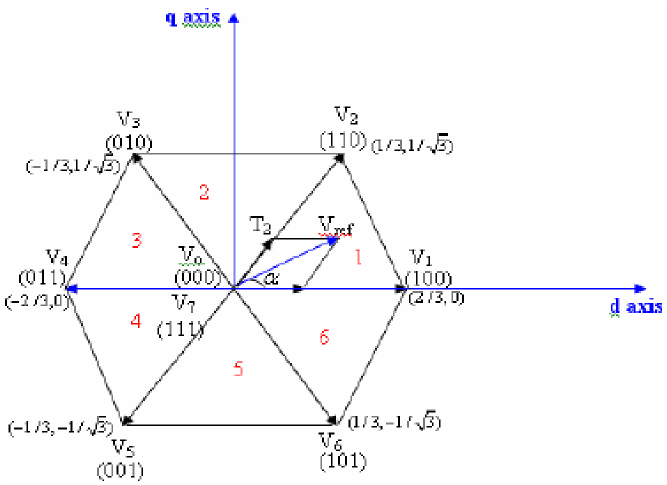

Figure 1. Voltage space vectors and sector definition

The V_1 to V_6 vectors are known as active voltage vectors and the remaining two vectors are known as zero voltage vectors. The reference voltage space vector V_{ref} represents the desired value of the fundamental components for the output phase voltages. In the space vector approach V_{ref} can be constructed in an average manner. The reference voltage vector V_{ref} is sampled at equal intervals of time, T_S referred to as sampling time period. The possible voltage vectors that can be produced by the inverter are applied for different time durations within a sampling time period such that the average vector produced over the T_s is equal to V_{ref}, both in magnitude and angle. It has been established that the vectors to be used to generate any sample are the zero voltage vectors and the two active voltage vectors forming the boundary of the sector in which the sample lies. As all six sectors are symmetrical, the discussion is limited to the first sector only. For the required reference voltage vector, the active and zero voltage vectors times can be calculated as in (1) - (3).

$$T_1 = \frac{2\sqrt{3}}{\pi} M_i \sin(60^0 - \alpha) T_s \tag{1}$$

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

$$T_z = T_s - T_1 - T_2 \tag{3}$$

Where M_i is the modulation index and defined as $M_i = \pi V_{ref}\, 2V_{dc}$. In the SVPWM algorithm, the total zero voltage vector time is equally divided between the two zero vectors and distributed symmetrically at the start and end of the each sampling time period. Thus, SVPWM uses 0127-7210 in sector-I, 0327-7230 in sector-II and so on.

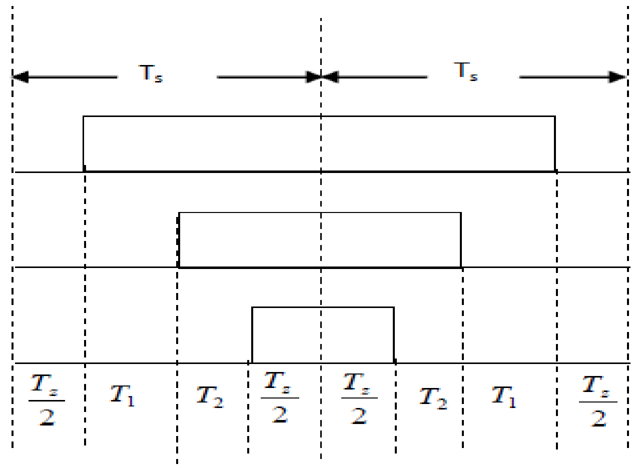

Figure 2(a): Sequence and gating times in sector 1 for proposed SVPWM

III. Proposed RZVDPWM Algorithm

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 h armonic distortion, many researchers have concentrated on random PWM (RPWM) algorithms. The RPWM algorithms can be classified into three categories as random switching frequency PWM, random pulse position PWM, and hybrid random PWM. Among these, the random pulse position PWM (RPPPWM) algorithms are simple and popular. RPPPWM algorithms are classified into random lead -lag PWM (RLLPWM), random centered distribution PWM (RCDPWM), random zero vector distribution PWM (RZVDPWM) and separately randomized pulse position PWM. However, this paper concentrates on RZVDPWM algorithm only. In a three-phase, three-wire system, the duration of the zero voltage vectors does not alter the phase voltages. In the proposed algorithm, the portion between the time durations for th e two zero voltage vectors 111 and 000 is randomized in each sampling interval and while randomizing the zero state durations, care must be taken to ensure that all pulses are center -aligned as in standard SVPWM. The active and zero voltage vector times are calculated by using (1) - (3).

Then a random number (k_o) is generated between 0% and 100% and must be less than 100% to modify the durations of zero state times. The zero state time durations can be modified as given in (4)-(5)

$$T_0 = k_o T_z; \tag{4}$$

$$T_7 = (1 - k_o) T_z \tag{5}$$

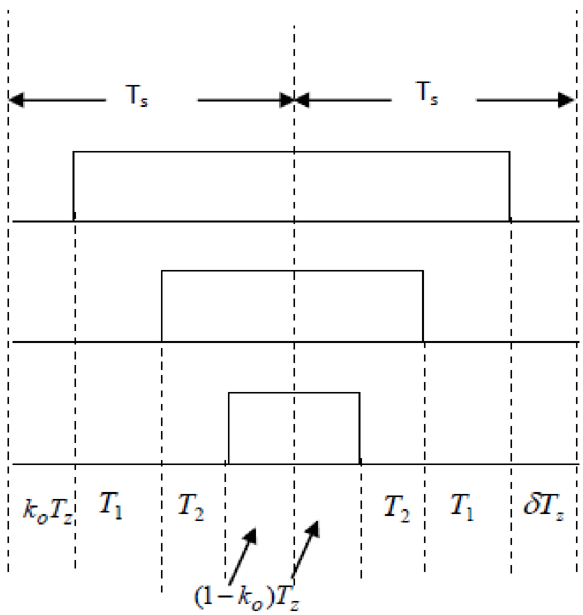

Figure 2(b): Sequence and gating times in sector 1 for proposed RZVDPWM

Figure 2(b) illustrates the sequence and timings of application of zero voltage vectors and active voltage vectors in the first sector of a standard SVPWM and proposed RZVDPWM algorithm.

IV. Proposed RZVDPWM Algorithm Based Direct Torque Controlled Induction Motor Drive

To reduce the complexity of the algorithm, in this paper, the required reference voltages to control the torque and flux cycle-by-cycle basis is constructed by using the errors between the reference d-axis and q-axis stator fluxes and estimated stator fluxes sampled from the previous cycle. The block diagram of the proposed RZVDPWM algorithm based DTC is as shown in Figure. 3 from which it can be seen that the proposed PWM based DTC scheme retains all the advantages of the CDTC, such as no co-ordinate transformation and robust to motor parameters but the complexity is increased in comparison with the CDTC method. In the proposed method, the position of the reference stator flux vector ψ_s^* is derived by the addition of slip speed and actual rotor speed. The actual synchronous speed of the stator flux vector ψ_s is calculated from the adaptive motor model. After each sampling interval, actual stator flux vector ψ_s is corrected by the error and it tries to attain the reference flux space vector ψ_s^*. Thus the flux error is minimized in each sampling interval. The d-axis and q-axis components of the reference voltage vectors are compared in the reference voltage vector calculator block and hence the errors in the d-axis and q-axis stator flux vectors are obtained as in (6)-(7). From the errors the appropriate reference voltage space vectors are determined as in (8)-(9).

$$\Delta\psi_{ds} = \psi_{ds}^* - \psi_{ds} \tag{6}$$

$$\Delta\psi_{qs} = \psi_{qs}^* - \psi_{qs} \tag{7}$$

$$V_{ds}^* = R_s i_{ds} + \frac{\Delta\psi_{ds}}{T_s} \tag{8}$$

$$V_{qs}^* = R_s i_{qs} + \frac{\Delta\psi_{qs}}{T_s} \tag{9}$$

The calculated d-q components of the reference voltage vector are fed to the SVPWM block in which these two-phase voltages are converter into three-phase voltages. Then, the switching times are calculated as explained in previous section.

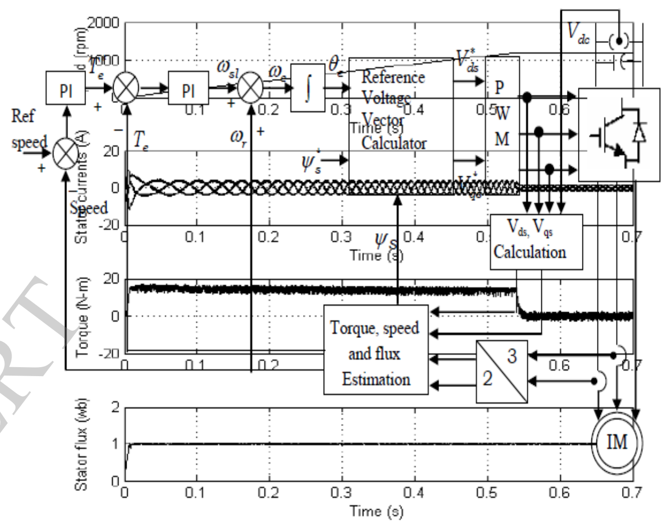

Figure 3: The block diagram of the proposed RZVDPWM algorithm based DTC

V. Simulation Results and Discussion

To validate the proposed algorithm based scheme, numerical simulation has been carried out by using Matlab/Simulink for which the reference flux is taken as 1wb and starting torque is limited to 15 N-m. The induction motor used in this simulation study is a 1.5 kW, 1440 rpm, 4-pole, 3-phase induction motor having the following parameters: Rs = 7.83Ω, Rr = 7.55 Ω, Ls = 0.4751H, Lr = 0.4751H, Lm = 0.4535 H and J = 0.06 Kg.m^2 . The starting and steady state simulation results of conventional DTC and SVPWM algorithm based DTC are shown in Figure. 4 – Figure.7.

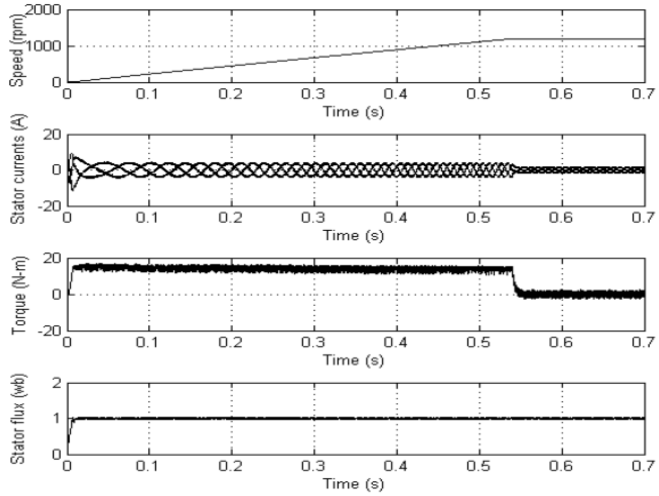

Figure 4:Starting transients and steady state plots for conventional direct torque controlled induction motor drive

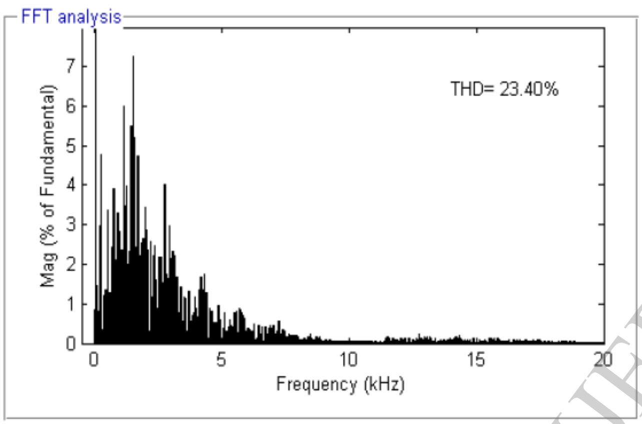

Figure 5:Harmonic spectra for line currents for conventional direct torque controlled induction motor drive

From the simulation results, it is clear that the total harmonic distortion (THD) and acoustical noise of conventional DTC algorithm is very high. To reduce the THD and acoustical noise of conventional DTC algorithm, SVPWM algorithm is used. From Figure 6 and Figure 7, it can be observed that the THD and acoustical noise is less when compared with the conventional DTC algorithm.

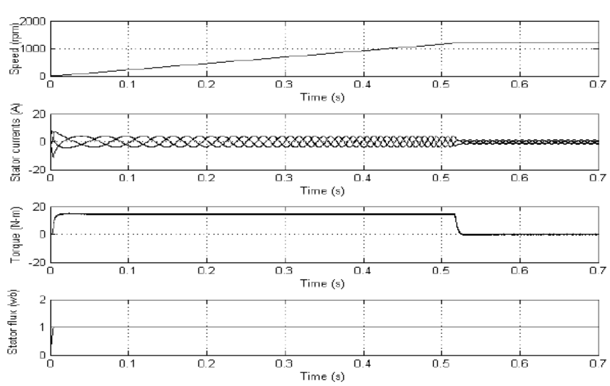

Figure 6: Starting transients and steady state plots for conventional SVPWM direct torque controlled induction motor drive

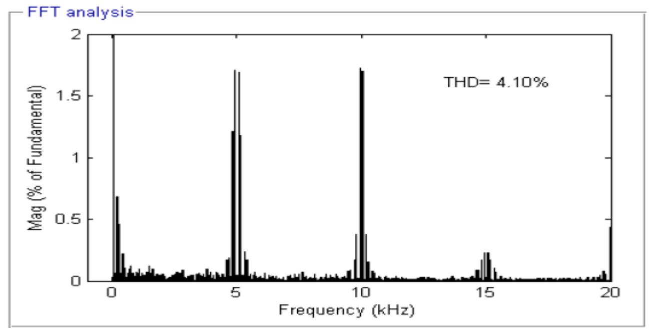

Figure 7:Harmonic spectra for line currents for conventional SVPWM direct torque controlled induction motor drive

To reduce these anomalies further, a novel RZVDPWM algorithm is proposed in this paper. The simulation results of proposed algorithm based DTC drive are shown from Figure. 8 to Figure. 11.

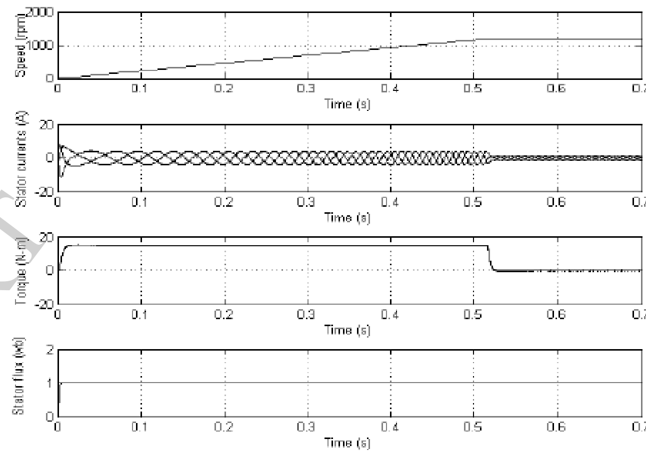

Figure 8: Starting transients and steady state plots for conventional SVPWM direct torque controlled induction motor drive

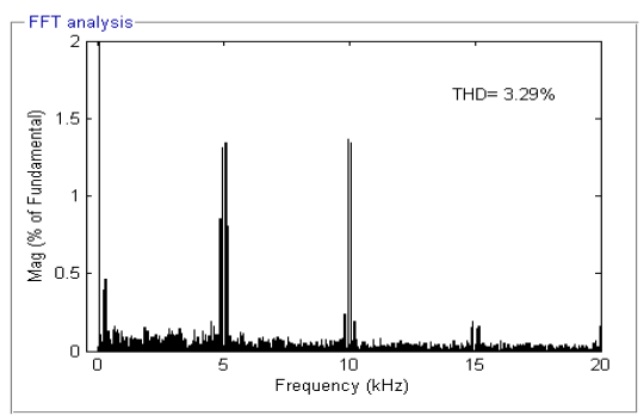

Figure 9:Harmonic spectra for line currents for conventional direct torque controlled induction motor drive

From the simulation results, it can be observed that the proposed RZVDPWM algorithm gives reduced THD resulting in reduced acoustical noise when compared with the standard SVPWM algorithm.

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Conclusions

Though the SVPWM based direct torque controlled induction motor drive gives good performance, it generates more acoustical noise and harmonic distortion. Hence, to reduce the acoustical noise, simplified RZVDPWM is proposed for direct torque controlled induction motor drive. From the simulation results, it can be observed that the proposed RZVDPWM algorithm based drive gives less harmonic distortion compared to conventional DTC and SVPWM algorithm based induction motor drive. As the magnitude of dominant harmonics around the switching frequency (5 kHz) is less in the proposed RZVDPWM algorithm, it gives less acoustical noise when compared with the standard SVPWM algorithm.

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