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Reduced Common Mode Voltage In Direct Torque Controlled Induction Motor Drives Using Near State PWM Technique

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Abstract
This paper presents a simplified near state PWM algorithm (NSPWM) for the reduction of common mode voltage (CMV) in direct torque controlled induction motor drives. In the proposed PWM algorithm instead of using zero voltage vectors, active voltage vectors are utilized for composing the reference voltage vector, So that the CMV changes from $+V_{dc}/6$ or $-V_{dc}/6$ due to application of active voltage vectors. As the proposed algorithm is 120^0 bus clamping PWM algorithm, it reduces the switching frequency and switching losses of the inverter. To validate the proposed algorithm, simulation studies have been carried out using MATLAB-Simulink and results have been presented
Keywords-c Common mode voltage, induction motor drives, PWM inverter, Space vector PWM.

I. INTRODUCTION

Recent development of fast switching semiconductor devices like IGBT, has brought high frequency switching operations to power electronic equipments there by improving the dynamic performance of PWM inverter fed ac motor drives. Moreover, this development created several unexpected problems such as conducted EMI, shaft voltages and breakdown of motor insulation. Many studies for reducing the CMV have been progressed [1]. Since these methods require additional hardware and has drawbacks of increase in inverter weight and volume which are unavoidable.

Direct Torque Control (DTC) is an emerging technique for controlling the PWM inverter-fed induction motor drives when compared with vector controlled induction motor. In spite of its simplicity, DTC has certain draw backs such as steady state ripple and generation of high level common mode voltage (CMV) variations [2-4]. To reduce steady state ripple and to get constant switching frequency operation, several PWM techniques have been developed. One of such Continuous PWM technique is conventional space vector PWM technique (SVPWM).

In this approach, two active voltage vectors and two zero voltage vectors are utilized to match the reference volt–seconds. This technique also generates high level common mode voltage variations due to the presence of zero voltage vectors [5-6]. DPWM method such as DPWM1 popularly known to reduce switching losses of inverter also suffers from high CMV variations due to presence of zero voltage vectors [7]. Various PWM methods for the reduction of CMV have been developed for inverter control. In Active Zero State PWM (AZPWM) algorithm division of active voltage vectors is same as SVPWM method whereas instead of zero voltage vectors two active opposite voltage vectors are used to program the output voltage. In Remote State PWM (RSPWM) method three active voltage vectors which are 120^0 apart are utilized to synthesize the output voltage. These methods are considered with standard PWM methods employing open loop v/f control algorithm for the reduction of CMV. Though these methods reduce CMV variations, switching losses and switching frequency of inverter is high for these methods [8-9].

This paper presents a novel near state PWM algorithm (NSPWM) for reduced CMV variations and reduced switching losses for DTC fed induction motor drive. In the proposed NSPWM method, three adjacent voltage vectors are utilized to match the reference volt-sec.

II. CONVENTIONAL DTC

The electromagnetic torque produced by the induction motor in stationary reference frame can be expressed as given in (1).

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{\sigma L_s L_r}|\lambda_r||\lambda_s|\sin\delta \qquad (1)$$

Where δ is the angle between the stator flux linkage space vector (λ_s) and rotor flux linkage space vector (λ_r).

III. COMMON MODE VOLTAGE

In a standard three phase two-level voltage source inverter the common mode voltage can be expressed as $V_{no} = \frac{V_{ao}+V_{bo}+V_{co}}{3}$ (2)

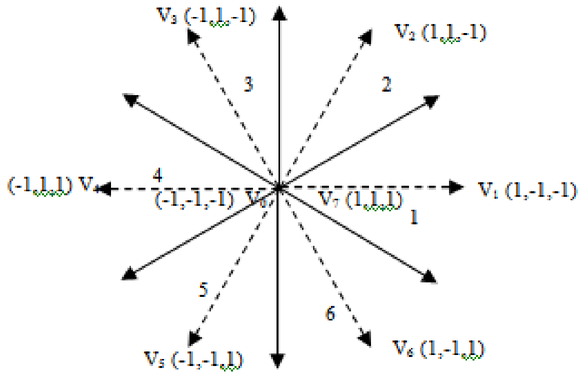
Where V_{ao}, $V_{bo,}$ V_{co} are the inverter pole voltages

Common mode voltage is different from zero, when the drive is fed from an inverter employing PWM technique and its instantaneous values can be determined from (2) based on the switching states summarized in [16].

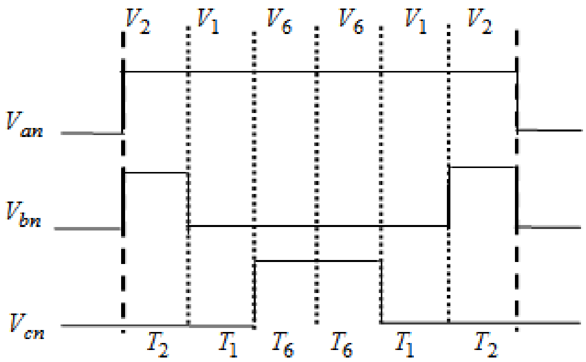
A. Conventional SVPWM

In conventional SVPWM, the reference voltage space vector (V_{ref}) is obtained by substituting the various sampled voltage vectors at each time interval, T_s, referred to as sub cycle in the average sense [16].

B. NSPWM algorithm



(a) Sector division



(b) pulse pattern in sector-I

Figure1. Sector division and PWM pulse pattern in NSPWM

As SVPWM uses zero voltage vectors in each sector CMV variations are very high. To reduce CMV variations in NSPWM algorithm three adjacent voltage vectors are utilized to match the reference volt – seconds. These voltage vectors are selected in such away that voltage vector closest to the reference voltage vector and its two neighbors are utilized to program the output in each sector. Thus NSPWM uses 216-612 in sector-I and 321-123 in sector-II and so on. Moreover the modulating waveform of NSPWM is similar to DPWM1 waveform. From Fig. 1(b) it can be observed that a-phase is clamped to positive dc bus. Hence the switching losses associated with the inverter are reduced. As all the sectors are symmetric this paper is limited to first sector only. For the required reference voltage vector, the active voltage vectors times can be calculated as given in (5), (6) and (7)

$$T_1 = \{-1 + \frac{3}{\pi} M \cos(\alpha + \frac{\pi}{3}) + \frac{3\sqrt{3}}{\pi} M \sin(\alpha + \frac{\pi}{3})\} T_s \quad (5)$$

$$T_2 = \{1 - \frac{3}{\pi} M \cos(\alpha + \frac{\pi}{3}) - \frac{\sqrt{3}}{\pi} M \sin(\alpha + \frac{\pi}{3})\} T_s \quad (6)$$

$$T_6 = T_s - T_1 - T_2 \quad (7)$$

In order to keep switching frequency constant for each pwm method equal number of commutations (Nc) per PWM cycle must be considered. In order to obtain the same Nc in each method, the switching frequency of NSPWM method must be divide by 2/3.

IV. PROPOSED NSPWM BASED DTC

The block diagram of proposed NSPWM algorithm based DTC is shown in Fig.2. In this method, actual values of d-axis and q-axis stator fluxes are compared with the reference values and an error in flux is obtained which when divided by the sampling time period gives a reference voltage. These d-axis and q-axis reference voltage vectors are then fed to the NSPWM block. Then actual gating pulses can be generated by using the instantaneous phase voltages. The generated pulses then fed to the inverter.

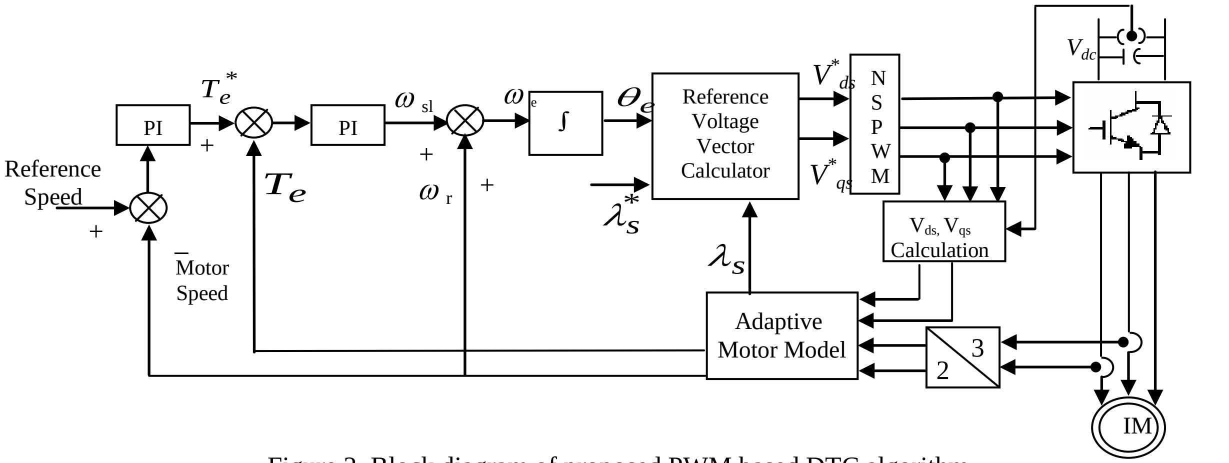


Figure 2. Block diagram of proposed PWM based DTC algorithm

V. SIMULATION RESULTS AND DISCUSSION

To validate the proposed PWM algorithms, numerical simulation studies have been carried out by using Matlab /Simulink. For the simulation, the reference flux is taken as 1wb and starting torque is limited to 45 N-m. For the simulation studies, a 3-phase, 400V, 4 kW, 4-pole, 50 Hz, 1470 rpm induction motor has considered. The parameters of the given induction motor are as follows: R_s=1.57ohm, R_r=1.21ohm, L_m= 0.165H, L_s= 0.17H, L_r= 0.17 H and J= 0.089 Kg - m^2. The results for conventional DTC based induction motor drive are shown in Fig. 4- Fig. 6. The results for conventional SVPWM based DTC are shown in Fig. 7- Fig. 9. From Fig. 4 and Fig. 7, it can be observed that, the ripple in torque, stator flux and current can be reduced with conventional SVPWM based DTC compared to that of conventional DTC algorithm. To mitigate the CMV variations NSPWM method is proposed for DTC fed induction motor drive in which only active vectors are used in each sector. The steady state results of proposed PWM algorithm based DTC are given in Fig.10 - Fig. 12 along with their CMV variations, line voltage and THD. Fig. 10 it can be observed that, the ripple in torque, stator flux and current is less in steady state. From Fig. 5, Fig. 8 and Fig. 11, it can be observed that, the CMV changes from $+V_{dc}/6$ to $-V_{dc}/6$ in proposed PWM method instead of $+V_{dc}/2$ to $-V_{dc}/2$ as in conventional DTC algorithm and SVPWM based DTC algorithm due to elimination of zero voltage vectors. From Fig. 6, Fig. 9 and Fig. 12 it can be observed that the THD of proposed PWM algorithm based DTC is less when compared with conventional methods.

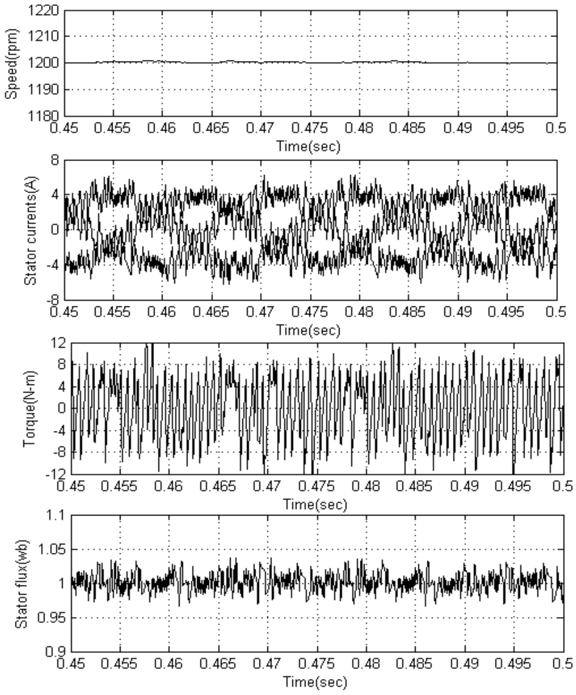
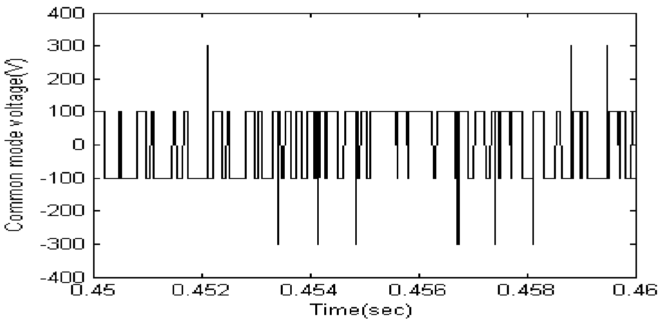


Figure 4. Steady state plots in conventional DTC algorithm



Figurre 5. CMV variations in conventional DTC algorithm

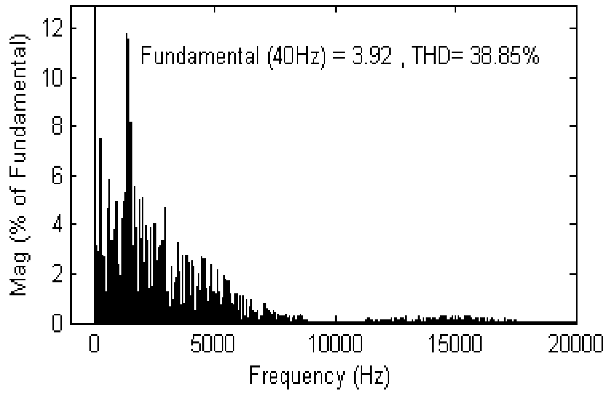


Figure 6. Total Harmonic Distortion in conventional DTC algorithm

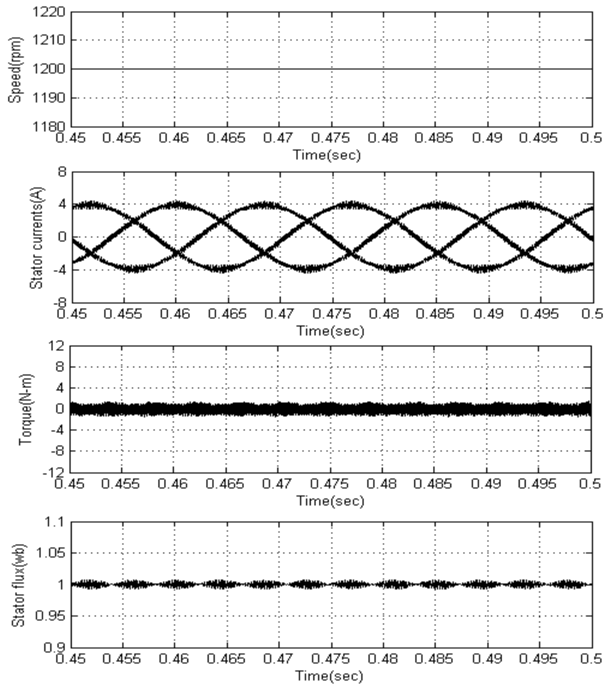


Figure 6. Steady state plots in conventional SVPWM based DTC algorithm

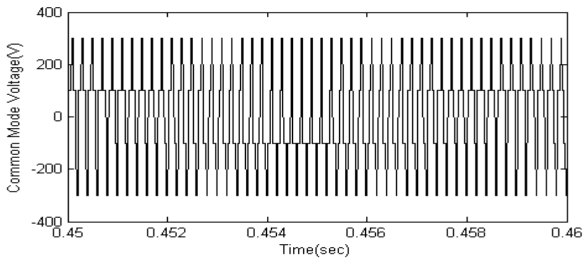


Figure 7.Common mode voltage variations in conventional SVPWM based DTC

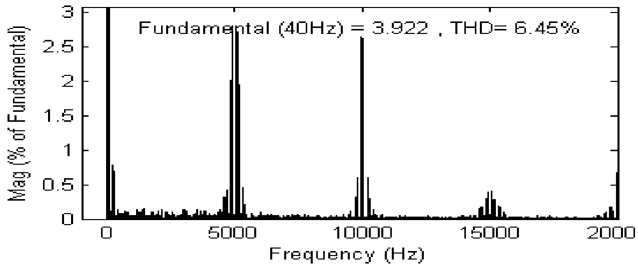


Figure 8.Total Harmonic Distortion in conventional SVPWM based DTC algorithm

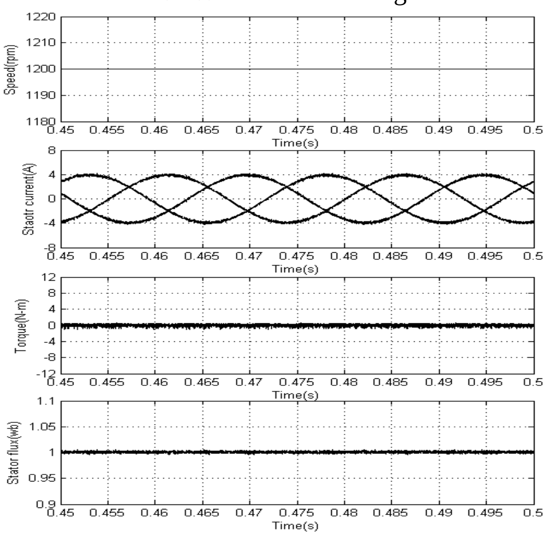


Figure 9. Steady state plots in proposed NSPWM based DTC algorithm

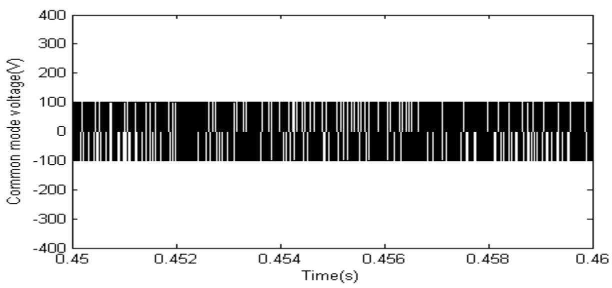


Figure 10. Common mode voltage variations in NSPWM based DTC algorithm

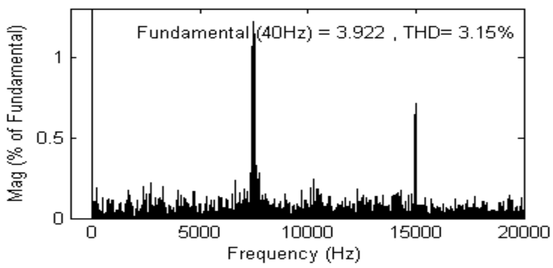


Figure 11. Total Harmonic Distortion in NSPWM based DTC algorithm

VI. CONCLUSIONS

Despite of its simplicity DTC generates high level CMV variations and large steady state ripple in torque and flux. To reduce steady state ripple and to get constant switching frequency operation, SVPWM technique has been proposed to DTC. Though this technique reduces steady state ripples it still suffers from CMV variations due to the usage of zero voltage vectors. To reduce the CMV variations, a simplified near state PWM algorithm (NSPWM) is proposed to DTC based induction motor drive. In the Proposed PWM algorithms instead of using zero voltage vectors, three adjacent active voltage vectors are utilized for composing the reference voltage vector. So, the proposed NSPWM method reduces the switching losses of the inverter and CMV variations.

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