Control Theory and Informatics www.iiste.org
ISSN 2224-5774 (print) ISSN 2225-0492 (online)
Vol 1, No.2, 2011

Space Vector Based Dual Zero-Vector Random Centered Distribution Pwm Algorithm for Direct Torque Control of Induction Motor Drive For Reduced Acoustical Noise

P. Nagasekhara Reddy
Mahatma Gandhi Institute of Technology
Gandipet, Hyderabad, Andhra Pradesh, India, pnsreddy04@gmail.com

J. Amarnath
Jawaharlal Nehru technological University
Kukatpally, Hyderabad, Andhra Pradesh, India, amarnathjinka@rediffmail.com

P. Linga Reddy
K.L. University
Guntur, Andhra Pradesh, India,lingareddy.klu@gmail.com

Abstract

The direct torque control (DTC) technique has been recognized as the viable solution to achieve precise and quick torque response but it suffers from few drawbacks such as high ripple in torque, flux and stator current resulting in increased vibrations and acoustic noise. The conventional SVPWM algorithm gives good performance for control of induction motor drive, but it also produces considerable acoustical noise resulting in increased total harmonics distortion. The deterministic pulse width-modulation (PWM) method adopted in induction-motor drives causes Acoustical noise due to the switching frequency. This paper presents a novel dual zero-vector random centered distribution PWM algorithm for direct torque controlled induction motor drive. The proposed PWM algorithm uses two zero voltage vectors. When the operating modulation index is less than the critical modulation index, the proposed PWM algorithm uses V_0 (000) as zero voltage vector. Otherwise, when the operating modulation index is greater than the critical modulation index, the proposed PWM algorithm uses V_7 (111) as zero voltage vector. To verify the proposed PWM algorithm, a numerical simulation studies have been carried out and results are presented and compared with classical SVPWM algorithm. The simulation results confirm the effectiveness of the proposed DZRCDPWM algorithm for the considered drive.

Key words: DTC, DZRCDPWM, RPWM, SVPWM, Acoustic noise.

1. Introduction

In recent years, the research has been focused to find out different solutions for the induction motor control having the features of precise and quick torque response and reduction of the complexity of field oriented algorithms. The invention of field oriented control (FOC) algorithm by F. Blaschke provides high-performance but the complexity involved is more due to the reference frame transformations. To overcome the drawbacks of FOC, a new control strategy renowned as direct torque control (DTC) was developed by Takahashi [1]-[2]. A detailed comparison between FOC and DTC has given in [3].Though conventional DTC (CDTC) is simple and easy to implement; it generates substantial steady state ripples in torque and current. To reduce the steady state ripple and to get the constant switching frequency, several pulse width modulation (PWM) techniques were proposed to DTC algorithm. A detailed survey of the various PWM algorithms is given in [4]. Recently, random PWM techniques are being investigated by various researchers, and which include driving at a low switching frequency to reduce the switching noise. Random PWM is classified into three categories as random switching frequency PWM [5]–[6], random pulse position PWM [7], and hybrid random PWM [8], [9]. Even though the random pulse position PWM is operated at a fixed frequency, the random pulse position has a similar effect as if the switching frequency is changed. Random pulse position PWM schemes are classified into random lead-lag (RLL) PWM [10], random centered distribution PWM (RCD-PWM), random zero vector distribution PWM [11], and separately randomized pulse position PWM [12].

In this paper, we propose the dual-zero-vector random centered distribution (DZRCD)-PWM algorithm which can obtain the randomization effect on the spectra in the entire area of modulation index with classical SVPWM algorithm approach. The results of this drive are compared with that of the conventional DTC and classical SVPWM based induction motor drive.

2. Space Vector PWM Algorithm

In recent years voltage source inverter (VSI) is widely used to generate variable voltage, variable frequency, 3-phase ac required for variable speed ac drives. The ac voltage is defined by two characteristics, namely amplitude and frequency. Hence, it is essential to work out an algorithm that permits control over both of these quantities. Pulse width modulation (PWM) controls the average output voltage over a sufficiently small period called sampling period, by producing pulses of variable duty-cycle. The approach to PWM that is described in this paper is based on the space vector representation of the voltage in the stationary reference frame. The set of balanced three-phase voltages can be represented in the stationary reference frame by a space vector of constant magnitude, equal to the amplitude of the voltages, and rotating with angular speed $\omega=2\pi f$. The space vector locations for the switching states may be evaluated using (4). Then, all the possible switching states of an inverter may be depicted as voltage space vectors as shown in Fig 1.

$$V_s = \frac{2}{3}\left(V_{ao} + V_{bo} e^{j\frac{2\pi}{3}} + V_{co} e^{j\frac{4\pi}{3}} \right) \qquad (4)$$

The active voltage vectors or active states can be represented as

$$V_k = \frac{2}{3} V_{dc} e^{j(k-1)\frac{\pi}{3}} \quad \text{where k} = 1,2,....,6 \qquad (5)$$

A combination of switching states can be utilized, while maintaining the volt-second balance to generate a given sample in an average sense during a sub-cycle. 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, Ts 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).

$$T_1 = \frac{2\sqrt{3}}{\pi} M_i \sin(60^o - \alpha) T_s \qquad (6)$$

$$T_2 = \frac{2\sqrt{3}}{\pi} M_i \sin(\alpha) T_s \quad (7)$$

$$T_z = T_s - T_1 - T_2 \quad (8)$$

Where M_i - 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 V_0 and V_7 and distributed symmetrically at the start and end of the each sampling time period. As the classical SVPWM algorithm gives the switching times in a deterministic manner, it is also known as deterministic SVPWM algorithm. In SVPWM algorithm, during steady state operation notable torque, flux and current pulsations occur which are reflected in speed estimation and in increased acoustical noise.

3. Proposed VDRPWM Algorithms

In RCDPWM algorithm the pulses are mutually center-aligned as in space vector modulation, but the common pulse center is displaced by the amount $\alpha_c T$ from the middle of the period. The parameter α_c is varied randomly within a band limited by the maximum duty cycle. The RCD-PWM is a type of random PWM in which the center of a two- or three-phase pulse position is placed randomly in the modulation interval. Compared with RLL PWM, this method has better spreading effects of the voltage and noise spectra [11]. However, the RCDPWM algorithm did not give good performance at higher modulation indices. Hence to get good performance at all modulation indices, this paper presents a novel dual zero-vector random centered distribution PWM (DZRCDPWM) algorithm for direct torque controlled induction motor drive. The proposed algorithm uses two-phase modulation with two zero voltage vectors. Among the two possible zero voltage vectors, any one is selected based on the operating modulation index. In the proposed PWM algorithm, the zero voltage vector V_0 (000) is used in the lower modulation indices and the zero voltage vector V_7 (111) is used in higher modulation indices. If V_0(000) is selected as the zero voltage vector, then the degree of freedom for the pulses is calculated by the zero state time duration T_0 and if V_7(111) is selected as the zero voltage vector, the active voltage vector time duration T_1. Thus, if T_0 is equal to T_1, the degree of freedom for the pulse position is equal irrespective of the selection of the zero voltage vectors. Therefore, a critical modulation index (M_c) can be introduced as a reference for the selection of zero voltage vectors. The M_c can be obtained by selecting M_i such that T_0 and T_1 are equal. For odd sectors, the $M_{c,odd}$ is expressed as given in (9).

$$M_{c,odd} = \frac{1}{\frac{4\sqrt{3}}{\pi}\sin(60^o - \alpha) + \frac{2\sqrt{3}}{\pi}\sin\alpha} \quad (9)$$

For even sectors, the $M_{c,even}$ is expressed as given in (10).

$$M_{c,even} = \frac{1}{\frac{2\sqrt{3}}{\pi}\sin(60^o - \alpha) + \frac{4\sqrt{3}}{\pi}\sin\alpha} \quad (10)$$

The variation of critical modulation index according to the angle of the reference voltage vector can be plotted by using (9) and (10) as shown in Fig. 2.

The variation of M_c is limited to one. From Fig. 2, it can be observed that the minimum value of M_c is 0.5236. In the proposed DZRCDPWM algorithm, the operating modulation index (M_i) is compared with the M_c in every sampling interval. The V_7 (111) is selected as zero voltage vector if M_i is greater than the M_c, otherwise, V_0 (000) is selected as zero voltage vector if M_i is less than the M_c. According to the selected value of zero voltage vectors, the gating pulses will be generated.

4. Proposed DZRCDPWM algorithm based induction motor drive

The reference voltage space vector can be constructed in many ways. But, to reduce the complexity of the algorithm, in this thesis, the required reference voltage vector, 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 d-axis and q-axis estimated stator fluxes sampled from the previous cycle. The block diagram of the proposed novel dual zero random centered algorithm based DTC is as shown in Fig 3.

In the proposed method, the position of the reference stator flux vector $\overline{\psi}_s^*$ is derived by the addition of slip speed and actual rotor speed. The actual synchronous speed of the stator flux vector $\overline{\psi}_s$ is calculated from the adaptive motor model. After each sampling interval, actual stator flux vector $\overline{\psi}_s$ is corrected by the error and it tries to attain the reference flux space vector $\overline{\psi}_s^*$. 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 hence the errors in the d-axis and q-axis stator flux vectors are obtained as in (11)-(12).

$$\Delta\psi_{ds} = \psi_{ds}^* - \psi_{ds} \quad (11)$$

$$\Delta\psi_{qs} = \psi_{qs}^* - \psi_{qs} \quad (12)$$

The knowledge of flux error and stator ohmic drop allows the determination of appropriate reference voltage space vectors as given in (13)-(14).

$$V_{ds}^* = R_s i_{ds} + \frac{\Delta\psi_{ds}}{T_s} \quad (13)$$

$$V_{qs}^* = R_s i_{qs} + \frac{\Delta\psi_{qs}}{T_s} \quad (14)$$

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 DZRCDWM control.

5. Simulation Results and Discussion

To verify the proposed conventional DZRCDPWM based induction motor 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 $R_s = 7.83\Omega$, $R_r = 7.55\ \Omega$, $L_s = 0.4751$H, $L_r = 0.4751$H, $L_m = 0.4535$ H and J = 0.06 Kg.m^2. The steady state results of conventional DTC and SVPWM algorithm based DTC are shown in Fig.4-Fig.5. 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 due to large amplitudes of dominating harmonics around switching frequency (5 kHz). Hence, to minimize the acoustical noise and THD of the drive, a novel DZRCDPWM algorithm is implemented. The simulation results of novel DZRCDRPWM algorithm based induction motor drive are shown in Fig. 6- Fig.11, from which it can be observed that the novel DZRCDPWM algorithm gives reduced acoustical noise when compared with a classical SVPWM algorithm based drive.

6. Conclusions

To overcome the drawbacks of classical SVPWM algorithm, a novel DZRCDPWM algorithm is presented in this paper. The proposed algorithm uses two-phase PWM algorithms with dual zero voltage vectors. According to the operating modulation index, suitable zero voltage vectors is selected to randomize the pulse pattern. From the simulation results, it can be observed that the proposed DZRCDPWM algorithm gives reduced acoustical noise as the dominating harmonics amplitude is less. Thus, the simulation results confirm the effectiveness of the proposed PWM algorithm.

References

1. Isao Takahashi, Toshihiko Noguchi, "*A new quick response and high-efficiency control trategy of an induction motor*", IEEE Trans Ind Appl, vol.IA-22, No.5, pp. 820-827, Sep/Oct, 1986.

[2] James N. Nash, "*Direct Torque Control, Induction Motor Vector Control Without an Encoder*", IEEE Trans. Ind. Appl., vol 33, pp. 333-341, Mar/Apr 1997.

[3] Domenico Casadei, Francesco Profumo, Giovanni Serra, and Angelo Tani, "*FOC and DTC: Two Viable Schemes for Induction Motors Torque Control*" IEEE Trans. Power Electron., vol. 17, no.5, Sep, 2002, pp. 779-787.

[4] Joachim Holtz, "*Pulsewidth modulation – A survey*" IEEE Trans. Ind. Electron.., vol. 39, no. 5, Dec 1992, pp. 410-420.

[5] J.-Y. Chai, Y.-H. Ho, Y.-C. Chang, and C.-M. Liaw, "*On acoustic-noise-reduction control using random switching technique for switch-mode rectifiers in PMSM drive*," IEEE Trans. Ind. Electron., vol. 55, no. 3, pp. 1295–1309, Mar. 2008.

[6] T. G. Habetler and D. M. Divian, "*Acoustic noise reduction in sinusoidal PWM drives using a randomly modulated carrier*," IEEE Trans. Power Electron., vol. 6, no. 3, pp. 356–363, Jul. 1991.

[7] Y. G. Jung, S. H. Na, and Y. C. Lim, "*A new random PWM (SRP-PWM) technique for decreasing acoustic noise radiated from v/f controlled motor drives*," in Proc. IEEE IECON, 2004, pp. 832–837.

[8] V. Blasko,M.M. Bech, F. Blaabjerg, and K. Pedersen, "*A new hybrid ran-dom pulse width modulator for industrial drives*," in Proc. IEEE APEC,2000, pp. 932–938.

[9] K. S. Kim, Y. G. Jung, and Y. C. Lim, "*A new hybrid random PWM scheme*," IEEE Trans. Power Electron., vol. 24, no. 1, pp. 192–200,Jan. 2009.

[10] R. L. Kirlin, S. Kwok, S. Legowski, and A. M. Trzynadlowski, "*Power spectra of a PWM inverter with randomized pulse position*," IEEE Trans.Power Electron., vol. 9, no. 5, pp. 463–471, Sep. 1994.

[11] M. M. Bech, J. K. Pedersen, and F. Blaabjerg, "*Random modulation tech- niques with fixed switching frequency for three-phase power converters*," IEEE Trans. Power Electron., vol. 15, no. 4, pp. 753–761, Jul. 2000.

[12] Y. G. Jung, S. H. Na, Y. C. Lim, and S. H. Yang, "*Reduction of audible switching noise in induction motor drives using random position space vector PWM*," Proc. Inst. Elect. Eng.—Elect. Power Appl., vol. 149, no. 3, pp. 195–200, May 2002.

Authors Profile

P. Nagasekhar Reddy received his M.Tech degree from Jawaharlal Nehru technological University, Hyderabad, India in 1976. He is presently working as Sr. Assistant Professor, MGIT, Hyderabad. Also, he is pursuing his Ph.D in Jawaharlal Nehru technological University, Hyderabad, India. His research interests include PWM techniques and control of electrical drives.

Dr. P. Linga Reddy received his Ph.D degree from Indian Institute of Technology, Delhi in 1978. He is presently working as Professor at K.L. University, Guntur, India. He is having more than 45 years experience in teaching. He published more than 15 papers in various national and international journals and conferences. His research interests include control systems and control of electrical drives.

Dr. J. Amarnath graduated from Osmania University in the year 1982, M.E from Andhra University in the year 1984 and Ph.D from J.N.T.University, Hyderabad in the year 2001. He is presently Professor and Head of the Electrical and Electronics Engineering Department, JNTU College of Engineering, Hyderabad and also he is the Chairman, Board of studies in Electrical and Electronics Engineering, JNTU College of Engineering, Hyderabad. He presented more than 100 research papers in various national and international conferences and journals.
His research areas include Gas Insulated Substations, High Voltage Engineering, Power Systems and Electrical Drives.

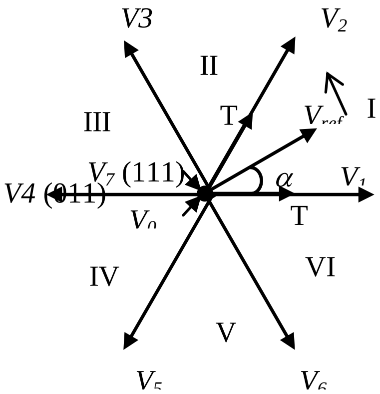

Fig 1. Voltage space vectors produced by an inverter

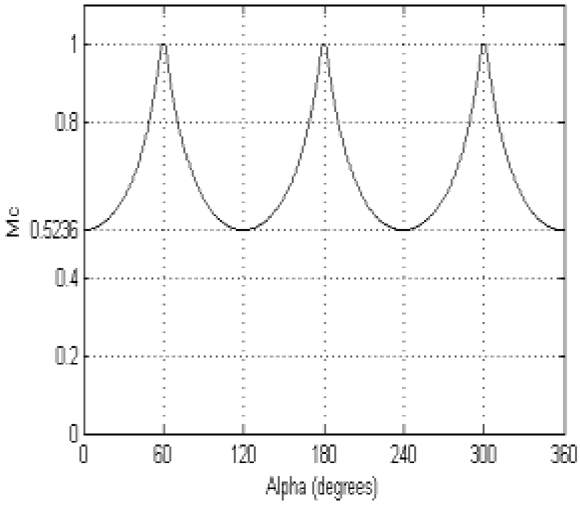

Fig. 2 Variation of M_c with α

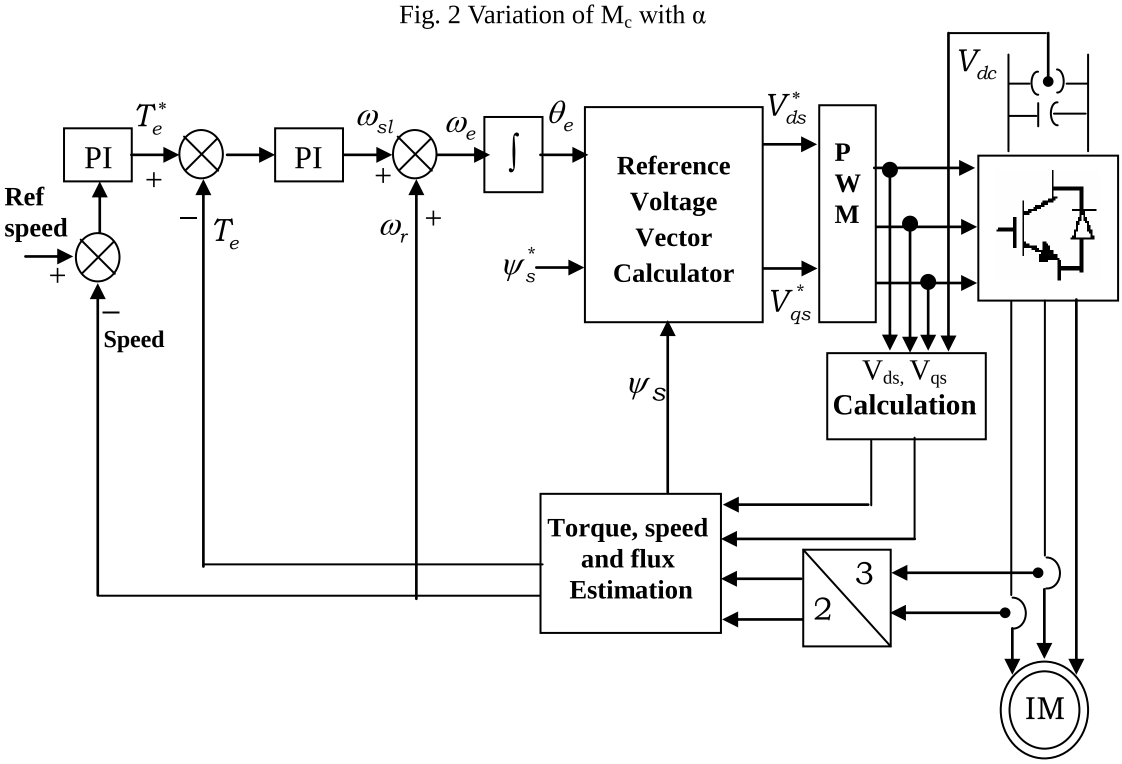

Fig. 3 Block diagram of proposed novel DZRCD based Direct Torque Control

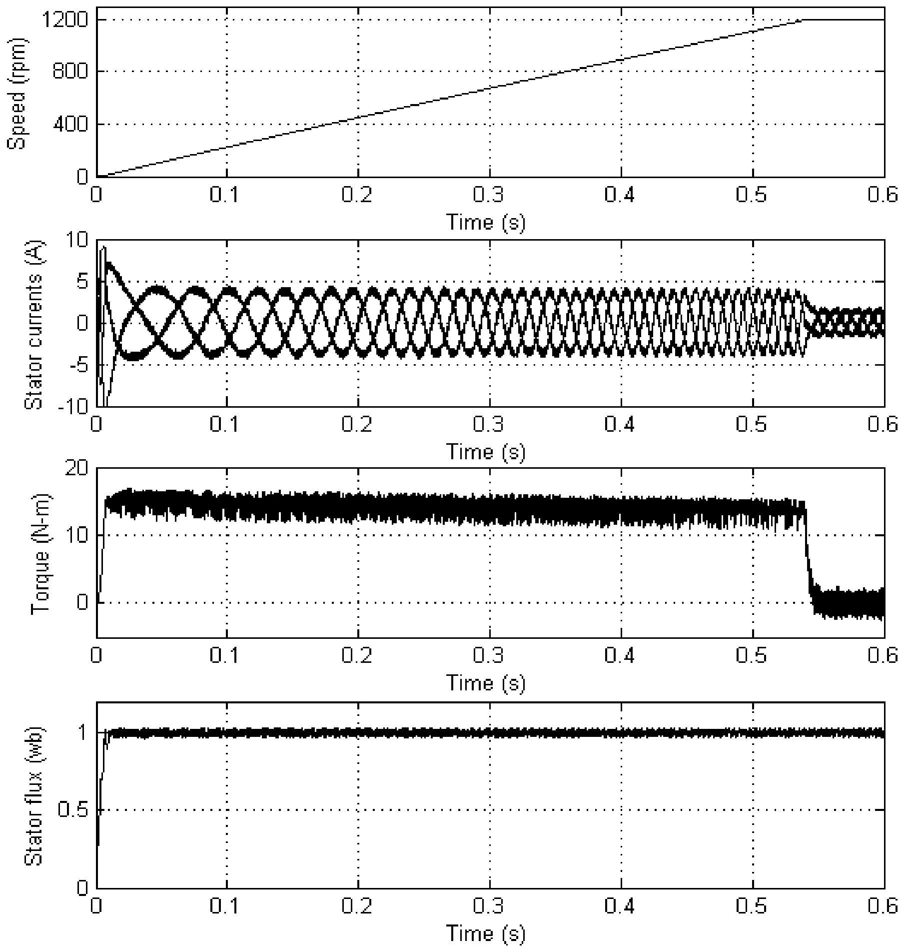

Fig. 4 Starting transients of conventional DTC

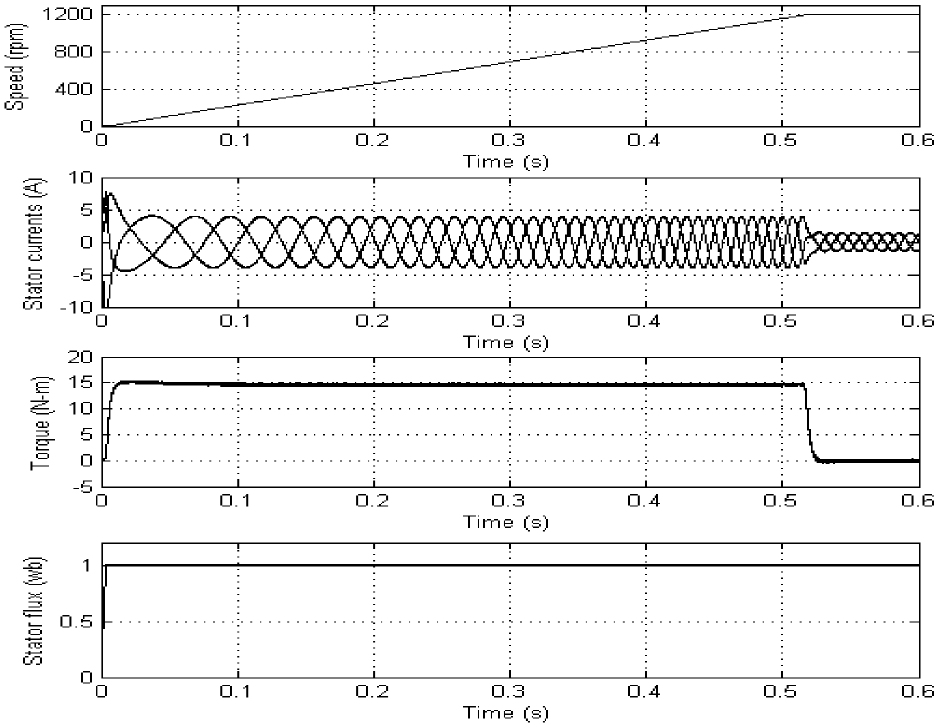

Fig. 5 Starting transients of classical SVPWM algorithm based DTC drive

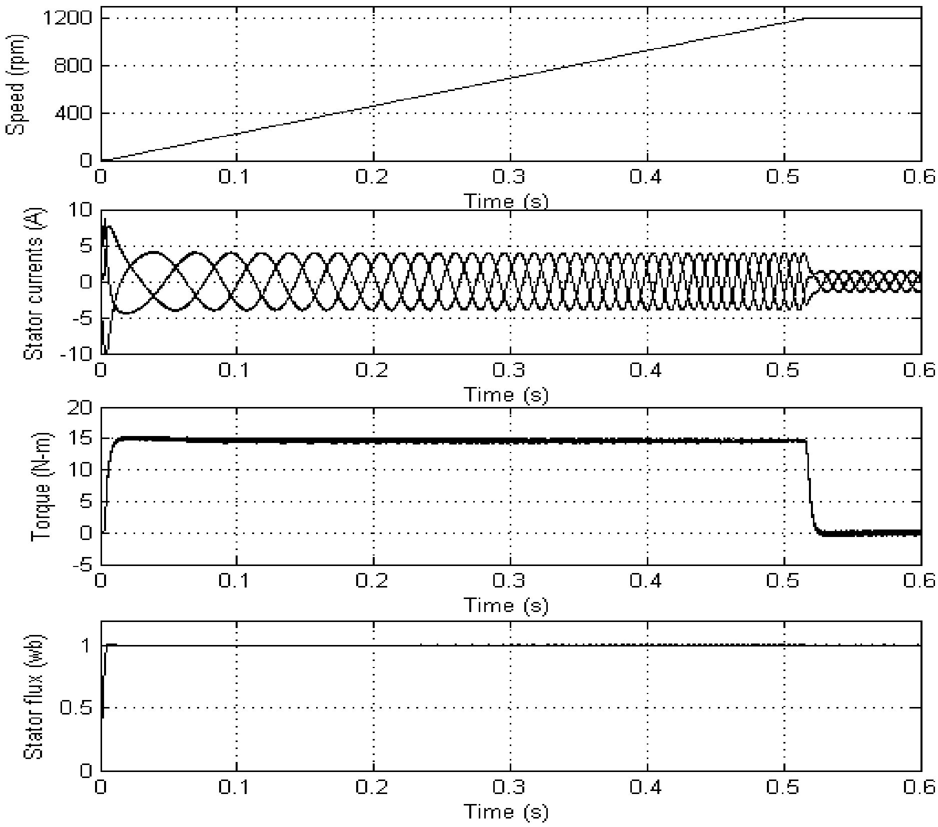

Fig. 6 Starting transients of a novel DZRCDPWM based DTC drive

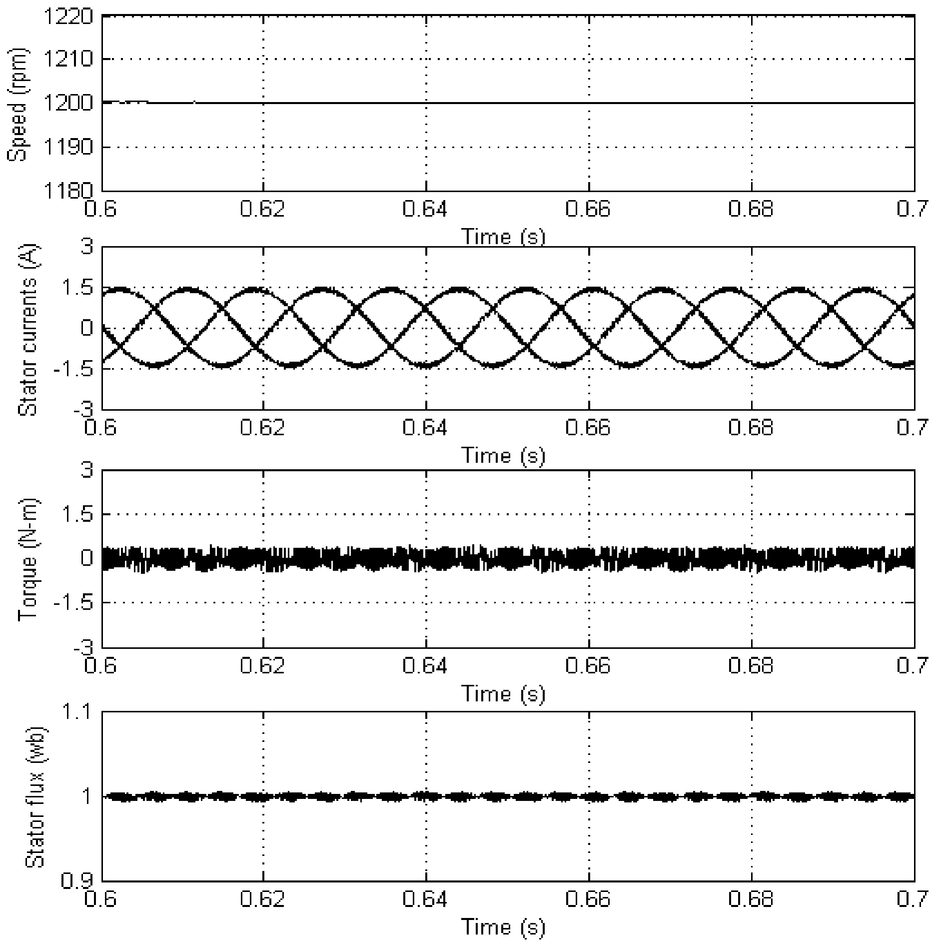

Fig. 7 Steady state plots of a novel DZRCDPWM based DTC drive

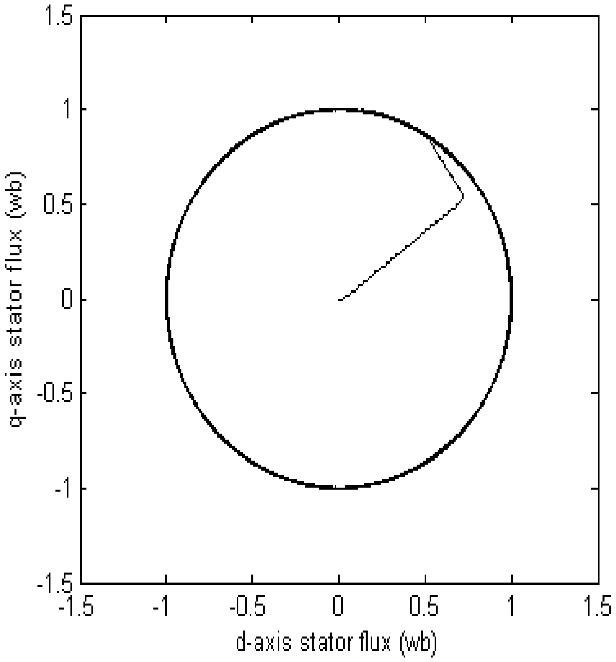

Fig. 8 Locus of the stator flux for proposed PWM algorithm based DTC

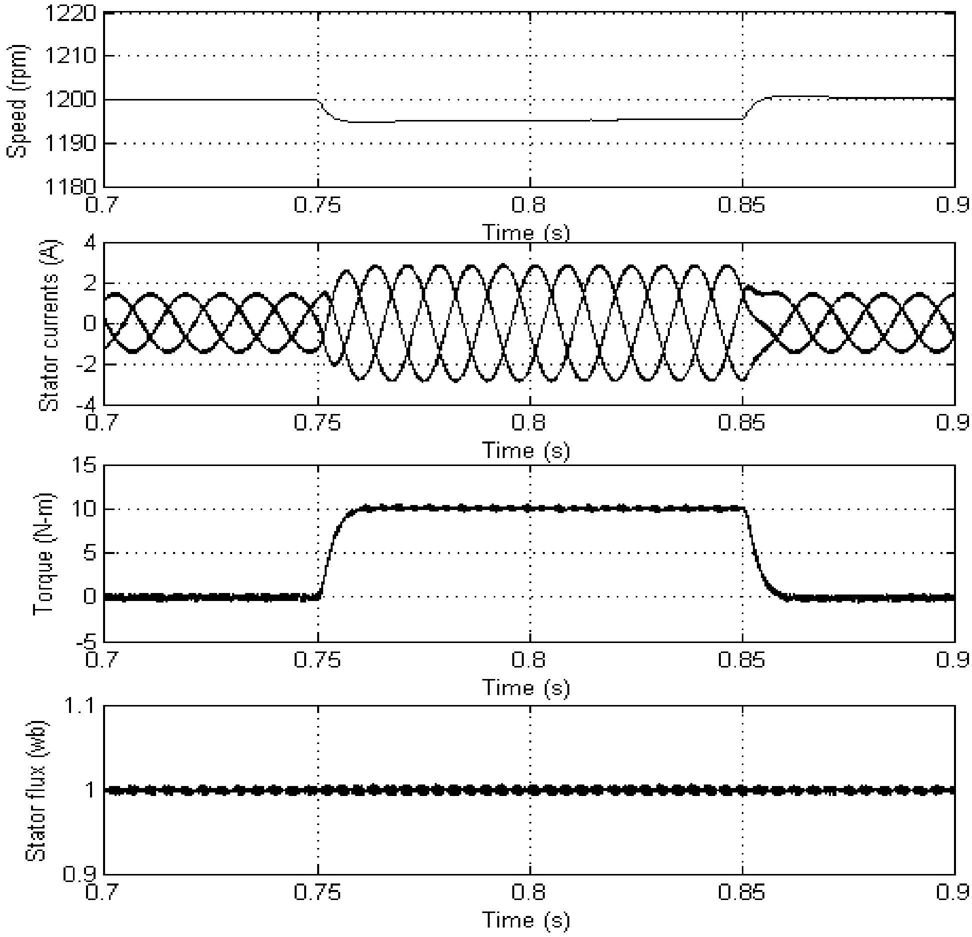

Fig. 9 Transients during step change in load for a novel DZRCDPWM based DTC drive

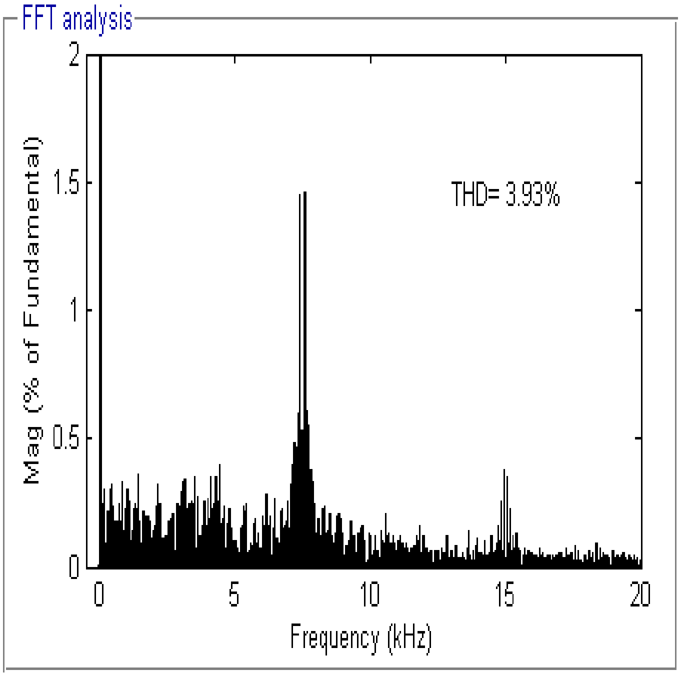

Fig. 10 Harmonic spectra of line current for a novel DZRCDPWM based DTC drive

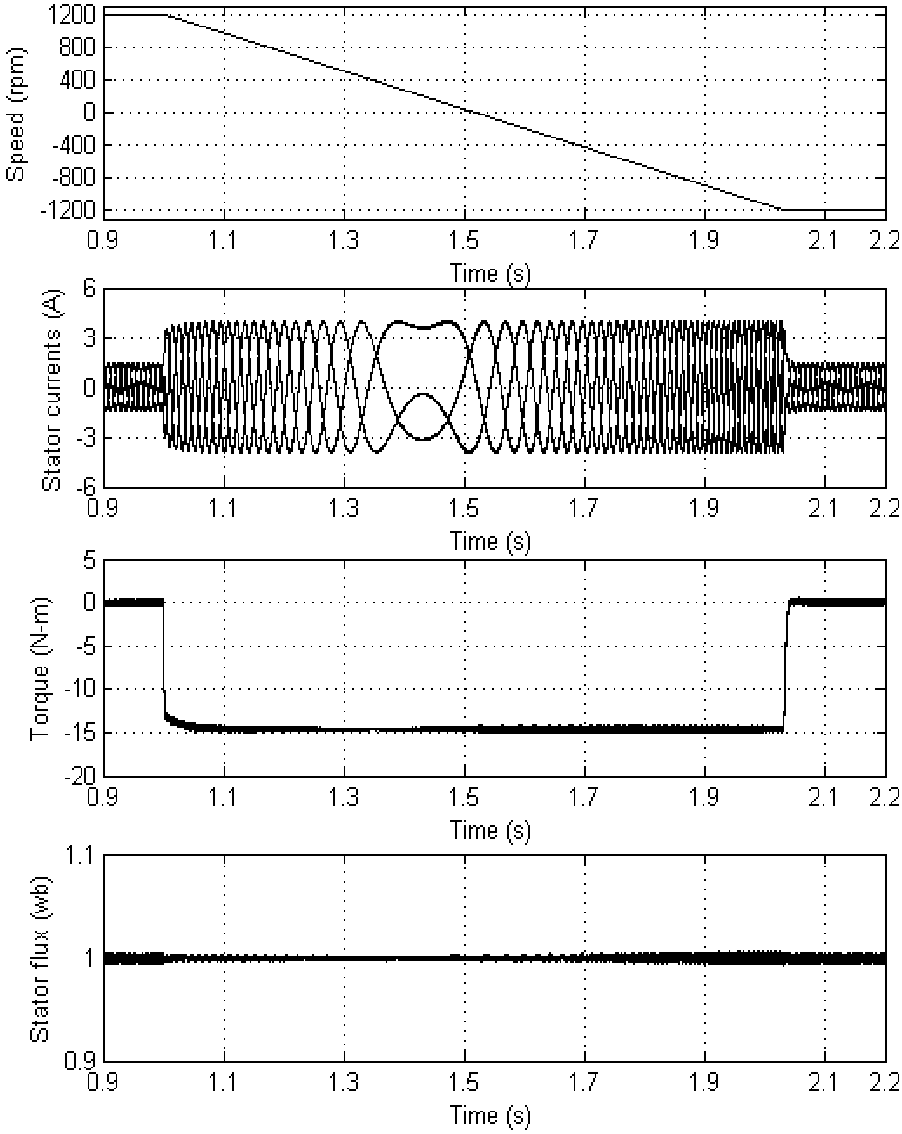

Fig. 11 Transients during speed reversal operation for a novel DZRCDPWM based DTC drive