SIMPLIFIED SVPWM ALGORITHM BASED DIODE CLAMPED 3-LEVEL INVERTER FED DTC-IM DRIVE

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Abstract:
This paper presents a simplified space vector pulse width modulation (SVPWM) based diode clamped three-level inverter fed direct torque controlled (DTC) induction motor drive. The space vector diagram of three-level inverter is simplified into two-level inverter. So the selection of switching sequences is done as conventional two-level SVPWM method. Thus, the proposed algorithm reduces the complexity involved in the PWM algorithm. To validate the proposed PWM algorithm, several simulation studies have been carried and results are presented. From the results, it can be observed that the proposed algorithm reduces the total harmonic distortion (THD) of the line current and line voltages when compared with the 2-level inverter fed induction motor drive.

Keywords: DTC, Induction motor drive, Space vector PWM.

1. Introduction

The pulsewidth modulated voltage source inverters (PWM-VSI) fed variable speed induction motor drives have gained more importance in many industrial applications. The invention of the field oriented control (FOC) brought a renaissance in the field of high performance drives. The FOC algorithm controls the induction motor similar to that of a separately excited dc motor [1]. However, the complexity involved in FOC algorithm is more due to reference frame transformations. To reduce the complexity in the algorithm and to achieve decoupled control, a new torque control strategy has proposed in [2]. As this method controls the torque directly, this is also known as direct torque control (DTC). A detailed comparison between FOC and DTC has been presented in [3]. After a detailed discussion, they concluded that DTC gives good dynamic torque response when compared with the FOC. Though DTC gives good dynamic performance, it gives large steady state ripples in torque, flux and currents. To reduce the ripples, discrete space vector modulation (DSVM) algorithm has proposed in [4].

As the classical DTC and DSVM based DTC use lookup tables for the switching of inverters, these exhibit variable switching frequency operation of the inverter. To reduce the ripples further and in order to meet the high power applications, nowadays, the multilevel inverters are becoming popular. A diode clamped three-level inverter has proposed in [5]. Three-level inverter based DTC has proposed in [6], which uses the switching tables to generate the gating pulses of the inverter. To achieve the constant switching frequency operation and to reduce the harmonic distortion various pulsewidth modulation algorithms have been developed. A detailed survey on various PWM algorithms is given in [7]. Among the various PWM algorithms, the space vector pulsewidth modulation (SVPWM) is popular due to its numerous advantages [8]. To achieve the constant switching frequency operation, SVPWM algorithm is used for DTC in [9]. As the number of levels increases in a multilevel inverter, the complexity involved in the SVPWM algorithm also increases. In order to reduce the complexity, a simplified SVPWM algorithm has been proposed for three-level inverter in [10].

This paper presents a simplified SVPWM algorithm for three-level inverter fed direct torque controlled induction motor drives. The proposed algorithm uses the concept of SVPWM algorithm which is used for two0level inverter. Same as a 2-level inverter, the proposed algorithm generates the switching pulses for three-level inverter.

2. Space Vector PWM Algorithm

The three-phase, two-level VSI generates a low-frequency output voltage with controllable amplitude and frequency. For a 3-phase, two-level VSI, there are eight possible voltage vectors, which can be represented as shown in Fig. 1. Among these voltage vectors, V_1 to V_6 vectors are known as active voltage vectors or active states and the remaining two vectors are known as zero states or zero voltage vectors.

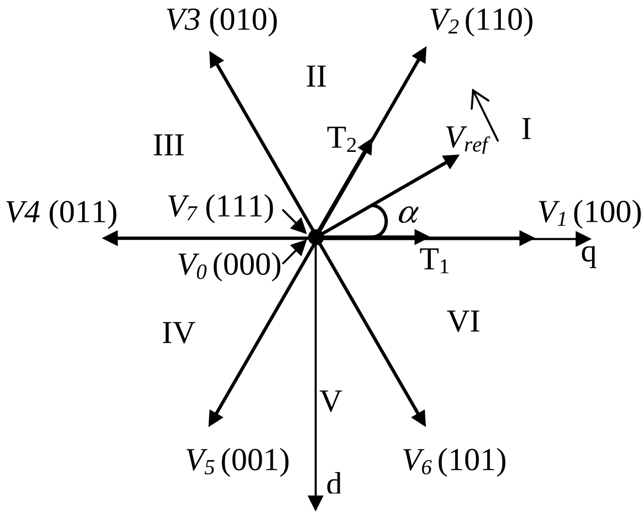

Fig. 1 Possible voltage space vectors for VSI

The reference voltage space vector or sample, which is as shown in Fig.1 represents the corresponding to the desired value of the fundamental components for the output phase voltages. In the space vector approach this can be constructed in an average sense. V_{ref} is sampled at equal intervals of time, T_s referred to as sampling time period. Different voltage vectors that can be produced by the inverter are 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. 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), (2) and (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 in [7]. 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. Thus, SVPWM uses 0127-7210 in sector-I, 0327-7230 in sector-II and so on.

3. Proposed Simplified SVPWM Algorithm for Three-Level Inverter:

A three level diode clamped inverter circuit diagram is shown in Fig.2. The space vectors associated with in the three level inverter on d-q plane are shown in Fig.2. In SVPWM approach, the reference vector $\overline{Vr}$ is sampled at regular interval of time T_s. The sampled reference vector is approximated by time averaging the nearest three vectors, $\overline{Vx}$, $\overline{Vy}$ and $\overline{Vz}$ as

$$\overline{V_r} T_s = \overline{V_x} T_x + \overline{V_y} T_y + \overline{V_z} T_z \qquad (4)$$

where T_x , T_y and T_z are the dwell times of $\overline{V_x}$, $\overline{V_y}$ and $\overline{V_z}$ respectively.

The zero vectors are not present in all the sectors, where these are present in two level inverters. In order to simplify the above equations, the space vector plane of three level inverter shown in Fig.3 is subdivided into six sectors each of 60^0 as shown in Fig.5 each sector S, S= 1,2…,6 are consists of one pivot vector $\overline{V_s}$ and other six vectors of sector 1 is reproduced in Fig.5 (a). The vectors of the other sectors are phase displayed by $\frac{\pi}{3}$ radians.

All the vectors associated with the given sector S are mapped to a set of seven fictitious vectors with $\overline{V_1}$ as pivot vector in centre as defined by (5) - (8), and represented in Fig. 5(b).

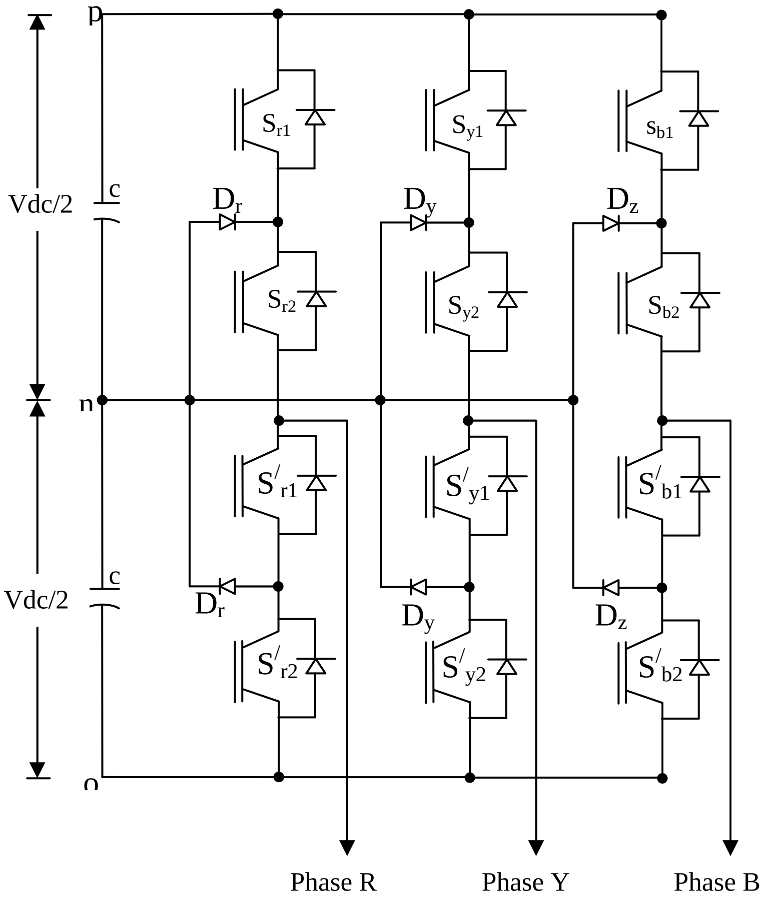

Fig.2 circuit diagram of three level diode clamped inverter.

$$\overline{V_r}^1 = \overline{V_r} e^{j(S-1)\frac{\pi}{3}} - \overline{V_1} \qquad (5)$$

$$\overline{V_x}^1 = \overline{V_x} e^{j(S-1)\frac{\pi}{3}} - \overline{V_1} \qquad (6)$$

$$\overline{V_y}^1 = \overline{V_y} e^{j(S-1)\frac{\pi}{3}} - \overline{V_1} \qquad (7)$$

$$\overline{V_z}^1 = \overline{V_z} e^{j(S-1)\frac{\pi}{3}} - \overline{V_1} \qquad (8)$$

The vector $\overline{V_z}^1$ forms the origin and its magnitude is always zero and for a given sector this vector is similar to the zero vector of two level inverters. The three nearest vectors can be identified as $\overline{V_z}^1$, $\overline{V_x}^1$ and $\overline{V_y}^1$ as shown in Fig.5 now the solution to (4) is similar to that of two level inverters, as

$$V'_{r\alpha}T_s = V'_{x\alpha}T_s + V'_{y\alpha}T_y \quad (9)$$

$$V'_{r\beta}T_s = V'_{x\beta}T_s + V'_{y\beta}T_y \quad (10)$$

$$T_z = T_s - T_x - T_y \quad (11)$$

The proposed method requires only the calculation of $\overline{V_r}^1$, hence computation of three level is similar and sample as that of two level. The switching sequences of conventional SVPWM are $\overline{V_{zx}}$ - $\overline{V_x}$ - $\overline{V_y}$ - $\overline{V_{zy}}$ and the T_z interval is equally distributed between pivot vectors $\overline{V_{zx}}$ and $\overline{V_{zy}}$. The state V_{zx} is denoted as the state of V_z obtained by switching only one phase of the inverter state V_x and state V_{zy} is defined as the state of V_z which has obtained by switching only one phase of the inverter state V_y. This implies that each phase is switched at least ones in every sampling time. During the state transmission only one switch has to be switched. And in present state whatever is the final state that would be the initial state in next sample has to satisfy for minimum switching frequency operation.

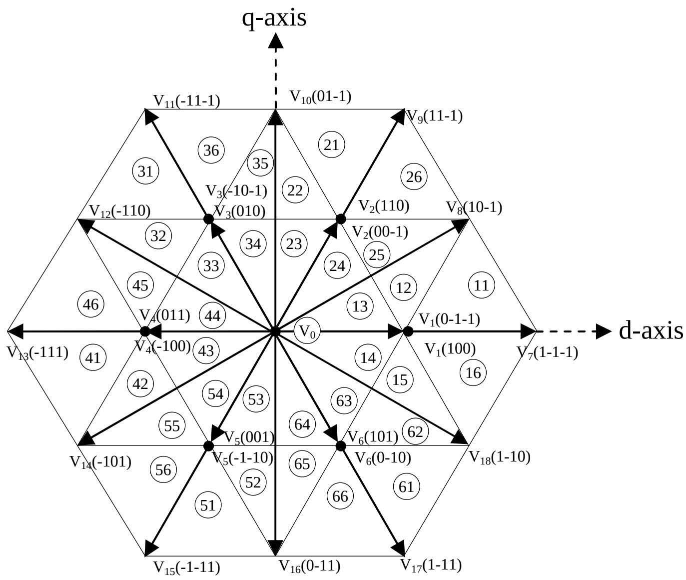

Fig.3 Space vector diagram of three-level inverter.

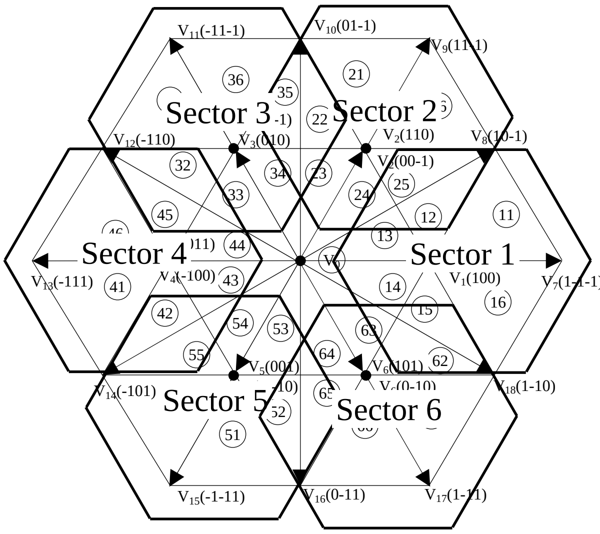

Fig.4 Sector representation of space vector diagram of three-level inverter.

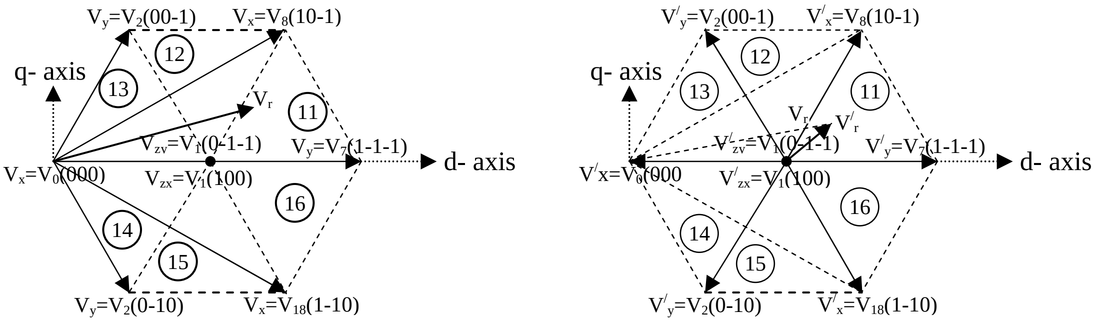

Fig. 5 (a) vectors of Sector 1 (b) Mapping of sector 1 to fictitious vector

4. Proposed Simplified SVPWM Algorithm Based DTC-IM Drive:

The block diagram of proposed DTC is shown in Fig.6. In every sampling time period, the flux errors are to be minimized which could be caused by $\overline{\Psi s}$ and $\overline{\Psi s}^*$ .And summation of actual rotor speed ω_r and additional slip speed ω_{sl} will produce the speed of $\overline{\Psi s}^*$ .The appropriate reference voltage space vectors produced by reference voltage vector calculator block are

$$v_{ds}^* = R_s i_{ds} + \frac{\Delta \psi_{ds}}{T_s} \tag{12}$$

$$v_{qs}^* = R_s i_{qs} + \frac{\Delta \psi_{qs}}{T_s} \tag{13}$$

The reference voltage vectors of d-q form are transformed to three phase reference voltages in SVPWM block from which actual switching times of each inverter leg are calculated as mentioned in previous section.

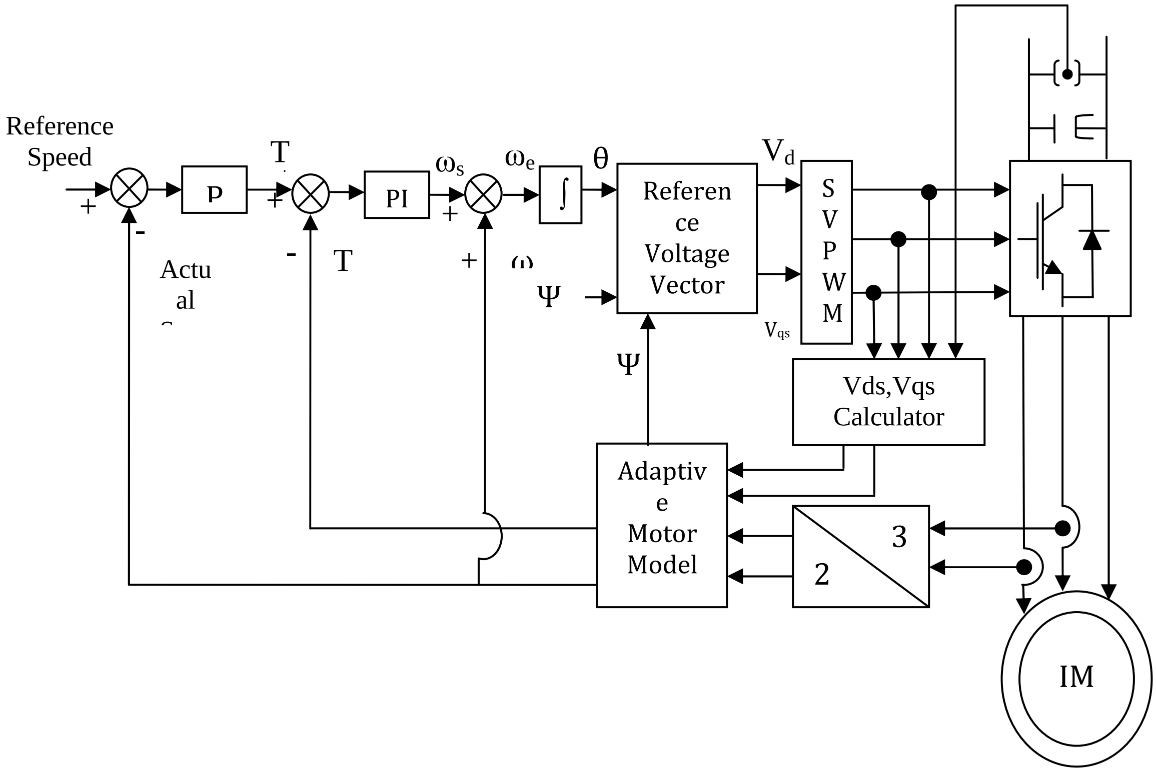

Fig.6 Block diagram of proposed DTC drive.

5. Simulation Results and Discussions:

By using Matlab/Simulink, the advantage of SVPWM application as a numerical simulation has been carried out with fixed step size of 1μs in ode4 (runge-kutta) method. A 3-phase, 4 pole, 4kW, 1200rpm induction motor with parameters of R_s = 1.57Ω, R_r = 1.21Ω, L_s = L_r = 0.17H, L_m = 0.165H and J = 0.089Kg.m^2 are considered. The steady state plots of classical DTC are shown in Fig. 7-FIg. 8, from which, it can be observed that the classical DTC gives large steady state ripples and more harmonic distortion. To reduce the ripples, SVPWM algorithm is used for 2-level inverter. The simulation results for SVPWM algorithm based 2-level inverter fed DTC-IM drive are shown in Fig. 9 - Fig. 11.

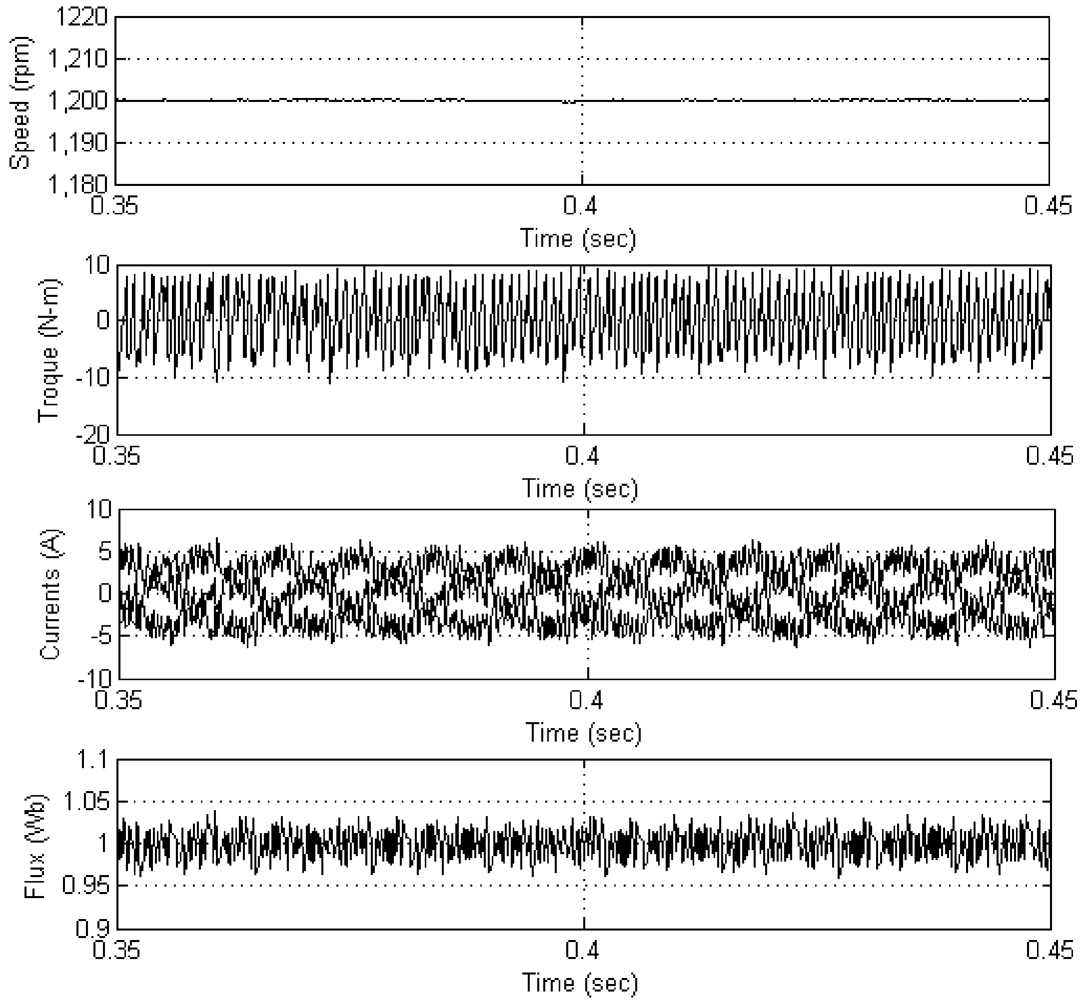

Fig 7 steady state plots of speed, torque, stator currents and stator flux for CDTC based IM drive at 1200 rpm

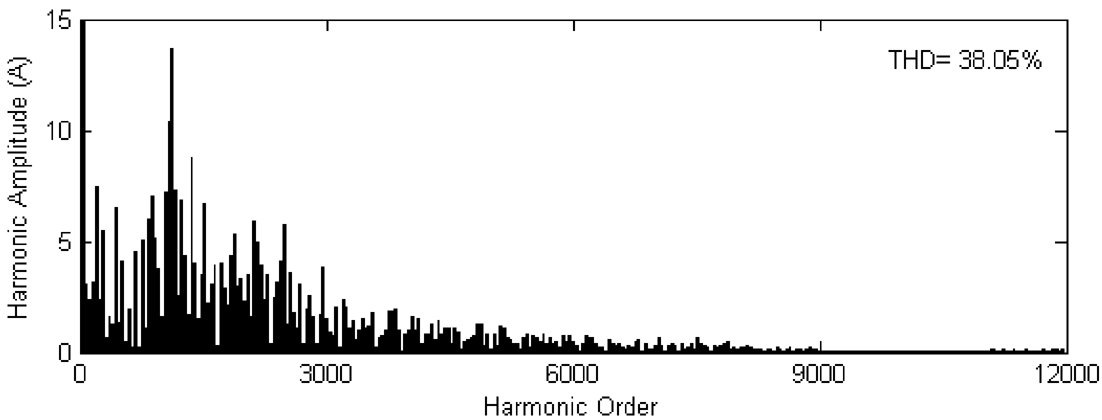

Fig 8 Harmonic Spectrum of stator current along with THD.

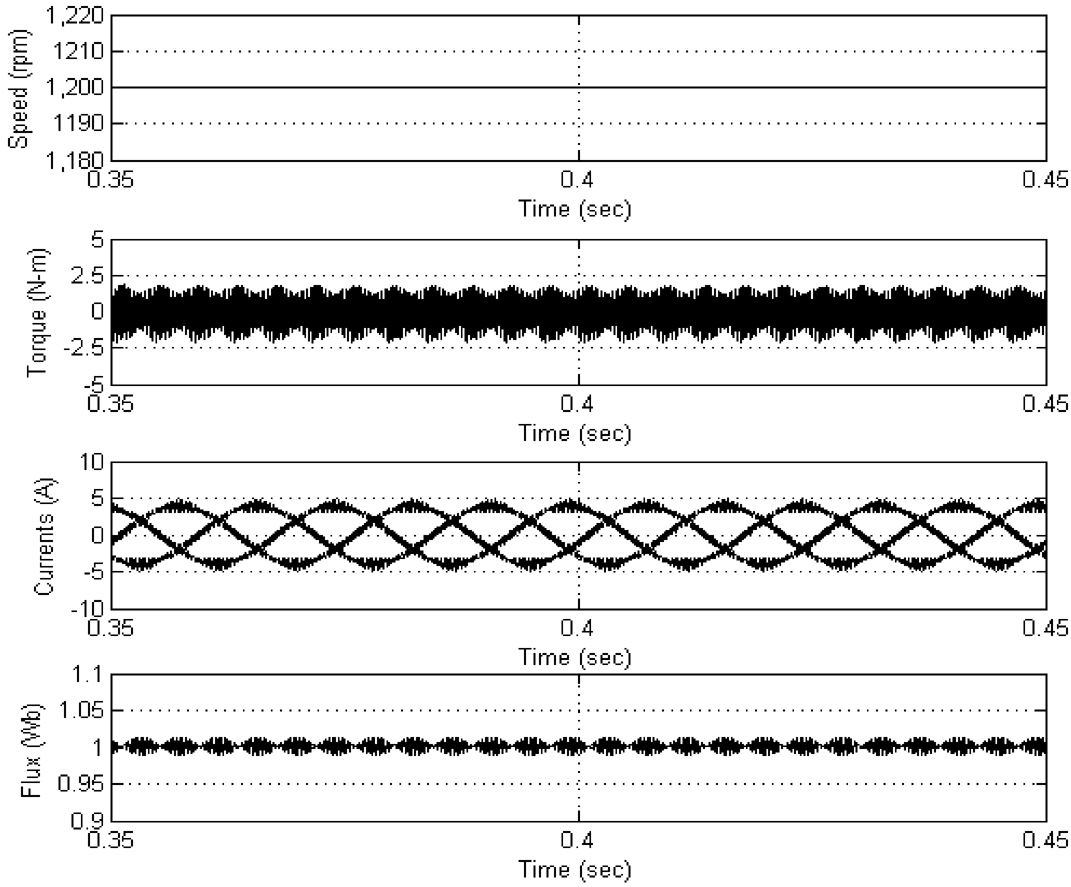

Fig. 9 Simulation results of SVPWM based DTC: steady-state plots at 1200 rpm

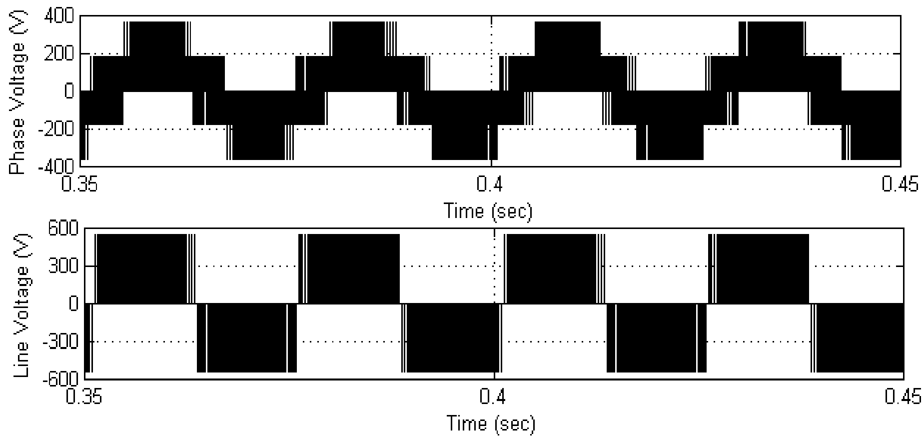

Fig. 10 the phase and line voltages of SVPWM based DTC drive during the steady state operation

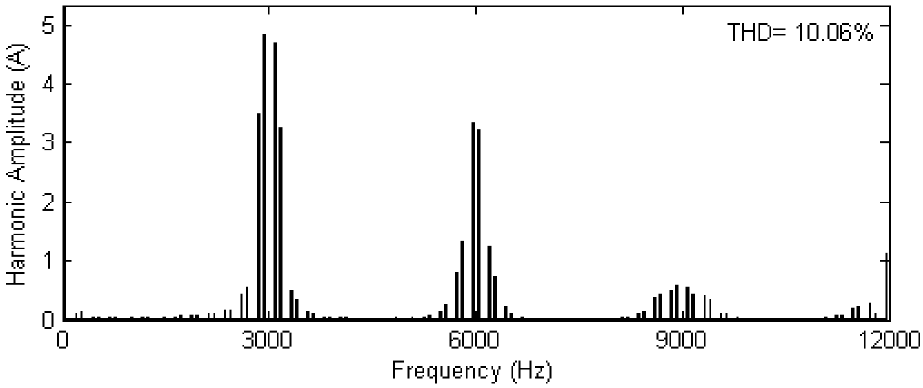

Fig. 11 Harmonic Spectrum of stator current along with THD for SVPWM based DTC-IM drive

The simulation results of proposed simplified SVPWM algorithm based 3-level inverter fed DTC-IM drive are shown in Fig. 12 - Fig. 14.

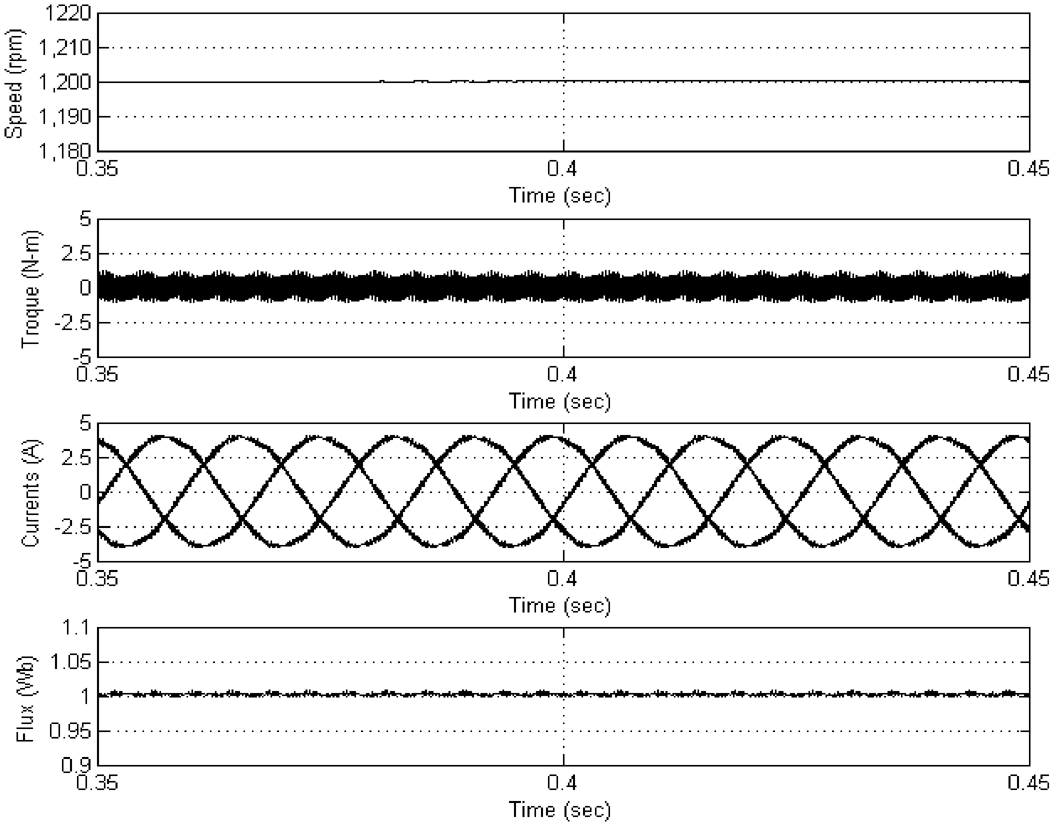

Fig. 12 Steady state plots of speed, torque, currents and flux for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

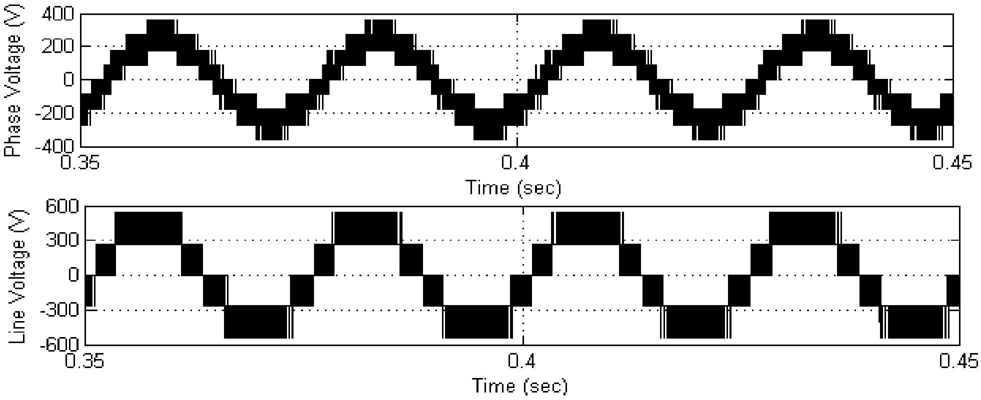

Fig. 13 phase and line voltages for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

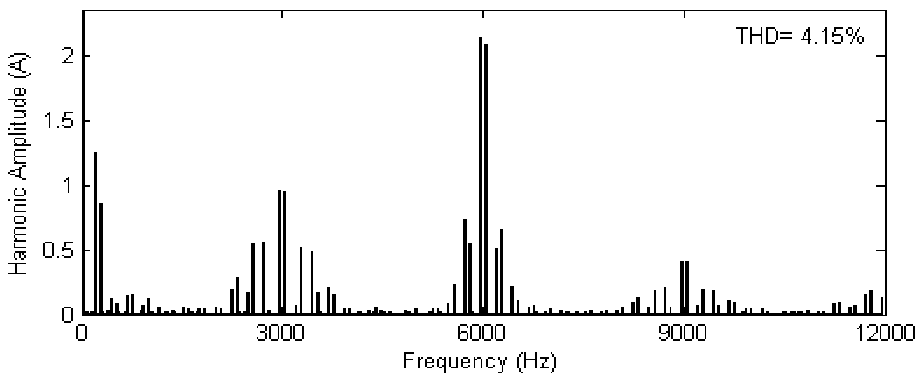

Fig. 14 Harmonic spectra of steady state line current for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

From the simulation results, it can be observed that proposed SVPWM algorithm based 3-level inverter fed DTC-IM drive gives reduced harmonic distortion when compared with the 2-level inverter fed DTC-IM drive.

6. Conclusions

In this paper, a simplified SVPWM algorithm is presented for three-level diode clamped inverter fed DTC drive. The proposed algorithm generates the switching pulses similar to a two-level inverter based SVPWM algorithm. Thus, the proposed algorithm reduces the complexity involved in the existing PWM algorithms. To validate the proposed PWM algorithm, numerical simulation studies have been carried our and results are presented. From the simulation results, it can be concluded that the three-level inverter fed DTC drive gives educed steady state ripples and harmonic distortion.

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