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Simple and Efficient SVPWM Algorithm for Diode clamped 3-level Inverter fed DTC-IM Drive

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---ABSTRACT---
In this paper, a simplified space vector pulse width modulation (SVPWM) method has been developed for three-phase three-level voltage source inverter fed to 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. Where in conventional direct torque control (CDTC), the stator flux and torque are directly controlled by the selection of optimal switching modes. The selection is made to restrict the flux and torque errors in corresponding hysteresis bands. In spite of its fast torque response, it has more flux, torque and current ripples in steady state. To overcome the ripples in steady state, a space vector based pulse width modulation (SVPWM) methodology is proposed in this paper. The proposed SVPWM method reduces the computational burden and reduces the total harmonic distortion compared with 2-level one and the conventional one also. To strengthen the voice simulation is carried out and the corresponding results are presented.

KEYWORDS : *DTC,DSVM,FOC,SVPWM.*

I. INTRODUCTION

The pulse width 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 pulse width modulation algorithms have been developed. A detailed survey on various PWM algorithms is given in [7]. Among the various PWM algorithms, the space vector pulse width 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 two-level inverter. Same as a 2-level inverter, the proposed algorithm generates the switching pulses for three-level inverter.

II. CONVENTIONAL DTC

The stator currents and DC bus voltage are sampled at every sampling inverter of time. The d-q components of stator voltage space vector are calculated by using inverter switching position and DC link voltage. Speed, torque, stator flux and flux angle are estimated in the adaptive motor model by considering voltages, currents to the drive. The estimated torque and flux are compared with their corresponding hysteresis comparators respectively. The number of sector where the stator flux space vector is located and the outputs of hysteresis comparators are fed to optimal switching table to select an appropriate voltage vectors. Then this voltage space vector is applied to inverter.

III. 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. 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.

IV. 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

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

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.4 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.4 (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. 4(b).

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

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

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

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

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.4 now the solution to (4) is similar to that of two level inverters, as $V'_{r\alpha}T_s = V'_{x\alpha}T_s + V'_{y\alpha}T_y$ (9)

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

$$T_z = T_s - T_x - T_y \tag{11}$$

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.

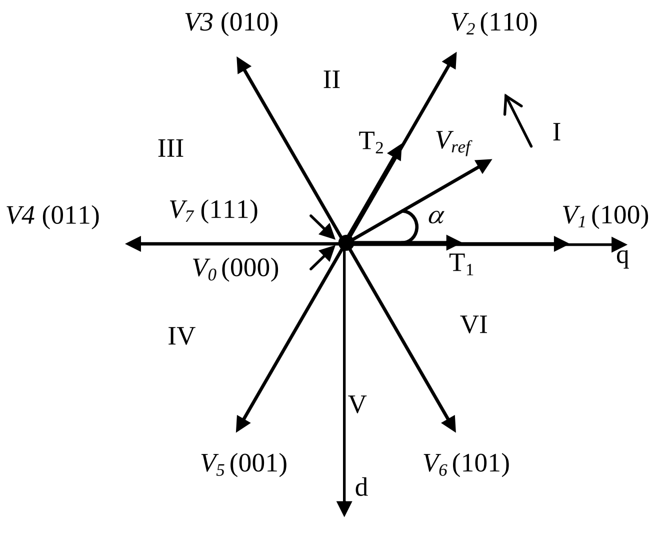

fig. 1 possible voltage space vectors for 2-level vsi

V. PROPOSED SIMPLIFIED SVPWM ALGORITHM BASED DTC-IM DRIVE

The block diagram of proposed DTC is shown in Fig.5. 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

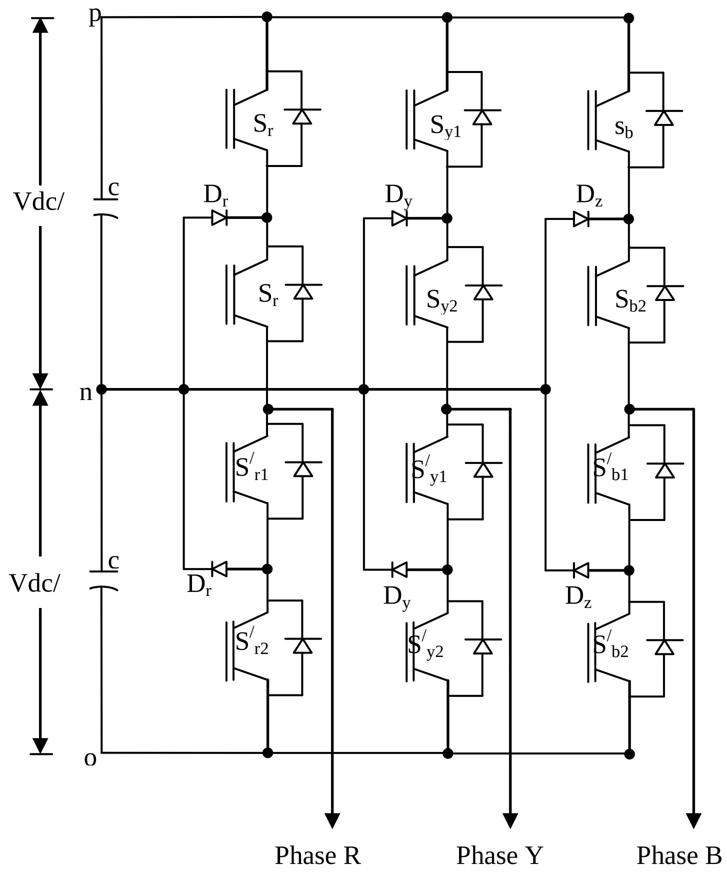

Fig.2 circuit diagram of three level diode clamped inverter.

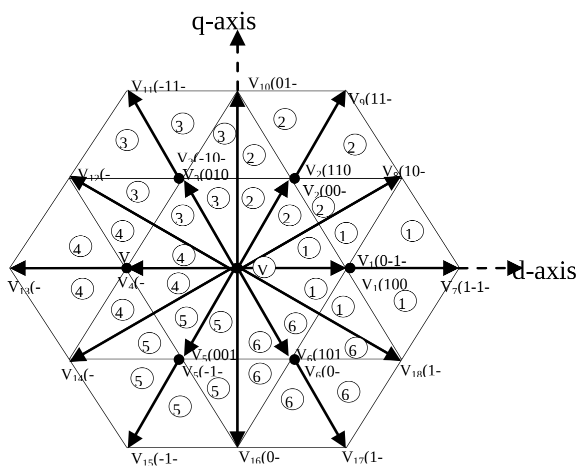

Fig.3 Space vector diagram of three-level inverter

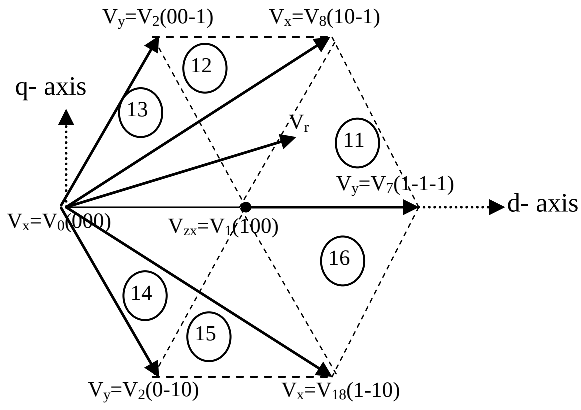

Fig. 4 (a) vectors of Sector 1

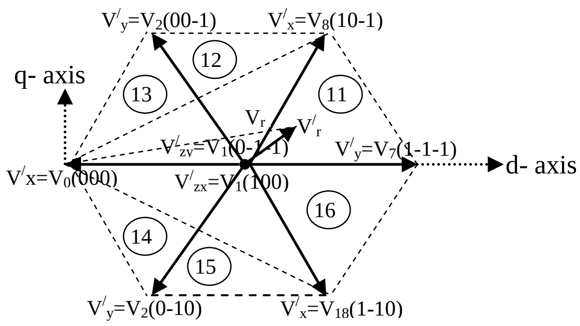

Fig. 4(b) Mapping of sector 1 to fictitious vector

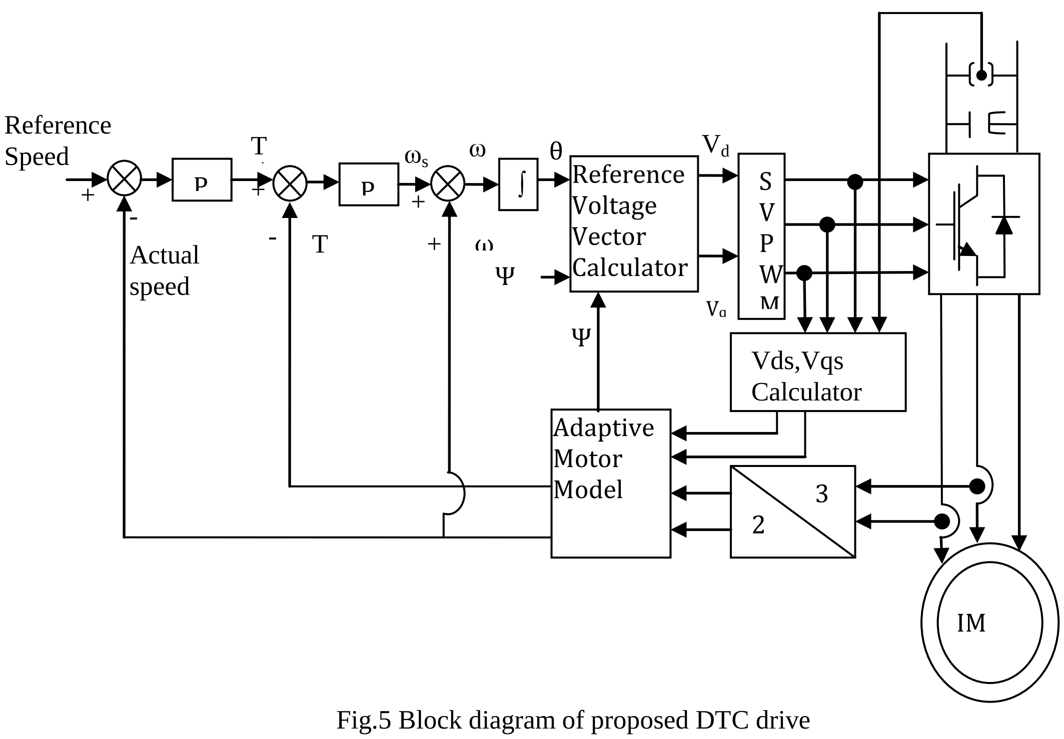

Fig.5 Block diagram of proposed DTC drive

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

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

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.

VI. 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 Conventional DTC are shown in Fig. 6 and Fig. 9, from which, it can be observed that the Conventional 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. 8 and Fig. 10. The simulation results of proposed simplified SVPWM algorithm based 3-level inverter fed DTC-IM drive are shown in Fig. 11 - Fig. 14.

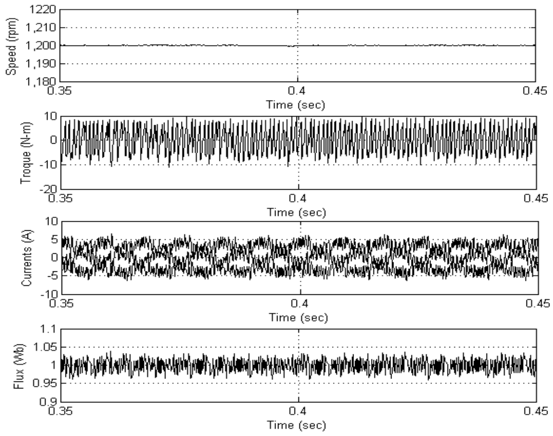

Fig.6 Steady state plots of speed, torque, stator currents and stator flux for CDTC based IM drive at 1200 rpm.

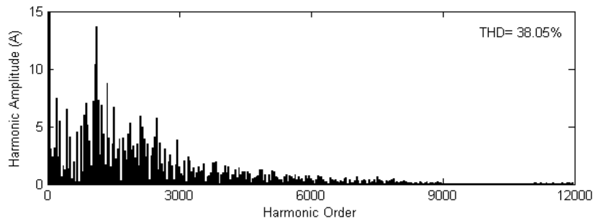

Fig.7 Harmonic Spectrum of stator current along with THD.

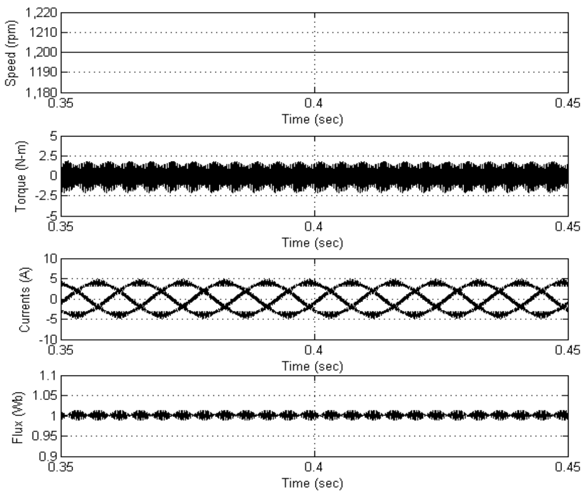

Fig.8 Simulation results of 2-level SVPWM based DTC: steady-state plots at 1200 rpm

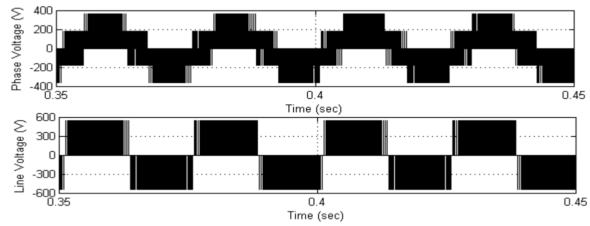

Fig.9 The phase and line voltages of 2-Level SVPWM based DTC drive during the steady state operation

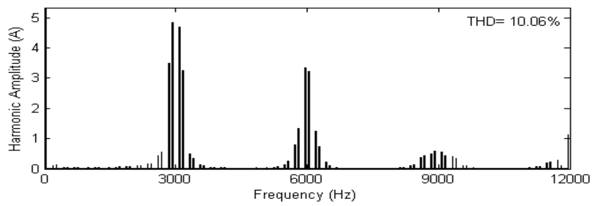

Fig.10 Harmonic Spectrum of stator current along with THD for 2-Level SVPWM based DTC-IM drive

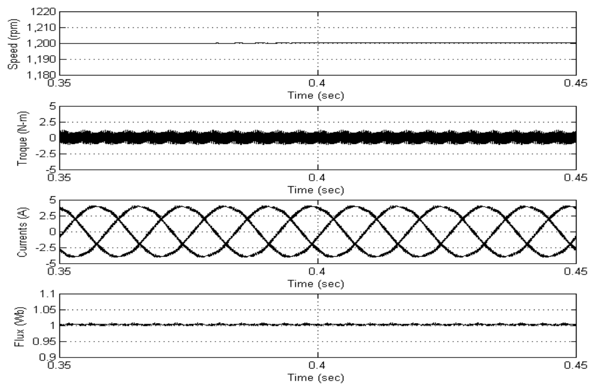

Fig.11 Steady state plots of speed, torque, currents and flux for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

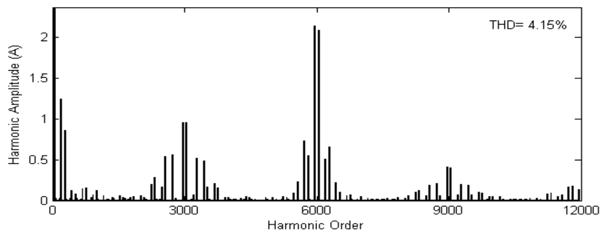

Fig.12 Harmonic spectra of steady state line current for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

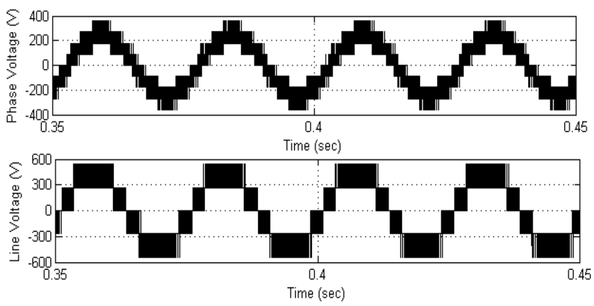

Fig.13 Steady state plots of phase and line voltages for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

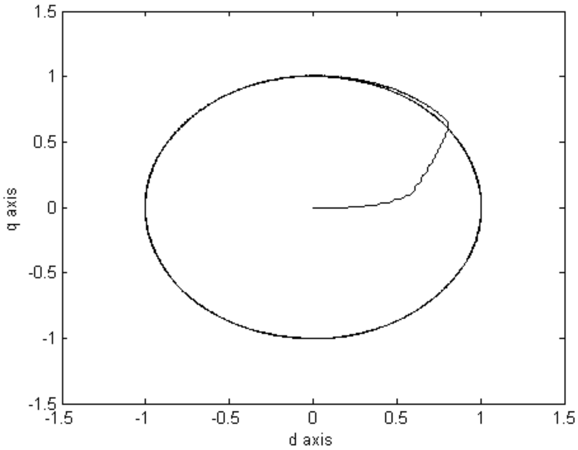

Fig.14 Locus of stator flux for simplified SVPWM algorithm based 3-level inverter fed DTC-IM

From the simulation results it can be observed that the proposed algorithm based DTC drive gives reduce harmonic distortion when compared with the CDTC and 2-level inverter fed DTC drive

VII. CONCLUSIONS

In this paper, a simplified SVPWM algorithm is presented for three-phase three-level 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 out and results are presented. From the simulation results, it can be concluded that the three-level inverter fed DTC drive gives reduced steady state ripples and harmonic distortion.

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Biographies and Photographs

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