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COMPARISON AND PERFORMANCE ANALYSIS OF DTC - DCMLI DRIVEN PMSM DRIVE USING SPACE VECTOR MODULATION

Dr. Rakesh G. Shriwastava, Professor, Department of Electrical Engineering, Govindrao Wanjari College of Engineering & Technology, Nagpur
Dr.Sunil S. Kadlag, Associate Professor, Departments of Electrical Engineering, Amrutvahini College of Engineering, Sangamner
Dr.Pravin B.Pokle, Associate Professor, Department of Electronics Engineering, Priyadarshini J.L.college of Engineering,Nagpur
Dr. Salim A. Chavan, Professor, Department of Electronics & Telecommunication Engineering, Govindrao Wanjari College of Engineering & Technology, Nagpur
Dr. Jagdish G. Chaudhari, Associate Professor, 3Department of Electrical Engineering, Nagpur Institute of Technology, Nagpur
Dr. Hemant R. Bhagat Patil, Professor, Department of Mechanical Engineering, Govindrao Wanjari College of Engineering & Technology, Nagpur
Dr Pratap R. Sonawane, Assistant Professor, Department Of Mechanical Engineering,Matoshri College of Engineering & Research Center, Nashik.
Dr.Ramesh S. Pawase, Associate Professor, Departments of Electronics & Telecommunication Engineering, Amrutvahini College of Engineering, Sangamner

Abstract
The paper focus on comparison and performance analysis of DTC - DCMLI driven PMSM drive using space vector modulation is designed, and implemented for automotive application. The simulation work is done using MATLAB software. A DTC based novel SVM was proposed to control of torque, torque angle and stator flux. From the detailed comparison, direct torque control (DTC) based three-level DCMLI driven PMSM drive has stood out as a feasible solution as compared to the conventional inverter in automotive application. Hence direct torque control (DTC) based PMSM drives can validated for hardware implementation. The proposed method three–level DTC - DCMLI driven PMSM drive is found acceptable because of its less distorted output, lower costs, better control performance and other advantageous features. Hence it is used in automotive applications.

Keywords: Direct Torque Control, Diode clamped Multilevel Inverter (DCMLI), Permanent Magnet Synchronous Motor (PMSM), Space Vector Modulation (SVM), Total harmonic distortion (THD).

1. Introduction

Electric motors (EMs) and generators are the primary workhorses in hybrid electric vehicles (HEVs). The generators convert mechanical power from the engine electrical power in order to charge the batteries and operate the motors. Motors produce the required torque to drive the wheels. There are many types of motors and generators used in HEVs: induction, switched reluctance, and permanent magnet. [1-5]. Electric propulsion systems are the main part of electric vehicle (EV).It consist of electric motors, power converters and electronic controllers [6-12].DTC method is proposed to maintain constant switching frequency also reduce torque and current ripple. [13-18]. This paper focus on DTC based DCMLI Using SVM techniques on a surface mounted PMSM used in electrical vehicle. A novel technology of space vector modulation for the DTC is proposed [19-26].

The DTC simulation of PMSM is developed using MATLAB Simulink. The DTC are the efficient control methods for AC machine. DTC method is robust, simple and also has excellent dynamic performance. The limitations of the DTC are its flux ripples and relatively high torque also variable switching frequency in case of Induction motor. The performance of the DTC of PMSM can be improved by reducing the high flux and torque ripples and maintaining a fix switching frequency using novel technology of space vector modulation. [27-35].

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This paper presents a DTC based 2-level & 3-level DCML inverter using SVM techniques.In section 1, the introduction is explained, In section 2, the Mathematical Analysis of PMSM model is explained, In section 3, the control topology is explained. In section 4, simulation model & results analysis is presents. In Section 5 the conclusion are present.

2. Mathematical Analysis of PMSM Model

The field winding is absent in rotor of PMSM [2]. There are two stator windings in the dq reference frame. The direct-axis winding is along with the axis of magnetic pole.

The induced voltage in the direct-axis winding:

$$u_d = R_d i_d + \frac{d\lambda_d}{dt} - \omega_r \lambda_q \quad (1)$$

Where, 'id' and 'Rd' are called d-axis stator current and resistance respectively
The induced voltage in the q-axis winding :

$$u_q = R_q i_q + \frac{d\lambda_q}{dt} - \omega_r \lambda_d \quad (2)$$

Where, 'Rq' and 'iq' are called the quadrature -axis resistance and current of stator.

$$\lambda_d = L_d i_d + \lambda_m \quad (3)$$

λd = flux-linkage in the direct-axis of stator in webers.
λm is the PM rotor flux and,

$$\lambda q = Lqiq \quad (4)$$

λq = flux-linkage in the quadrature-axis stator (Wb)
In this case of quadrature-axis ,there are no magnets so λm is absent.
Considering round rotor PMSM ,we have

$$Ld = Lq \quad (5)$$

3. Control Topology

Direct torque control

In DTC, it is to calculate the torque and flux errors from hysteresis comparators and select voltage vectors directly based on the differences between reference and actual value of flux linkage & torque Low complexity, low computational power, and good dynamic performance are the advantages of Direct Torque Control. The basic concept of Direct Torque Control is to controlled the amplitude and angular position of the stator flux vector. λr be the rotor flux linkage vector in d-q coordinate and λs be the stator flux linkage vector.

In d-q coordinate system, PMSM stator flux linkage and torque equations are

$$D=LDID+ R \quad (6)$$

$$Q = LQIQ \quad (7)$$

$$\lambda_s = \sqrt{(\lambda_D^2 + \lambda_Q^2)} \quad (8)$$

$$T_{EM} = \left(\frac{3}{2}\right) P \left(\lambda_D I_Q - \lambda_Q I_D\right) \quad (9)$$

The d-q current equation are

$$I_D = \frac{\lambda_D - \lambda_Q}{L_D} \quad (10)$$

$$I_D = \frac{\lambda_D}{L_Q} \quad (11)$$

The flux linkage equation is

$$\lambda_D = \lambda_s \cos\delta \quad (12)$$

$$\lambda_Q = \lambda_s \sin\delta \quad (13)$$

put in the torque expression

$$T_{EM} - \left(\frac{3}{2}\right) P \frac{|\lambda_s|}{2 L_D L_Q} \left(2\lambda_m L_Q \sin\delta - |\lambda_s| (L_Q - L_D) \sin 2\delta\right) \quad (14)$$

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Inverter topology

i) Two level Inverter

In Figure1, the number of switches is two per leg and the capacitor is used as a filter. Problems associated with conventional adjustable speed drive inverter are High frequency switching is responsible for large switching losses,Motor bearing failure and stator winding insulation breakdown problems occurs due to high dv/dt and Electromagnetic interference problems occur due to high frequency switching

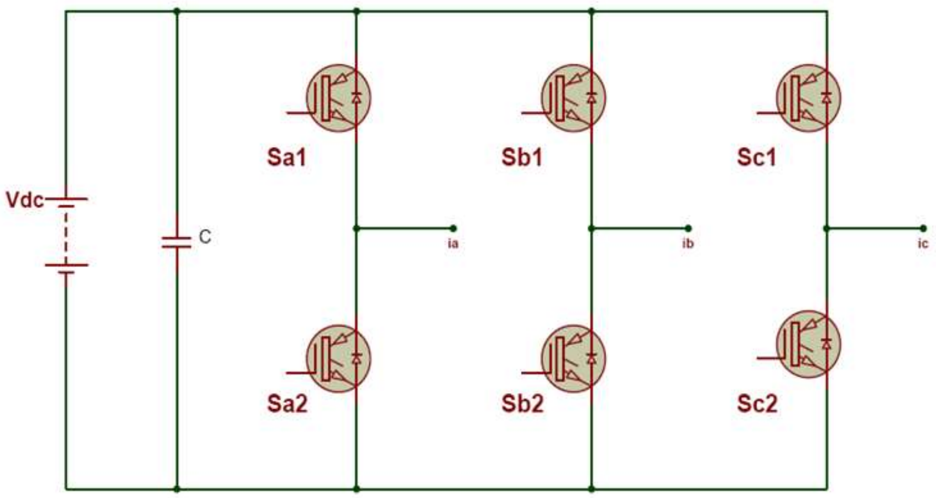

Figure 1: Conventional, two-level inverter

Table 1 switching vectors and line voltages

Voltage Vectors	Switching Vectors			Line to line voltage		
	a	*b*	*c*	*Vab*	*Vbc*	*Vca*
V_0	0	0	0	0	0	0
V_1	1	0	0	1	0	-1
V_2	1	1	0	0	1	-1
V_3	0	1	0	-1	1	0
V_4	0	1	1	-1	0	1
V_5	0	0	1	0	-1	1
V_6	1	0	1	1	-1	0
V_7	1	1	1	0	0	0

ii) Diode Clamped Multilevel Inverter

The DCMLI comprises of two series-connected capacitors, C1 and C2, the DC-link capacitors which divide the DC bus voltage into three levels; +Vdc/2,0 & -Vdc/2. ‘n’ is the neutral point between two capacitors C1 and C2. (Sa1, Sa3) and (Sa2, Sa4) are two complementary switch pairs and (D1, D10) are the two clamping diodes per phase.

If Sa1 and Sa2 is ON, so Van =+Vdc/2.

If Sa2 and Sa3 is ON, so Van = 0.

If Sa3 and Sa4 is ON, so Van =-Vdc/2

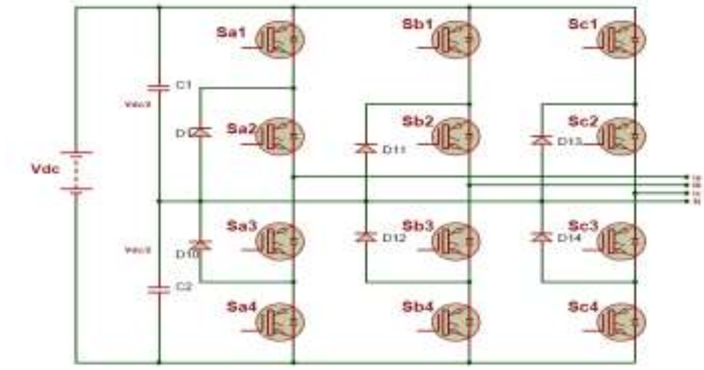

Figure 2: Three-level Diode-Clamped Inverter

Simulation model & Results analysis

The investigations on DTC based conventional inverter and DCMLI -PMSM drive has been done in MATLAB software. The SVM techniques have been applied to the conventional inverter and DCMLI fed PMSM drive system under steady state only. The load torque is applied in steps. The Simulink model of DTC based conventional inverter and DCMLI –PMSM drive shown in the Fig.3& Fig.4The output voltage& current waveforms of conventional inverter and DCMLI using SVM are in fig.2 and fig.3.The speed, electromagnetic torque, and Stator rotor flux response respectively are in fig.7, fig.8 and fig.9. The frequency spectrum of line voltage and phase current are in fig.10 and fig.11 TableI and Table II shows the THD analysis and torque ripple analysis of DTC based conventional inverter and DCMLI-PMSM drive .The specification of Permanent Magnet Synchronous Motor as in the Table III.

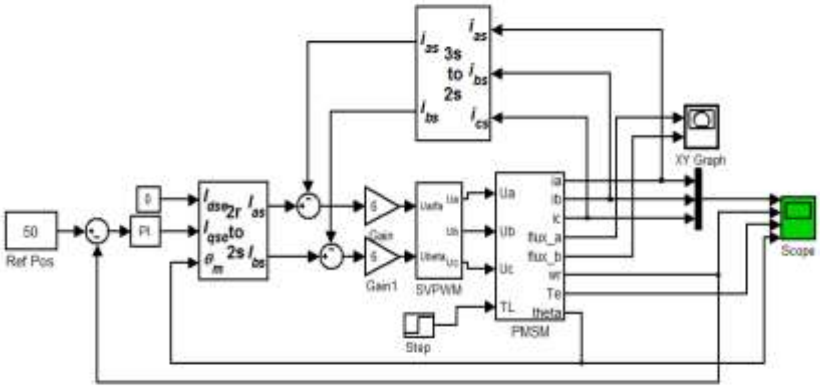

Figure 3: Simulink model of DTC based conventional inverter PMSM drive

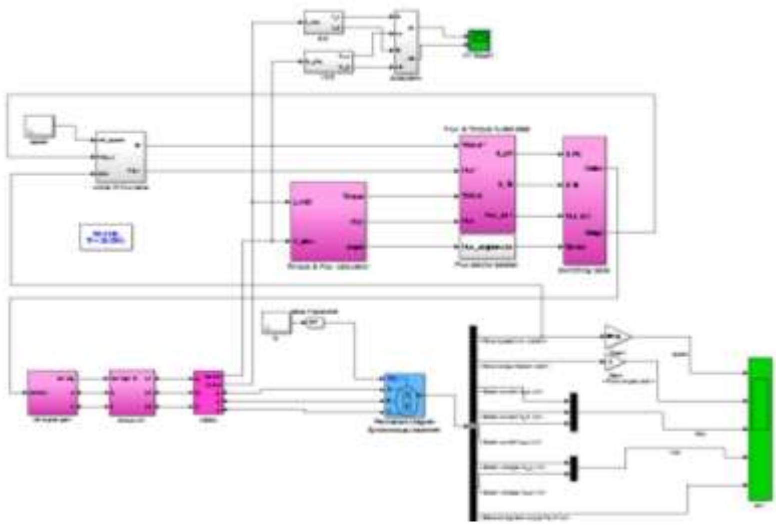

Figure 4: Simulation Model of DTC based DCMLI PMSM drive

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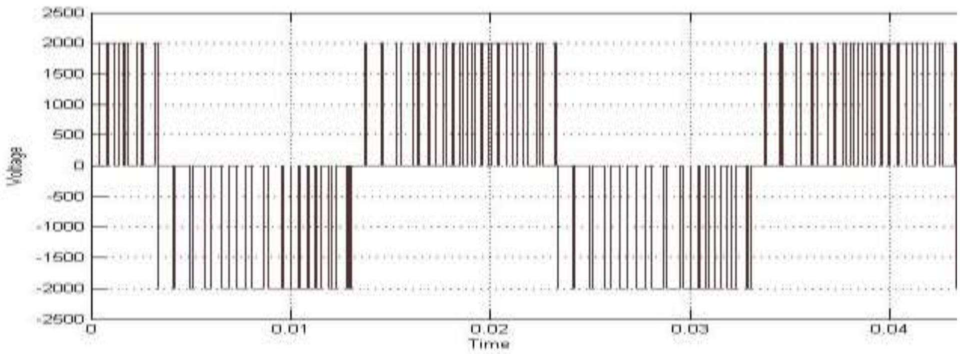
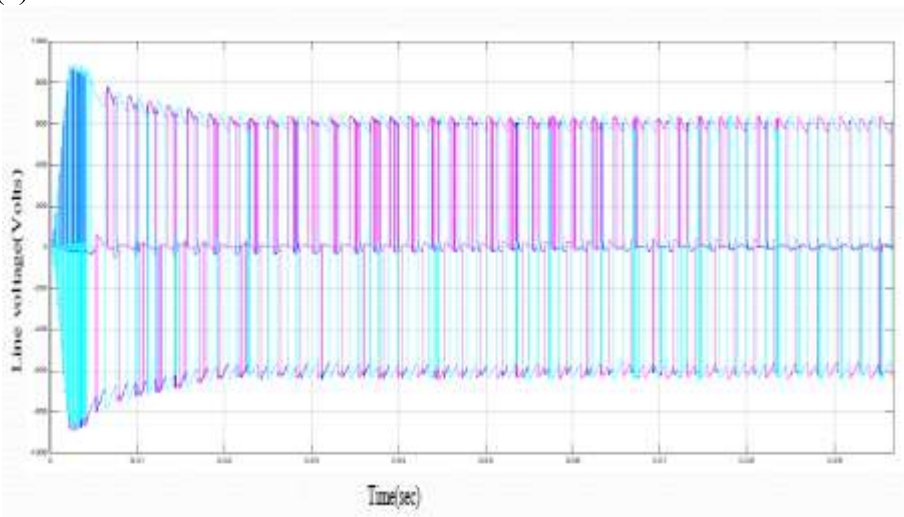
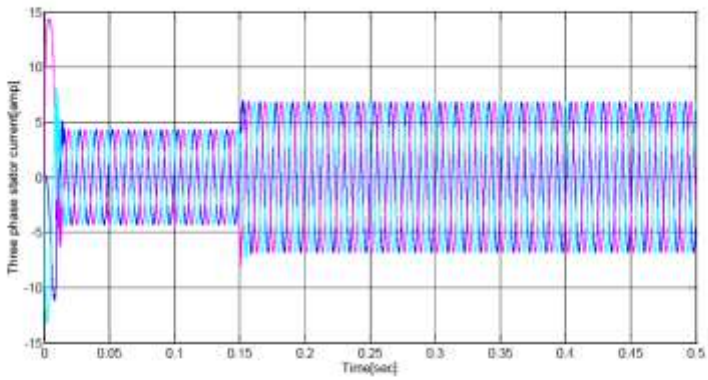


(a) Two-level



(b) Three-level inverter

Figure 5: voltage response of (a) Two-level (b) Three-level inverter



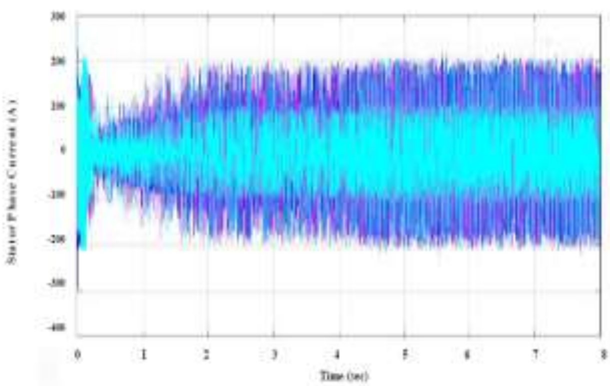


Figure 6: Stator current response of (a) Two-level (b) Three-level inverter

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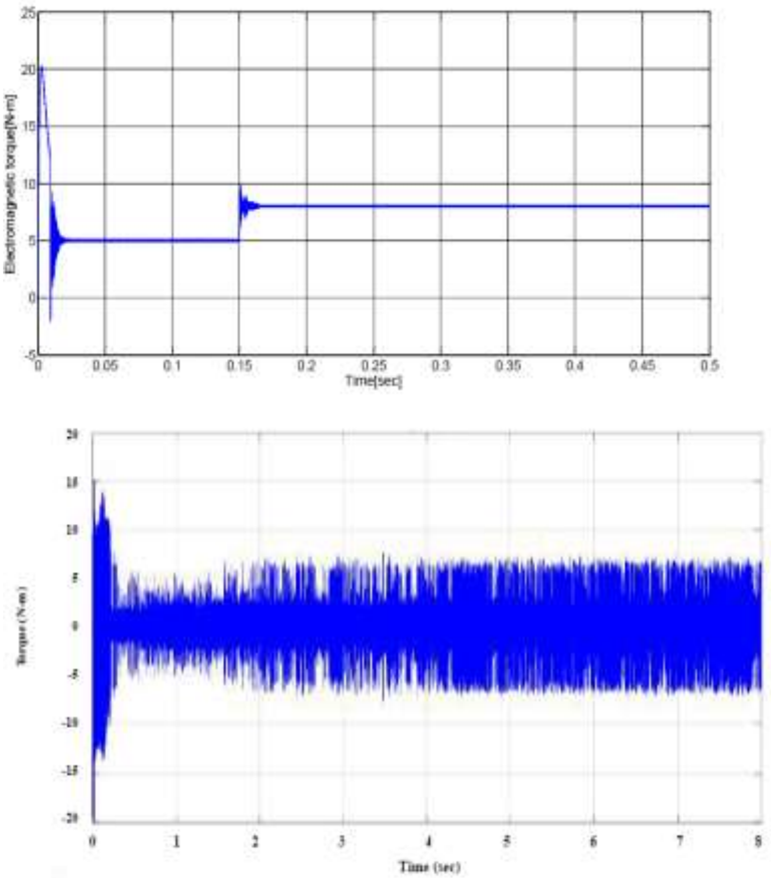


Figure 7: Torque response of (a) Two-level (b) Three-level inverter

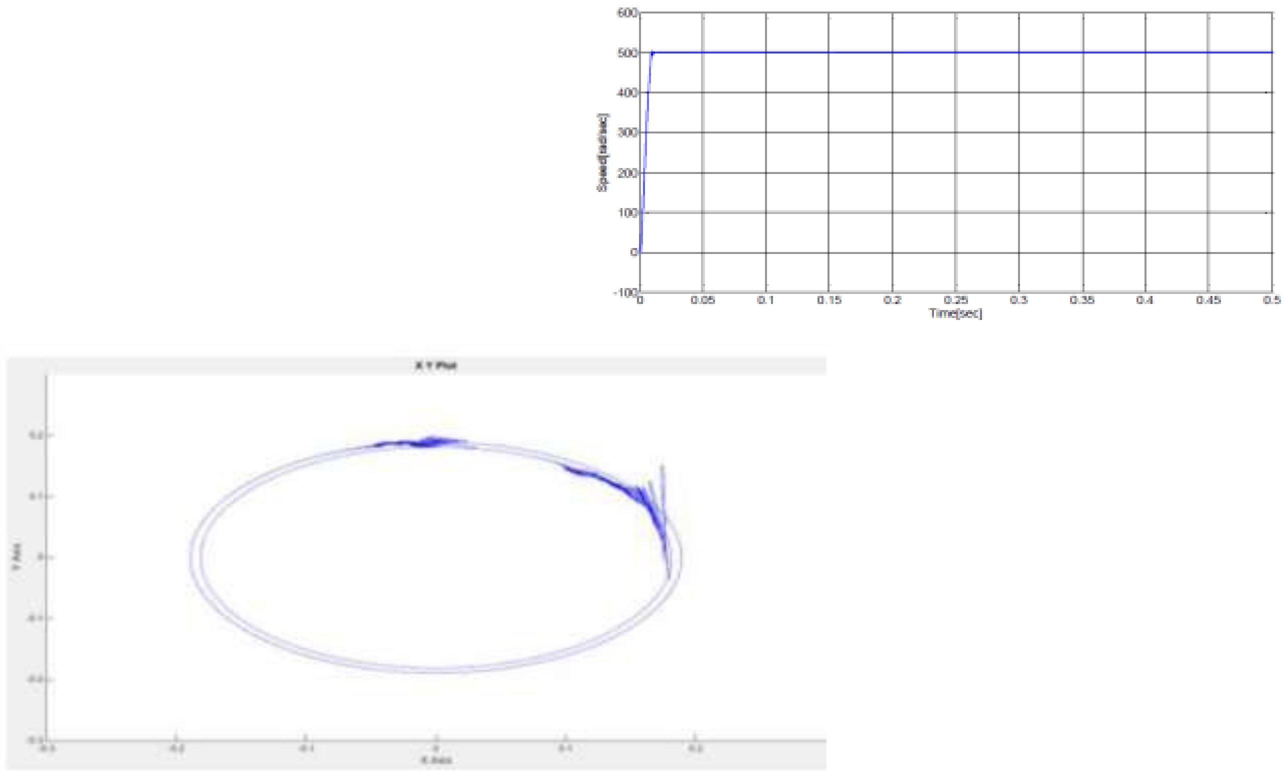


Figure 8:   Speed response of (a) Two-level (b) Three-level inverter

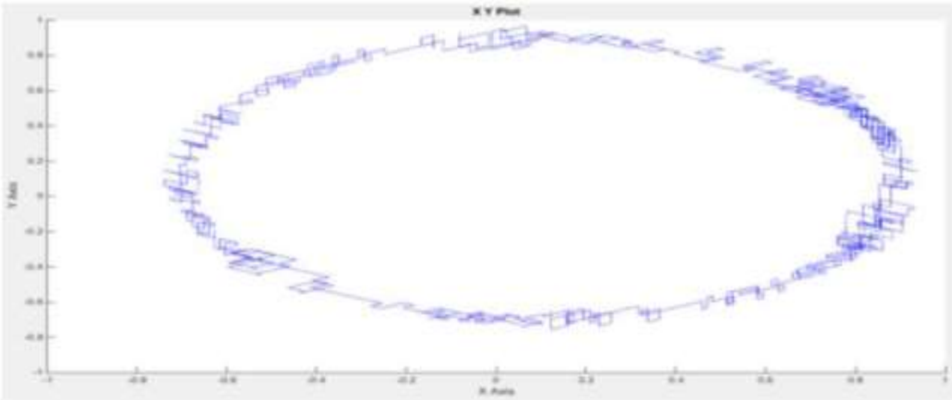
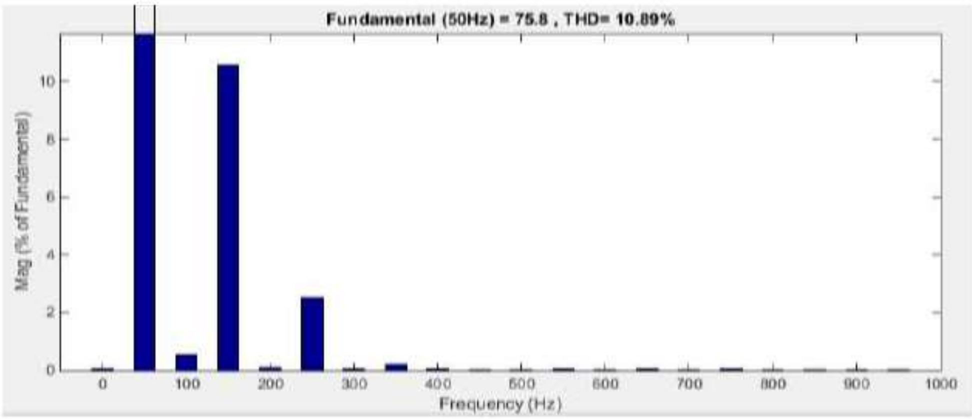
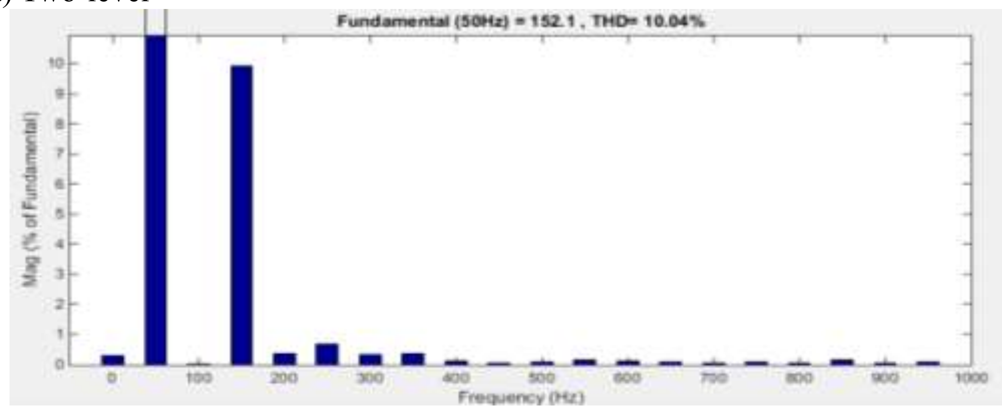


Figure 9: motor flux response (a) Two-level (b) Three-level inverter

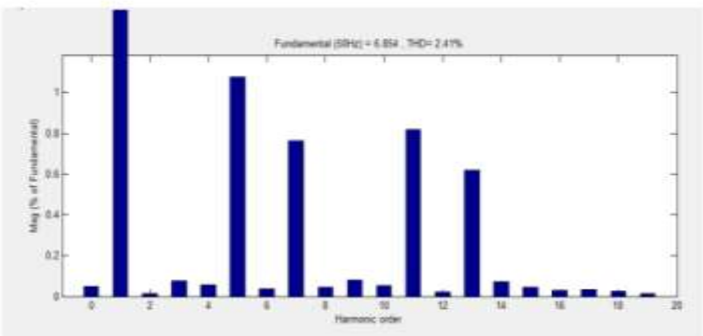


(a) Two-level



(b) Three-level inverter

Figure 10: FFT response of stator voltage (a) Two-level (b) Three-level inverter



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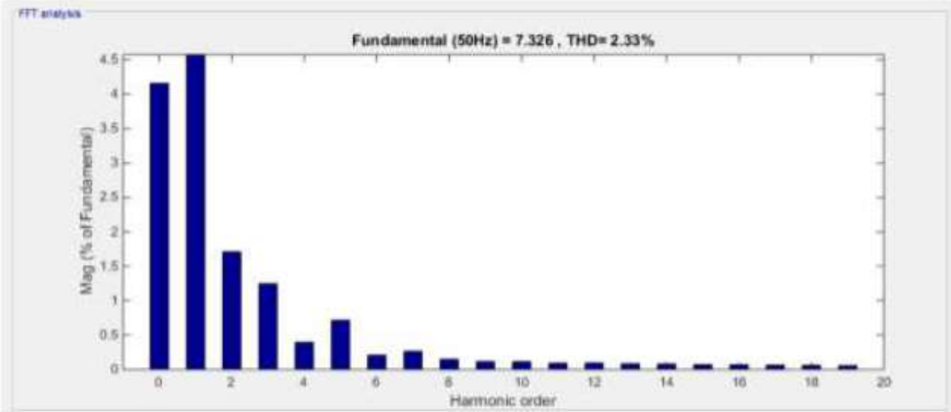
(a) Two-level



(b) Three-level inverter

Figure 11: FFT response of stator current (a) Two-level (b) Three-level inverter

Table 1. THD analysis

Controller Speed	Two-Level with DTC-SVM	Three-Level with DTC-SVM
500 rpm	21.58%	18.5449%
1000 rpm	20.54%	17.26%
1500rpm	18.27%	15.86%

Table 2. Torque Ripple Analysis

THD	Two Level with SVPWM	Three -Level with SVPWM
Line Voltage	10.89%	10.04%
Line Current	2.41%	2.33%

Table 3. Specification of PMSM

Sr. No.	**PMSM Parameter**	**Value**
1.	Stator Resistance	2.885Ω
2.	Permanent Magnet Flux	0.185Wb
3.	No of Pole pairs	4
4.	d-axis Inductance	8.5×10^{-3}H
5.	q-axis Inductance	8.5×10^{-3} H
6.	Torque	0.051Nm
7.	Movement of Inertia	2.26×10^{-5}Kg/m^2
8.	Viscous coefficient	1.349×10^{-5}Nms

5. Conclusion

The comparison and performance analysis of DTC - DCMLI driven PMSM drive using space vector modulation is designed, and implemented for automotive application has been done in this paper using MATLAB software. Modelling and simulation investigations of SVM -DTC based conventional inverter and SVM -DCMLI PMSM drive SVM method provides better steady state response of DCMLI driven PMSM drive as compared to conventional inverter. As seen from its response, the SVM is easy and the fastest method. The methods demonstrated the reduction in torque ripple, THD in inverter output and improved driving performance. Due to these characteristics, investigations on DCMLI driven PMSM drive system is found better suited for EV application

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