Comparative Analysis of FOC Based Three Level DCMLI Driven PMSM Drive

Dr.R.G.Shriwastava
Professor,
Dept. of Electrical Engineering
MCOERC, Nashik, India
rakesh_shriwastava@rediffmail.com

Mr. D.R.Bhise
Assistant Professor,
Dept. of Electrical Engineering
MCOERC, Nashik, India
digambar8021@gmail.com

Mr. Pravin Nagrale
Assistant Professor,
Dept. of Electrical Engineering
VPKBIET, Baramati, India.
pravin.nagrale@vpkbiet.org

Abstract— This paper deals with an comparative analysis of field-oriented control (FOC) based three level diode clamped multilevel inverter (DCMLI) driven Permanent Magnet Synchronous motor (PMSM) drive. The FOC of PMSM is widely used methods for the speed and torque control. The FOC PMSM drive system is designed simulated and implemented using various modulation techniques to calculate the desired torque, speed and stator current. The main disadvantage of Pulse Width Modulation (PWM) & Space Vector Modulation (SVM) are the problem of higher total harmonic distortion (THD) and lower effective DC utilization. In CBSVM, The main advantages of SVM is fast and efficient implementation, without sector determination & work on the effective time relocation algorithm. The Simulation analysis of the novel scheme is carried out by using MATLAB software. The simulation results show that the proposed novel control scheme has a good dynamic response in terms of speed and torque response. It can also reduce the torque ripple and THD of voltage and current gives better motor performance.

Keywords— Carrier Based Space Vector Modulation (CBSVM),Diode Clamped Multilevel Inverter (DCMLI), Field Oriented Control (FOC)Permanent Magnet Synchronous Motor (PMSM), Pulse Width Modulation (PWM), Space Vector Modulation (SVM), Total Harmonic Distortion (THD).

I. INTRODUCTION

The main advantages of PMSM drives are reduced losses, motor size and use of reluctance torque hence overall efficiency improved over the induction motor. Recently for PMSM drive control, the different schemes are used having the good torque response and the FOC has been considered as best solution for torque control.[1]Multilevel inverter technology has played very important role in the area of high-power medium voltage energy control. For reducing THD as compared to conventional inverter, a new family of DCMLI has optimum solution to increase the voltage levels and lower harmonic distortion [2-3]. In three level DCMLI, clamping diodes can produce additional voltage level for reduces the harmonic distortion. A various modulation techniques have been discussed to control the inverter [4]. The main characteristics of CBSVM technique is used control variable directly for improving DC link voltage utilization, reducing THD and losses. The main objective of the FOC is achieved by using a direct and quadrature axis d-q reference frame and also the torque equation [5]. In DCMLI inverter because of better gate pulses not only it gives better sinusoidal voltage or current also gives better speed control of machines [6].

In this paper, we presented a simple algorithm to perform the CBSVM for three level DCMLI. In CBSVM, it is run on concept of effective time to allow fast and efficient implementation of SVM without sector determination. So that the inverter output voltage is directly calculated in the effective times. It can be converted in a simple by effective time relocation method and based on the duty ratio profiles. In CBSVM, the common mode voltage injection method is used to generate [9-11].

II. MATHEMATICAL MODEL OF PMSM

The PMSM model equations are:

$$V_d = RI_d + L_d(dI_d/dt) - P\omega L_q I_q \quad (1)$$

$$V_q = RI_q + L_q(dI_q/dt) + P\omega L_d I_d + P\omega\lambda_f \quad (2)$$

$$T_e = T_L + B\omega + J_m(d\omega/dt) \quad (3)$$

$$T_e = K_t I_q + (3/2)P(L_d - L_q)I_d I_q \quad (4)$$

In Surface mounted permanent magnet motor,Ld = Lq

So, $T_e = K_t I_q$ (5)

$$K_t = (3/2)P\lambda_f \quad (6)$$

In equation (5) the torque producing current is along the q-axis current.

The d, q variables are converted in to a, b, c variables through the Park's transformation

$$\begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ \cos\theta & \cos(\theta-2\pi/3) & \cos(\theta+2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

The inverse Parks transformation is defined below:

ISBN -978-1-7281-1901-4

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix} \quad (8)$$

For a balanced system the power equation is:

$$V_a I_a + V_b I_b + V_c I_c = (3/2)(V_d I_d + V_q I_q) \quad (9)$$

III. CONTROL TOPOLOGY

A. Field Oriented Control

In Block diagram of FOC- CBSVM based three level DCMLI PMSM drive,the measured voltages and currents the into *a*-β reference frame are transform into d-q frame using Park transformation. The error is given to the PI controller after comparing the reference speed with the motor speed. The output of the PI controller is taken as q- axis current goes to current controller with reference id =0. The reference waves and triangular waves compared and pulses are given three level DCMLI.

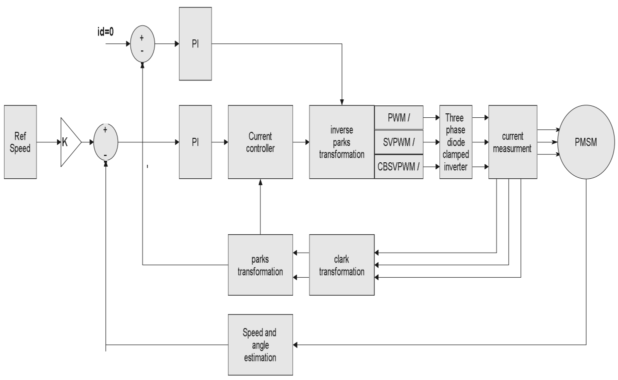


Fig. 1. Block diagram of FOC based three level DCMLI

B.

C. Multilevel Inverter Topology

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. Figure 2 shows the three-level DCMLI driven to PMSM drive.The switching sequence for the three level diode clamped inverter are shown in table-I

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

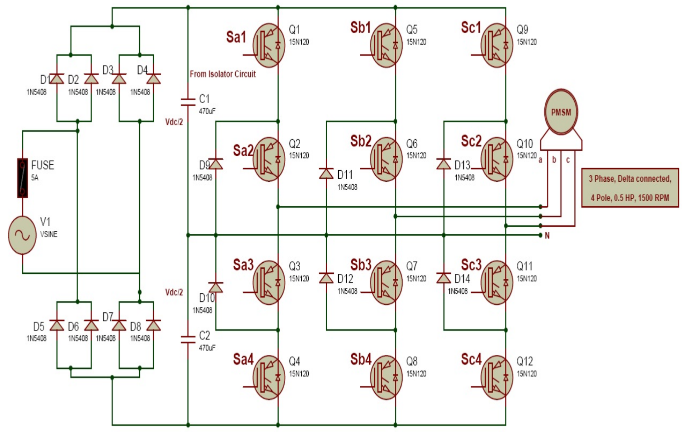


Fig. 2. Power circuit of three-level DCMLI driven PMSM

D. CBSVM Algorithm

In CBSVM there are four switches per phase of the three level inverter and two triangular carriers are required to turned-on and –off complementarily. A universal representation of modulation signals are represented by

$$u_i(t) = u_i^*(t) + e_i(t) \quad (10)$$

$$u_i^*(t) = m \sin \omega t$$
$$u_b^*(t) = m \sin(\omega t + 2\pi/3)$$
$$u_c^*(t) = m \sin(\omega t + 4\pi/3) \quad (11)$$

Where is m the modulation index, and

$$u_a^*(t) + u_b^*(t) + u_c^*(t) = 0$$

$$U_a N(t) = [E/2][m \sin \omega t + e_i(t)]$$
$$U_b N(t) = [E/2][m \sin(\omega t + 2\pi/3) + e_i(t)]$$
$$U_c N(t) = [E/2][m \sin(\omega t + 2\pi/3) + e_i(t)] \quad (12)$$

$$U_{ab}(t) = U_a N(t) - U_a N(t) = [E/2][\sqrt{3}m \sin(\omega t + \pi/6)]$$
$$U_{bc}(t) = [E/2][\sqrt{3}m \sin(\omega t + 5\pi/6)]$$
$$U_{ca}(t) = [E/2][\sqrt{3}m \sin(\omega t + 3\pi/6)] \quad (13)$$

It is clear that the injected harmonics do not appear in the line to line voltages.

IV. RESULTS ANALYSIS

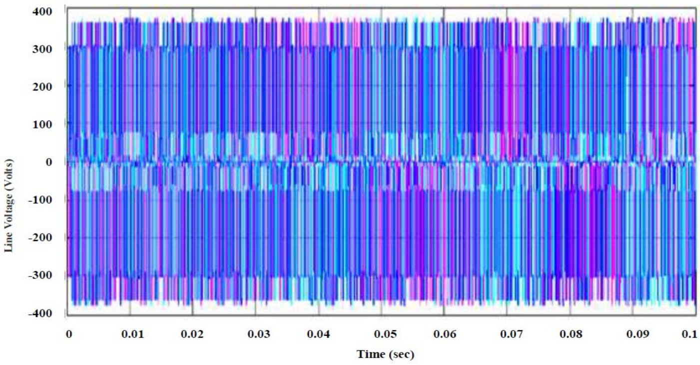
The result analysis of FOC based three level DCMLI using CBSVM driven PMSM drive is find for the steady and transient condition. The outputs of CBSVM are shown from fig.5 to fig.8.Fig.9 to fig.10 Show the THD analysis of line voltage and phase current. Table I shows that torque ripple analysis of PMSM drive TableII show that the lower THD of three level DCMLI using CBSVM technique.

ISBN -978-1-7281-1901-4

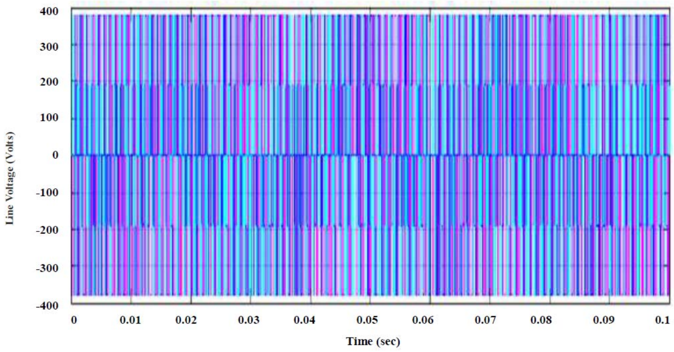
Ld=0.006365H; Lq=0.006365H; R=1.6Ω;

PM_flux=0.1852Wb; P=2; F=0.00005396 Nm-s;

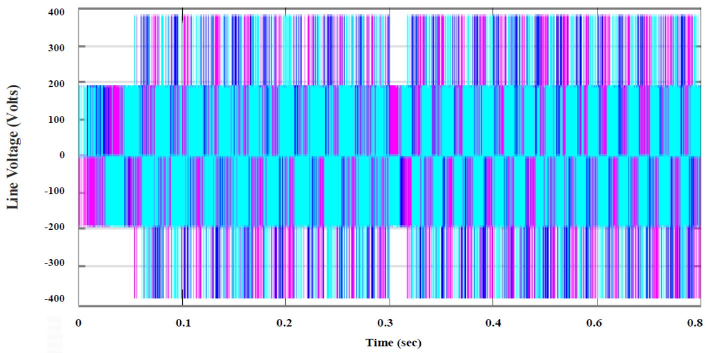
J=0.0001854 Kgm^2



(a)

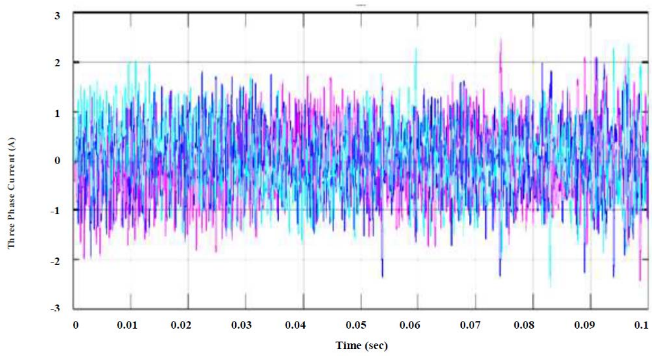


(b)

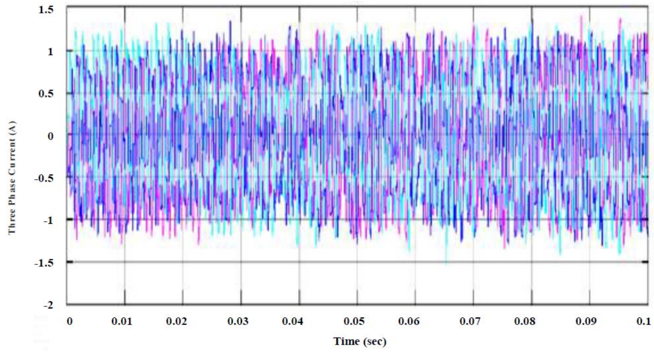


(c)

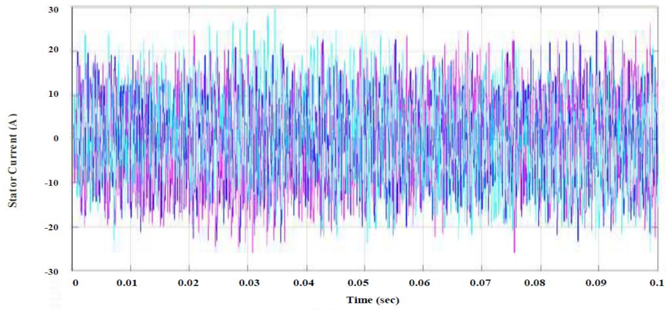
Fig. 3.Inverter voltage using
(a) PWM (b) SVM (C) CBSVM



(a)

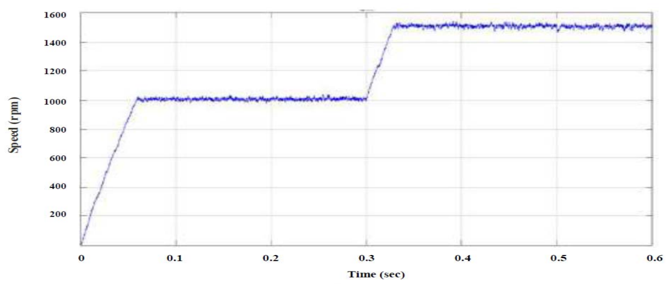


(b)

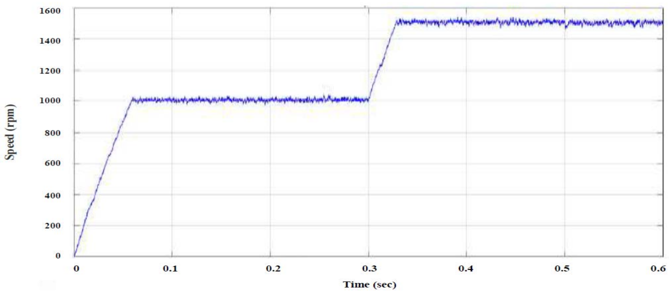


(c)

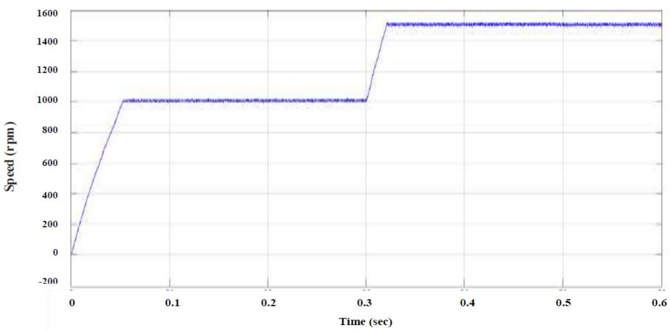
Fig. 4.Inverter current using
(a) PWM (b) SVM (C) CBSVM



(a)

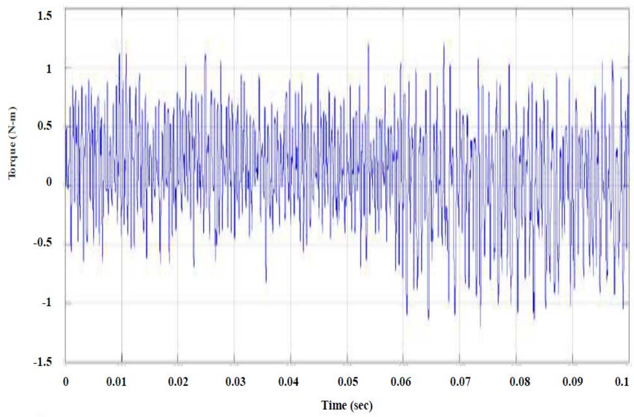


(b)

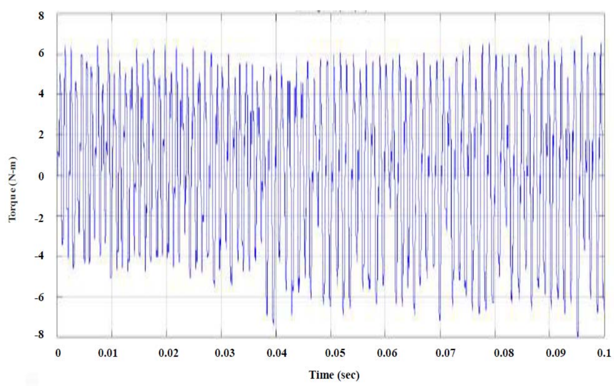


(c)

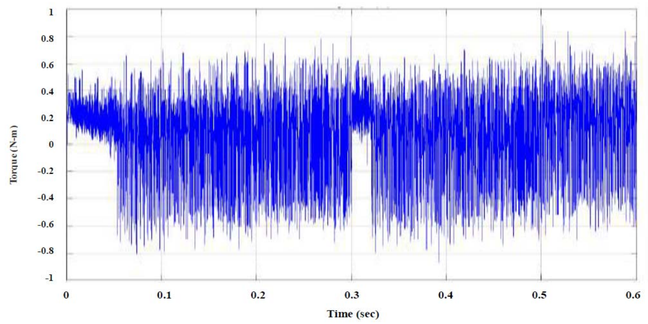
Fig. 5.Speed response using
(a) PWM (b) SVM (C) CBSVM



(a)

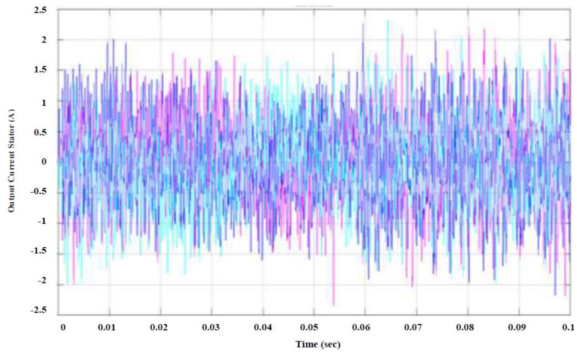


(b)

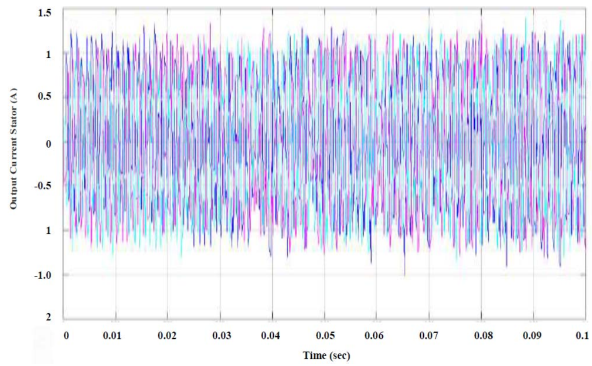


(c)

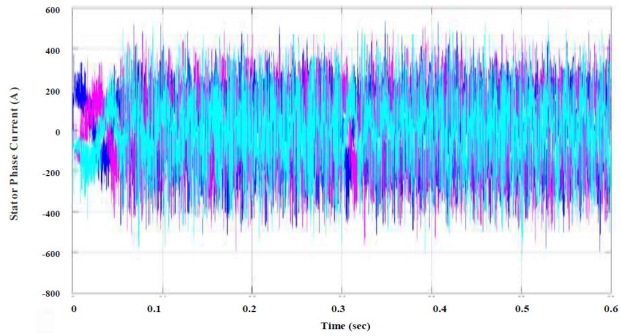
Fig. 6.Torque response using
(a) PWM (b) SVM (C) CBSVM



(a)

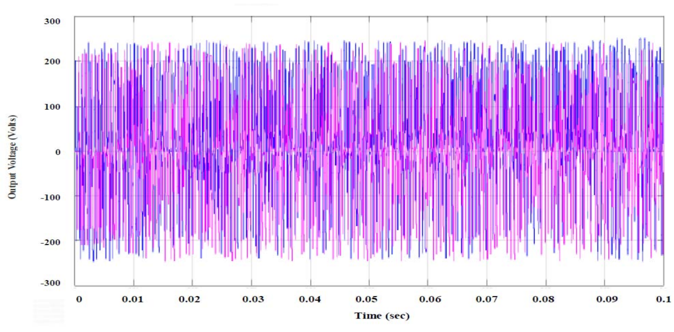


(b)

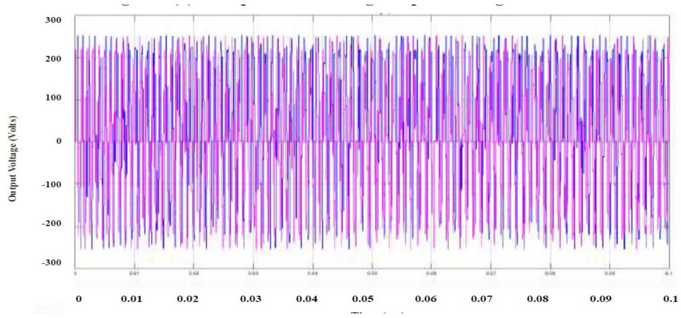


(c)

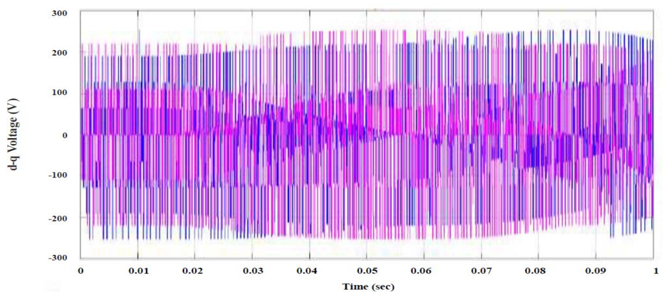
Fig. 7.Motor current using
(a) PWM (b) SVM (C) CBSVM



(a)

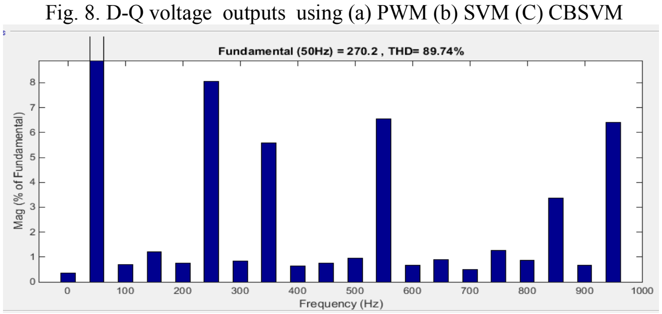


(b)

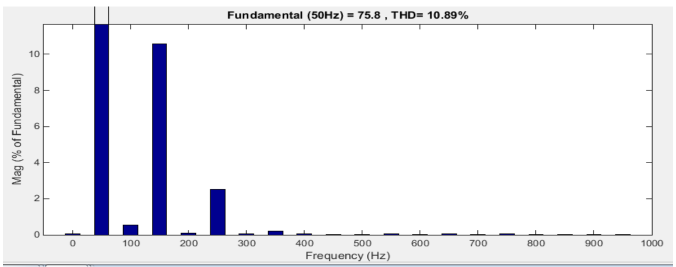


(c)

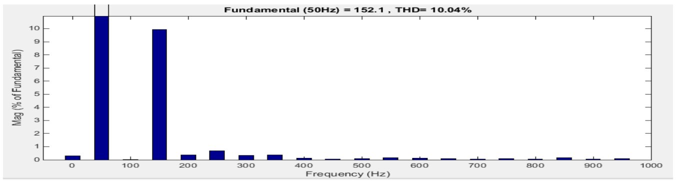
Fig. 8. D-Q voltage outputs using (a) PWM (b) SVM (C) CBSVM



(a)

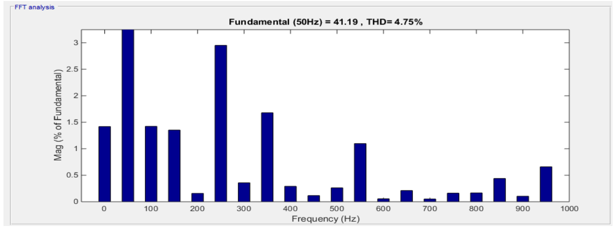


(b)

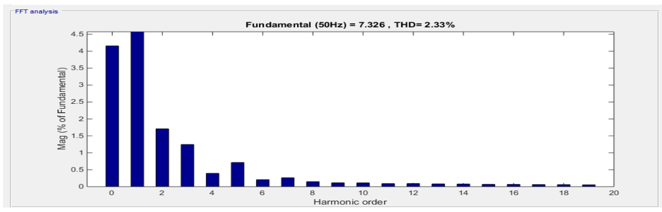


(c)

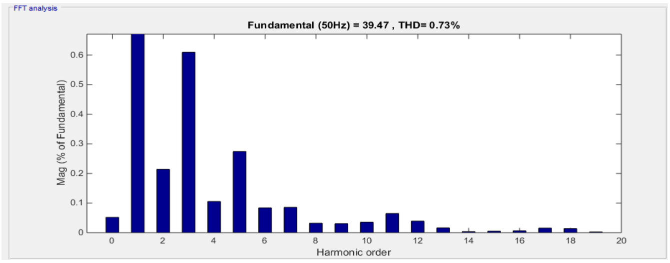
Fig.9. THD of line voltage using (a) PWM (b) SVM (C) CBSVM



(a)



(b)



(c)

Fig. 10. THD of Current using (a) PWM (b) SVM (C) CBSVM

Torque ripple can be calculated

$$\%\text{Torque ripple} = (T_{max} - T_{min})/T_{avg} * 100$$

TABLE I. TORQUE RIPPLE ANALYSIS

% Torque Ripples	**Torque Analysis**		
	PWM	***SVM***	***CBSVM***
	20%	18%	15.38%

TABLE II. THD ANALYSIS

THD	**THD Analysis**		
	PWM	***SVM***	***CBSVM***
Line Voltage	89.74%	10.89%	10.04%
Line Current	4.75%	2.33%	0.73%

V. Conclusion

The simulation analysis of FOC-CBSVM based three-level DCMLI driven PMSM drive has been studied in this paper. The comparative analysis of inverter voltage, current, speed, torque and the three-phase motor currents of the PMSM for PWM, SVM and CBSVM have plotted. It conclude that the FOC based three-level DCMLI driven PMSM using CBSVM gives better speed-torque characteristics compared to PWM and SVM techniques with less transients and good steady state response. The % torque ripple of FOC based three level DCMLI driven PMSM drive using novel CB-SVM technique is less as compare to PWM and SVM techniques' which in shown in table I.

References

[1] E.Prasad B.Suresh, K.Raghuveer Field Oriented Control of PMSM Using SVM Technique, Global Journal of Advanced Engineering Technologies, Vol1, Issue2-2012

[2] Jose Rodriguez, Steffen Bernet, Peter K Steimer, Ignacio E Lizama. A Survey on Neutral-Point-Clamped Inverters. IEEE Transactions on Industrial Electronics. 2010; 57(7).

[3] José Rodríguez, Jih-Sheng Lai, Fang ZhengPeng. Multilevel Inverters: A Survey of Topologies, Controls, and Applications. IEEE Transactions on Industrial Electronics. 2002; 49(4).

[4] Colak, Ilhami, Kabalci, Ersan, Bayindir, Ramazan. Review of multilevel voltage source inverter topologies and control schemes. Energy Conversion and Management. 2011; 52(2): 795-1574.

[5] Kiran Boby, Prof.Acy M Kottalil, N.P.Ananthamoorthy "Mathematical Modeling of PMSM Vector Control System Based on SVM with PI Controller Using MATLAB" International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 2, Issue 1, January 2013

[6] Raja Ram Kumar, Sunil Kumar, Alok Yadav "Comparison of PWM Techniques and Inverter Performance," IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), ISSN: 2278-1676 Volume 4, Issue 1 (Jan. - Feb. 2013), PP 18-22.

[7] Nam S. Choi, Jung G. Cho and Gyu H. Cho, [1991]" A General Circuit Topology of Multilevel Inverter," IEEE Conference Publication, PP: 96-103.

[8] Leopoldo G. Franquelo, Jose Rodriguez, Jose I. Leon, Samir Kouro, Ramon Portillo, and Maria A. M. Prats,[2008]" The Age of Multilevel Converters Arrives," IEEE Industrial Electronics Magazine,Vol.2, No.2,PP:28-39.

[9] Xiao-ling Wen and Xiang-gen Yin,[2007]" TheUnified PWM Implementation Method for Three- Phase Inverters," IEEE Conference Publication, PP:241-246.

[10] Jang-Hwan Kim, Seung-Ki Sul and Prasad N. Enjeti, [2005]" A Carrier-Based PWM Method with Optimal Switching Sequence for a Multi-level Four-leg VSI,"IEEE Conference Publication,PP:99-105.

[11] Wenxi Yao, Haibing Hu, and Zhengyu Lu, [2008]"Comparisons of Space-Vector Modulation and Carrier-Based Modulation of Multilevel Inverter,"IEEE Transactions on Power Electronics, Vol. 23,No. 1, PP: 45-51.

[12] J. Ebrahimi, E. Babaei, and G. B. Gharehpetian " A new multilevel converter topology with reduced number of power electronic components," IEEE Trans. Ind. Electronics., vol. 59,No.2 pp. 655-667, Feb 2012.

[13] R. S. Alishah" New hybrid structure for multilevel inverter with fewer number of components for high-voltage levels" IET Power Electron. Vol. 7, ss. 1, pp. 96–104, 2014

[14] A. Masaoud, H. W.Ping, S. Mekhilef and A. S. Taallah " New three-phase multilevel inverter with reduced number of power electronic components," IEEE Trans. Power Electronics, vol. 29,No.11 pp. 6018-6029, Nov.2014.

[15] K. Gupta, P. Bhatnagar, L. K. Sahu, and S. Jain, " Multilevel inverter topologies with reduced device count: A review," IEEE Trans. Power Electronics, vol. 31,No.1 pp. 135-151, Jan.2016.

[16] N. Celanovic and D. Boroyevic, "A fast space vector modulation algorithm for multilevel three-phase converters," in Conf. Rec. IEEE-IAS Annu. Meeting, Phoenix, AZ, Oct. 1999, pp. 1173–1177.

[17] J. Rodríguez, P. Correa, and L. Morán, "A vector control technique for medium voltage multilevel inverters," in Proc. IEEE APEC, Anaheim, CA, Mar. 2001, pp. 173–178.

[18] R.G.Shriwastava, M.B.Daigavane , S.R.Vaishnav, " Sensorless Field oriented control of PMSM Drive System for Automotive Application", 7th International Conference on Emerging Trends in Engineering and Technology, Kobe Japan, Published in IEEExplore Conference record no10.1109/ICETET .Nov 2015..11; 106-112.

[19] R.G.Shriwastava,M.B.Daigavane, P.M.Daigavane, "A Comparison between CBSVM Based FOC and DTC of PMSM drive with a three level DCMLI under different inverter switching frequencies", 4th International Conference on Computing for Sustainable Global Development(INDIACOM-2017), IEEE Conference, Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi, March 01-03, 2017.

[20] R.G.Shriwastava,M.B.Daigavane,S.R.Vaishnav, "Simulation analysis of 3-level diode clamped multilevel inverter driven PMSM drive using carrier based space vector Pulse Width Modulation (CB-SVM)", 7th Annual International Conference, ICCCV 2016 in Association with Elsevier Publication , Published in Science Direct (Elsevier) Procedia Computer Science 79(2016)Pg.no.616-623 .Nov 2015..11; 106-112.