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A Comparison between CBSVM Based FOC and DTC of PMSM drive with a three level DCMLI under different inverter switching frequencies

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***Abstract- This* paper deals with comparison between CBSVM based FOC and DTC of PMSM drive with a three level DCMLI under different inverter switching frequencies. The three level DCMLI were operated at 2.5kHz,5 kHz and 7.5kHz inverter switching frequencies. The Simulation of the novel scheme is carried out by using Matlab.The purpose of the paper is to decrease in the ripples in torque and also reduced copper losses. The CBSVM based FOC and DTC control was used for speed & torque control. As compared to the FOC-CB, the DTC-CB based three level DCMLI promised decrease in the ripples in torque and also reduced copper losses. The average value of the ripples in torque and also copper losses in FOC-CB is 14.52% & 34.31%. The average value of the ripples in torque and also reduced copper losses in DTC-CB is 9.68% &29.39%. The results showed that, the choice of the control strategy in terms of the ripples in torque and also reduced copper losses depend on the switching frequency and the motor speed.**

Keywords: Diode Clamped Multilevel Inverter (DCMLI), Permanent Magnet Synchronous motor (PMSM), Carrier Based Space Vector Modulation (CBSVM), Direct torque control (DTC), Field oriented control (FOC).

I. INTRODUCTION

The main advantages of PMSM are elimination of brushes, slip rings, and rotor copper losses in the field winding and also higher efficiency, reduction of the machine size. The PMSM can be further divided into two main groups in respect how the magnet bars have mounted in the rotor [1,2,3]. In the first group magnets are mounted in the rotor . and this type is called interior PMSM. The second group is represented by surface mounted PMSM in which magnet bars are mounted on the rotor surface.ie *Ld = Lq T*he reluctance torque disappears due to same flux paths in d and q axis. [4]. In 70s, The most popular vector control method developed known as FOC [5].Its gives the permanent magnet synchronous motor high performance are transformed in a coordinate system rotating in synchronism with PM flux. It allows indirectly control torque and flux quantities by using current control loop.[6]. Recently MLI technology are used in the area of high power and medium voltage control[7].Advantages of MLI over conventional two-level inverter are less switching losses, reduced harmonics. Multilevel VSI unique structure allows them to reach high voltage. Nowadays researchers all over the world spending their great efforts to improve the performance of multilevel inverters and optimized algorithms in order to decrease THD and torque ripples.

This paper introduced a comparison between CBSVM based FOC and DTC of PMSM drive with a three level DCMLI under different inverter switching frequencies.

II. MACHINE MODEL

Considering a four-pole three phase Permanent Magnet Synchronous Motor, the voltage equation in the dq domain.

$$\overline{u_{dqos}} = R_s.\overline{i_{dqos}} + p\overline{\lambda_{dqos}} \qquad (1)$$

Where *p* is the differentiating operator. The indexes *d*, *q* and *0* denote d axis, q axis and zero component of the variables.
Now linkage in the *dq* frame can be calculated as follows.

$$\overline{\lambda_{dqos}} = L_{dqo}.\overline{i_{dqos}} + \overline{\lambda_{dqo,m}} \qquad (2)$$

Where the inductance matrix is expressed

$$L_{dqo} = \begin{bmatrix} L_d & 0 & 0 \\ 0 & L_q & 0 \\ 0 & 0 & L_o \end{bmatrix} = \begin{bmatrix} L_s & 0 & 0 \\ 0 & L_s & 0 \\ 0 & 0 & L_s \end{bmatrix} \qquad (3)$$

The voltage equations for d and q axes are

$$u_{ds} = R_s i_{ds} + L_s \frac{di_{ds}}{dt} - \omega_r L_s i_{qs} \qquad (4)$$

$$u_{qs} = R_s i_{qs} + L_s \frac{di_{qs}}{dt} - \omega_r (L_s i_{ds} + \lambda_{pm}) \qquad (5)$$

The electromagnetic torque of the machine as follows

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \qquad (6)$$

If the equation (2) is substituted in the torque equation, it is obtained:
For a non-salient machine, control technique can be easily implemented because Ld=Lq and produces only one torque i.e electromechanical torque,

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\lambda_{pm} i_{qs}\right) \qquad (7)$$

From the above equation (7) the torque producing current is along the quadrature-axis.

The d, q variables are related with a, b, c variables through the Park's transformation defined as:

$$\begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

The inverse Parks transformation is defined below:

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} . \begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix} \qquad (8)$$

III. METHOLOGY

A. Field Oriented Control (FOC)

The simulation diagram of FOC-CB based three level DCMLI fed PMSM drive with CB-SVPWM techniques is shown in Fig1.. Block diagram of FOC of PMSM (Fig.1.) shows the generated reference waves and triangular waves are compared. The pulses generated are provided to the three levels DCMLI. The inverter output is given to the PMSM. The Closed loop, FOC of PMSM drive system have various components such as PMSM, position sensors, multilevel inverters and CB-SVPWM controller.

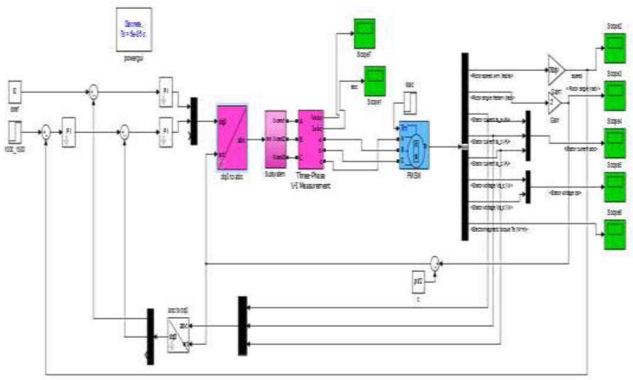


Fig.1. Simulation Model of FOC-CB based three level DCMLI fed PMSM drive

B. Direct torque control (DTC)

In conventional DTC, it has high ripples in flux linkage, stator current, and torque which is overcome using Carrier based Space Vector Modulation (CB-SVM).

In DTC-SVM if the hysteresis comparators consist of estimator used to calculate an voltage vector for compensation of torque and flux errors. This gives excellent dynamic performance but introduces more complexity.CBSVPWM is explained using effective time concept. The block diagram of the DTC-CBSVPWM fed PMSM using DCMLI is shown in Fig.2. By using Clarke transformation,the measured currents are transformed into α-β variables. Also the estimation of voltage is done from switching state of the inverter and also by using the DC-link voltage in the reference frame of α-β.

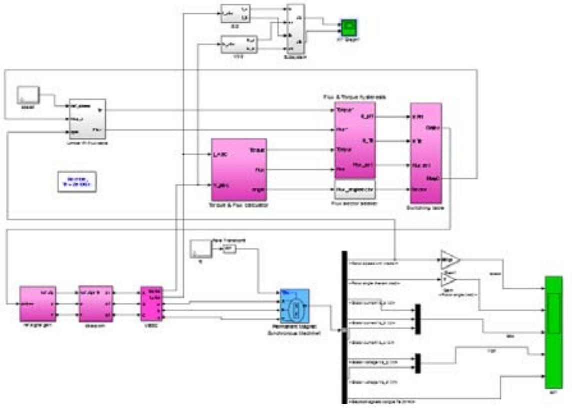


Fig.2. Simulation Model of DTC-CB based three level DCMLI fed PMSM drive

IV. SIMULATIONS RESULTS AND ANALYSIS

FOC and DTC based three levels DCMLI fed PMSM drive using CB-SVM at different switching frequency has been evaluated in Matlab/Simulink®2014b.The reference speed of 1200-1500 rpm for step input at dc link voltage is 380V. Fig.3 (a),(b) ,(c) to Fig.5 (a),(b) ,(c) shows output speed response, stator current &torque response using CB-FOC using

2.5KHz,5KHz and 7.5 KHz. Fig.6 (a),(b) ,(c) to Fig.8 (a),(b) ,(c) shows output speed response, stator current &torque response using CB-DTC using 2.5KHz,5KHz and 7.5 KHz. Table.I shows the Specification of PMSM. Table II shows that torque ripple & copper loss analysis of CB-FOC & CB-DTC based three level DCMLI at different switching frequencies.

A. Analysis of FOC-CB fed PMSM drive at different inverter switching frequencies

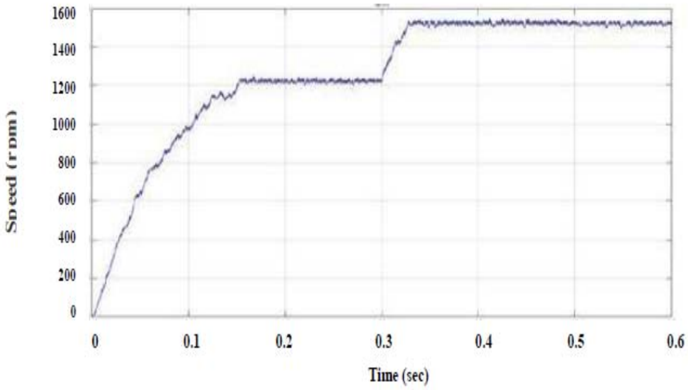


Fig.3 (a): Output speed response using FOC-CB using 2.5KHz

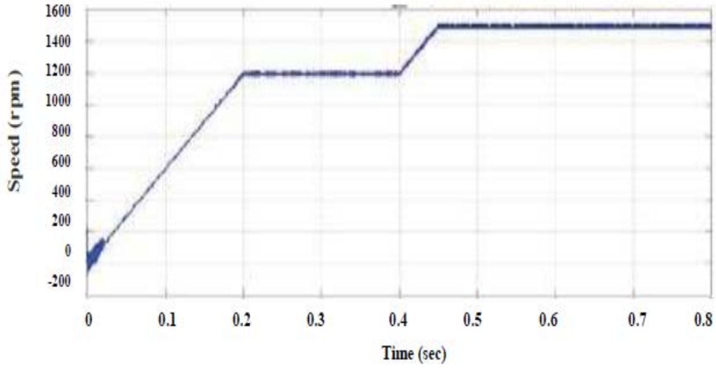


Fig.3 (b) Output speed response using FOC-CB using 5KHz

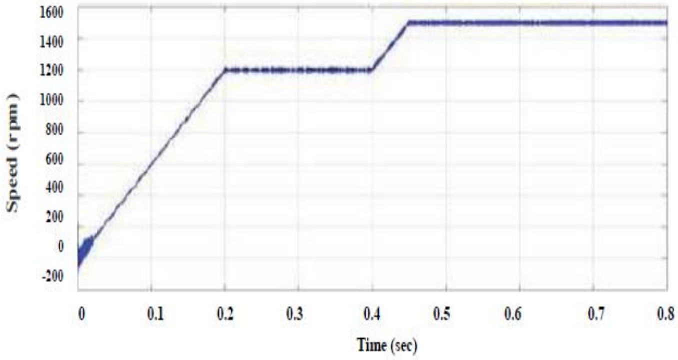


Fig.3 (c) Output speed response using FOC-CB using 7.5KHz

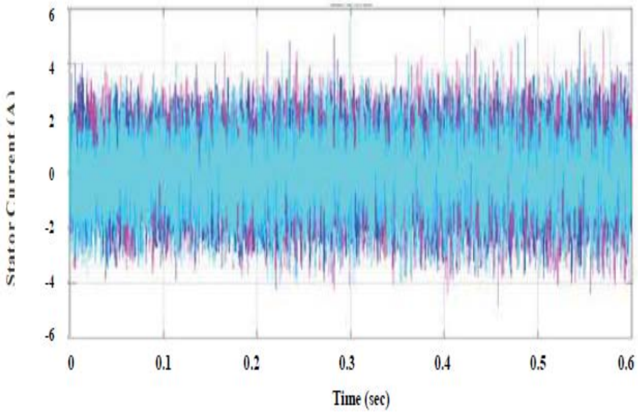


Fig. 4(a) :Output stator current response using FOC-CB using 2.5KHz

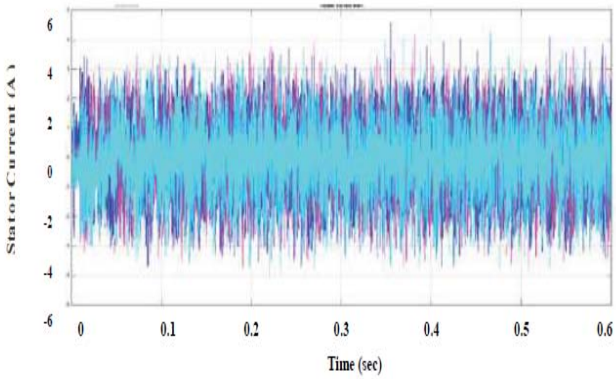


Fig. 4(b) :Output stator current response using FOC-CB using 5KHz

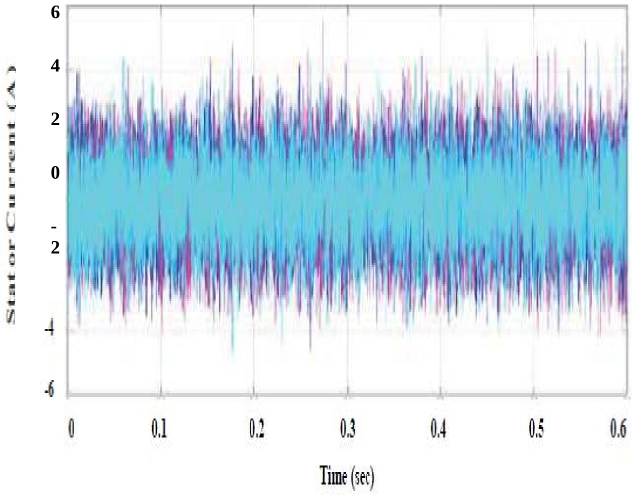


Fig. 4(c): Output stator current response using FOC-CB using 7.5KHz

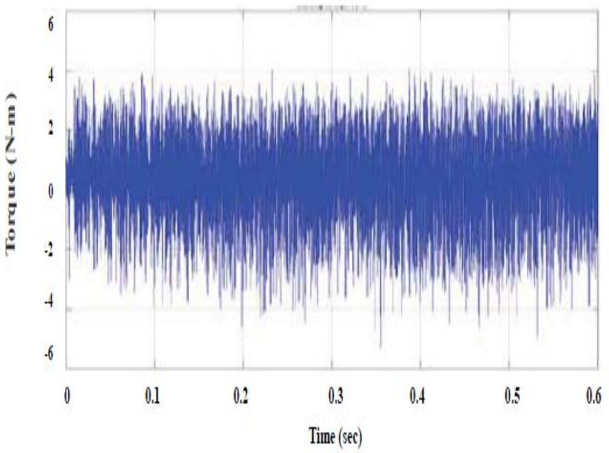


Fig.5 (a) :Output torque response using FOC-CB using 2.5KHz

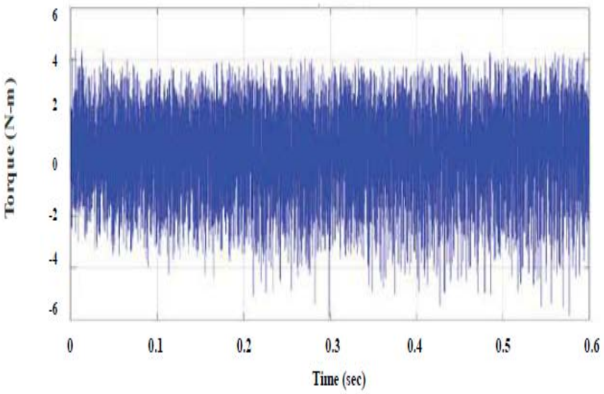


Fig.5 (b) :Output torque response using FOC-CB using 5KHz

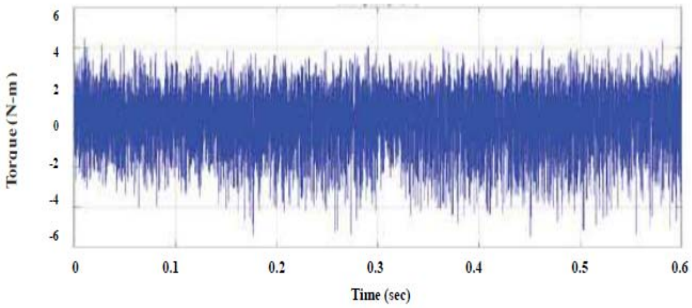


Fig.5 (c) :Output torque response using FOC-CB using 7.5KHz

B. *B) Analysis of DTC-CB fed PMSM drive at different inverter switching frequencies*

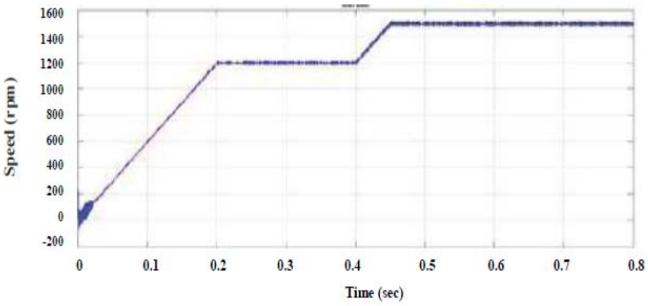


Fig.6 (a) :Output speed response using DTC-CB at 2.5KHz

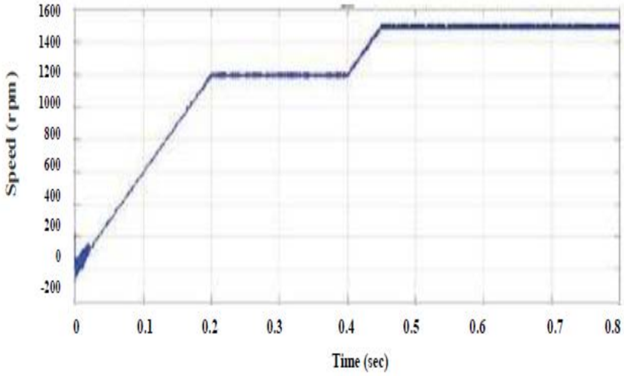


Fig.6 (b) :Output speed response using DTC-CB at 5KHz

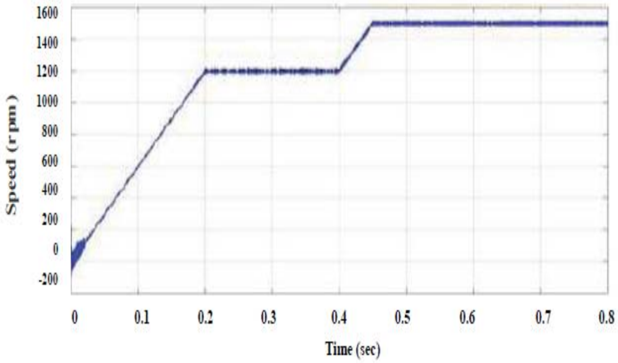


Fig.6 (c) :Output speed response using DTC-CB at 7.5KHz

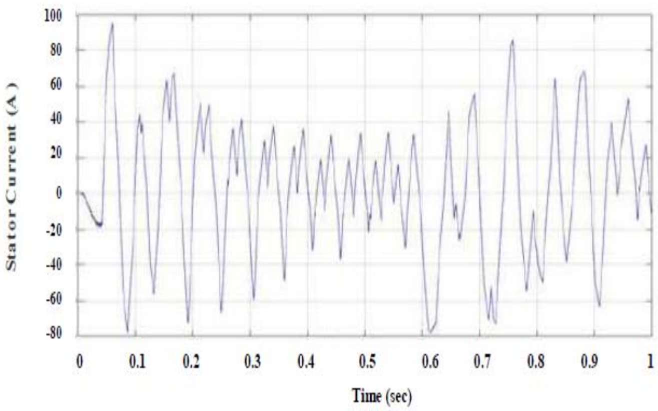


Fig. 7(a) :Output stator current response using DTC-CB at 2.5KHz

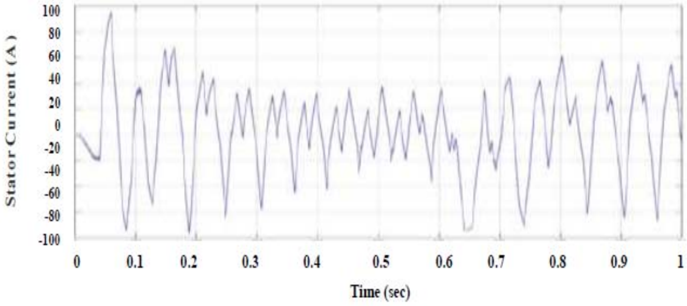
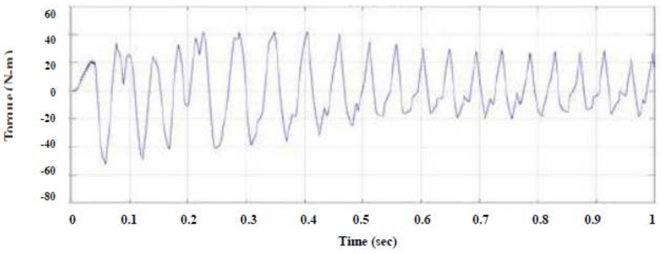


Fig. 7(b) :Output stator current response using DTC-CB at 5KHz



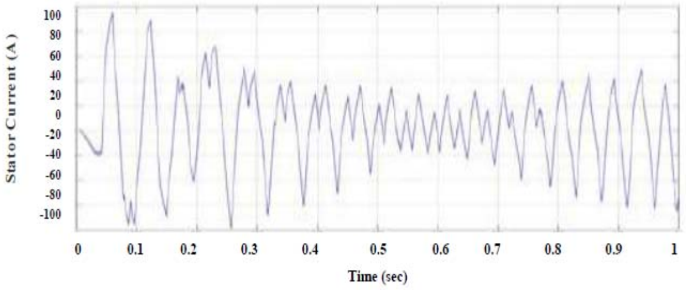


Fig. 7(c) :Output stator current response using DTC-CB at 7.5KHz

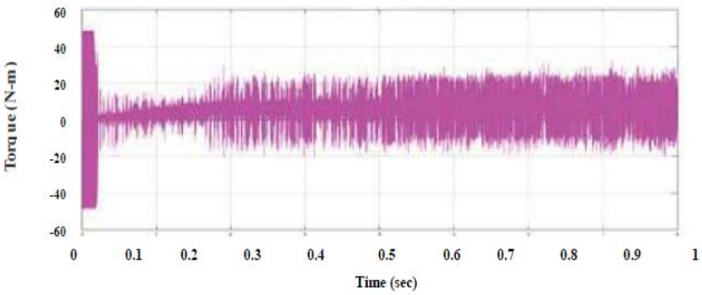


Fig.8 (a) :Output torque response using DTC-CB at 2.5KHz

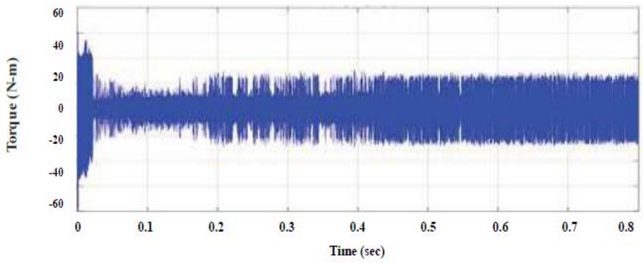


Fig.8 (b) :Output torque response using DTC-CB at 5KFig.8 (c) :Output torque response using DTC-CB at 7.5KHz

$$\text{Torque ripple (\%)} = (Tmax - Tmin)/\, Tavg * 100$$

TABLE. I: PMSM SPECIFICATION

Sr. No.	PMSM Parameter	Value
1.	Resistance of Stator Rs	1.6 Ω
2.	Inductance of d-axis	0.006366H
3.	Inductance of q-axis	0.006366H
4.	*PM Flux*	*0.1862Wb*
6.	No of Poles	2
6.	Movement of Inertia(J)	0.0001864 Kg/m^2
7.	Viscous coefficient(f)	0.00006396 Nms

TABLE II: TORQUE RIPPLE & COPPER LOSS ANALYSIS OF CB-FOC & CB-DTC BASED THREE LEVEL DCMLI AT DIFFERENT SWITCHING FREQUENCIES

Speed(RPM)	Switching Frequency Range(KHz)	%Torque ripple		P_{cu} in watt	
		CB-FOC	CB-DTC	CB-FOC	CB-DTC
1200-1500 rpm	2.5 KHz	15.38%	10.52%	42.33W	36.19W
1200-1500 rpm	5 KHz	14.32%	9.43%	37.67W	32.63W
1200-1500 rpm	7.5 KHz	13.86%	9.10%	21.95W	19.37W

V. CONCLUSION

This paper presents the comparison of FOC-CB and DTC-CB based three level DCMLI at 2.5 KHz, 5 KHz, and 7.5 KHz switching frequencies is investigated. The average value of torque ripple & copper losses in FOC-CB is 14.52% &34.31%. The average value of torque ripple & copper losses in DTC-CB is9.68% &29.39%.Analysis of different switching frequency can be seen in table-II. Along with the torque ripples, copper losses are also reduced at 2.5 KHz, 5 KHz, and 7.5 KHz switching frequencies in the speed range 1200-1500 rpm

REFERENCES

[1] I. Boldea, S.A. Nasar, “Electrical drives”, CRC Press, 1999.

[2] R. Krishnan, “Electric Motor Drives – Modeling, Analysis, and Control”, Prentice Hall, 2001.

[3] T. Kaczmarek, K. Zawirski, “Układy napędowe z silnikiem synchronicznym”,Politechnika Poznańska, 2000.

[4] P. Vas, “Sensorless Vector and Direct Torque Control”, Oxford University Press, 1998.

[5] K. Rajashekara, A. Kawamura, K. Matsuse, “Sensorless Control of AC Motor Drives”, IEEE Press,1996, USA.

[6] M. P. Kaźmierkowski, H. Tunia, “Automatic Control of Converter-Fed drives”, Elsevier, 1994.

[7] M. P. Kaźmierkowski, R. Krishnan, F. Blaabjerg, “Control in Power Electronics”, Academic Press, 2002.

[8] Bowesand, S.R.; Lai, Y.S.: The relationship between space-vector modulation and regular-sampled PWM. IEEE Trans. Ind. Electron. 44, 670–679 (1997)

[9] Dae-Woong Chung, Joohn-Sheok Kim and Seung- Ki Sul, [1996]” Unified Voltage Modulation Technique for Real Time Three-phase Power Conversion,” IEEE Transaction, Vol.34, N0.2, PP:374 -380.

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

[11] 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.

[12] Keliang Zhou and Danwei Wang,[2002] “Relationship Between Space-Vector Modulation and Three-Phase Carrier-Based PWM: A Comprehensive Analysis,” IEEE Transactions on Industrial Electronics, Vol. 49, No. 1,PP:186-195.

[13] 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

[14] T. M. Rowan, R. J. Kerman, and T. A. Lipo, “Operation of naturally sampled current regulators in transition mode,” IEEE Trans. Ind. Applicat., vol. 23, pp. 586–596, July/Aug. 1987.

[15] V. Kaura and V. Blasko, “A new method to extend linearity of a sinusoidal PWM in the overmodulation region,” IEEE Trans. Ind. Applicat.,vol. 32, pp. 1115–1121, Sept./Oct. 1996

[16] X. del Toro, S. Calls, M. G. Jayne, P. A. Witting, A. Arias, J. L. Romeral. Direct torque control of an induction motor using a three-level direct torque control of an induction motor using a three-level. In Proceedings of IEEE International Symposium on Industrial Electronics, IEEE, vol. 2, pp. 923–927, 2004.

[17] S. Wei, B. Wu, F. Li, C. Liu. A general space vector PWM control algorithm for multilevel inverters. In Proceedings of the 18th Annual IEEE Applied Power Electronics Conference, IEEE, Miami, Florida, USA, vol. 1, pp. 562–568, 2003.

[18] S. Busquets-Monge, J. Bordonau, D. Boroyevich, S. Somavilla. The nearest three virtual space vector PWM — A modulation for the comprehensive neutral-point balancing in the three-level NPC inverter. IEEE Power Electronics Letters, vol. 2, no. 1, pp. 11–15, 2004.

[19] L. Zhong, M. F. Rahman, W. Y. Hu, and K. W. Lim, “Analysis of direct torque control in permanent magnet synchronous motor drives,” IEEE Transaction on Power Electronics, 1997, vol. 12, pp. 528–536.