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Performance Investigations of PMSM Drive using Various Modulation Techniques for Three Level NPC Inverter

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***Abstract*— Performance analysis of three level Neutral point clamped inverter fed Permanent Magnet Synchronous Motor drive for Electrical vehicle application has been investigated in this paper. In the proposed approach, mathematical modeling and simulation of the system is done in MATLAB Simulink environment. A PMSM drive system based on Field Oriented Control is designed, and simulated for three level NPC inverter. Both SVM and CBSVM modulation methods are demonstrated in the present study. Steady state response and the performance of the drive system is compared to investigate the effectiveness of the either method. Output voltage, current, speed and torque of the proposed system are demonstrated. Computer simulation of the system shows the percentage torque ripple in FOC-CBSVM is 7.38 percentage is less compare to FOCSVM. Hence three-level NPC inverter PMSM drive is found suitable for electrical vehicle application due to its less distorted output and lower cost. The enhanced performance with respect to torque ripples and harmonics are the key features of study.**

Keywords—Carrier Based Space Vector Modulation (CBSVM), Electrical Vehicle (EV), Field Oriented Control (FOC), Permanent Magnet Synchronous Motor (PMSM), Space Vector Modulation (SVM), Three level Neutral point clamped (NPC) Inverter.

I. INTRODUCTION

With the upgradatation of automobile application, air pollution and the rapid reduces of the earth's petroleum resources are becoming serious threats. Electrical vehicle (EV) which includes battery EV, hybrid EV and fuel cell EV has drawn increasing interests (1)-(2). Electric motors, power converters and electronic controllers are hearts of EV systems. The main advantage of PMSM are high reliability, efficiency, power density respectively. For high dynamic performance, it is used in the modern EV application. (3)-(4). FOC is often used in variable speed drive application. In variable speed drive motor, the proportional integral controller method has been widely used for indirect FOC method. There are many types of controller methods are used like artificial intelligent control,PI control, fuzzy logic control, and variable structure control to get best performance of the motor.(5)-(11). Due to the simple structure, The PI controller is used which can be easily understood and implemented. For wide speed range, FOC independently control the torque & stator current.

Multilevel inverter technology has been used in the area of high-power application recently. Using single power semiconductor switch, it is difficult to connect a directly to medium voltage grids because of high harmonic distortion in conventional inverter. NPC multilevel inverters as the right solution for working with lower harmonic distortion and higher voltage levels (12).many multi-level inverter methods to improve the quality of the power delivered to the load has been presented (13). In this paper, NPC inverter is used to produce additional voltage level that reduces the harmonic distortion with clamping diode.

The objective of this paper is to simulate FOC based NPC inverter fed PMSM drive using SVM and CBSVM techniques and compare the performance of FOC based NPC Inverter fed PMSM drive using SVM and CBSVM for Electrical vehicle application. Section I focus on the Introduction, Section II focus on the mathematical modeling of PMSM, Section III gives the overview of FOC. Section IV deals with simulation results and discussion in steady state period. The comparison between the NPC Inverter fed PMSM drive using SVM and CBSVM has been presented.

II. MATHEMATICAL MODELING OF PMSM

The voltage equation of four-pole three phase PMSM in the d-q domain is,

$$\overline{u_{dqos}} = R_s.\overline{i_{dqos}} + p\overline{\lambda_{dqos}} \tag{1}$$

The calculated value of linkage in the *d-q* frame is

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

Where the inductance matrix is expressed as, (14)-(15)-(16)

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

In d and q axes, the voltage equations are(14)-(15)

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

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

For machine, the electromagnetic torque is

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

For a non-salient pole machine, with L_d=L_q, using better controls, only Electromechanical torque T_e given by,

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

can be produced.

From equation (7) it is seen that, the torque is produced due to Quadrature-axis current.Park's transformation converts d, q variables to a, b, c variables in following matrix. (14)-(15)-(16)

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

(8)

The inverse transformation of the above is (14)-(15)-(16)

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & \sin(\theta + 2\pi/3) & 1 \end{bmatrix} . \begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix} \quad (9)$$

III. METHODOLOGY

A. Field Oriented Control

The FOC based PMSM drive system consist of various components such as PMSM, position sensors, multilevel inverters, SVM and CB-SVM controllers. The block diagram of FOC based three-level NPC inverter fed PMSM drive system is shown in Fig.1.In block diagram, the reference waves which generated are compared with the triangular waves and obtained the pulses for three levels NPC inverter. The inverter output is given to the PMSM(14)-(15) .

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\lambda_{pm} i_{qs} - (L_q - L_d) i_{qs} i_{ds}\right) \quad (10)$$

From equation (2) the electromechanical torque and the reluctance torque is given by,

$$T_r = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left((L_q - L_d) i_{qs} i_{ds}\right) \quad (11)$$

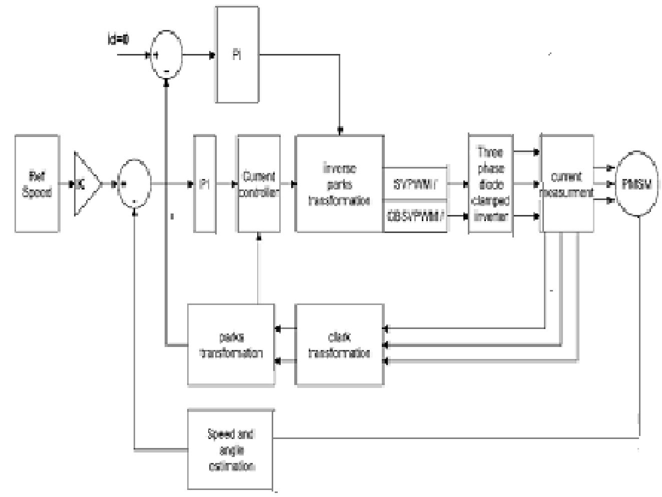


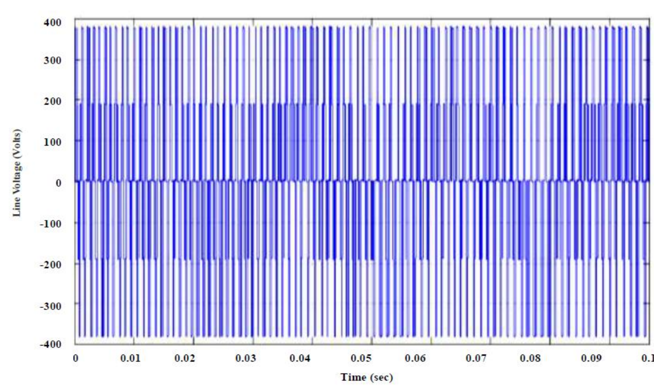
Fig. 1. Block diagram of PMSM drive using FOC techniques

IV. SIMULATION RESULTS AND DISCUSSION

Investigations on NPC inverter fed PMSM drive system using FOC has been done in matlab environment. The SVM&CBSVM techniques have been applied to the NPC inverter fed PMSM drive system under steady state only. The load torque is applied in steps. The output voltage& current waveforms of NPC inverter using SVM&CBSVM are shown in fig.2 and fig.3.The speed, electromagnetic torque, and stator phase current respectively are shown in fig.4, fig.5 and fig.6. The frequency spectrum of line voltage and phase current are shown in fig.7 and fig.8. TableI shows the THD analysis using, SVM, CBSVM. Table II shows the torque ripple analysis of NPC inverter fed PMSM drive using SVM & CBSVM method (14)-(15) .

Following are the parameters used in MATLAB simulation (16).

L_d=8.5x10^{-3}H; L_q=8.5x10^{-3}H; R=2.885Ω; PM_flux=0.185Wb; P=4; F=1.349x10^{-5}Nms; J=2.26x10^{-5}Kg/m^2



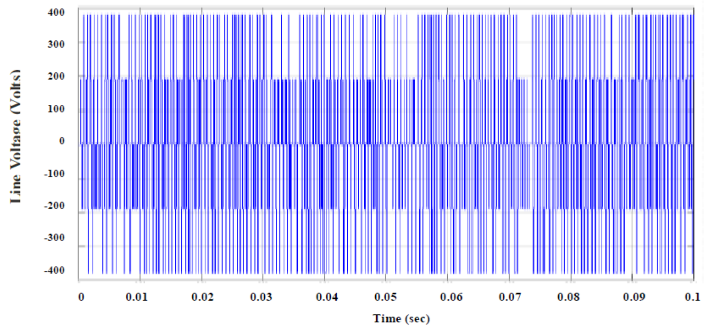


Fig. 2. Output voltage waveform of NPC inverter using SVM,&CBSVM.

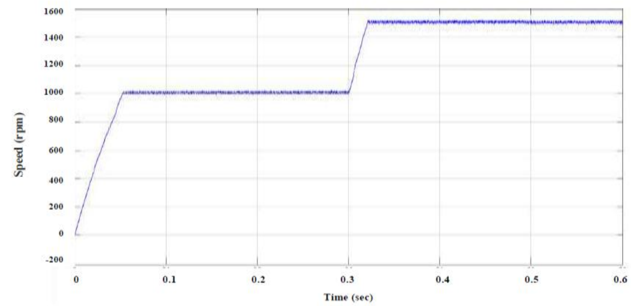


Fig. 4. Output speed response of PMSM drive.

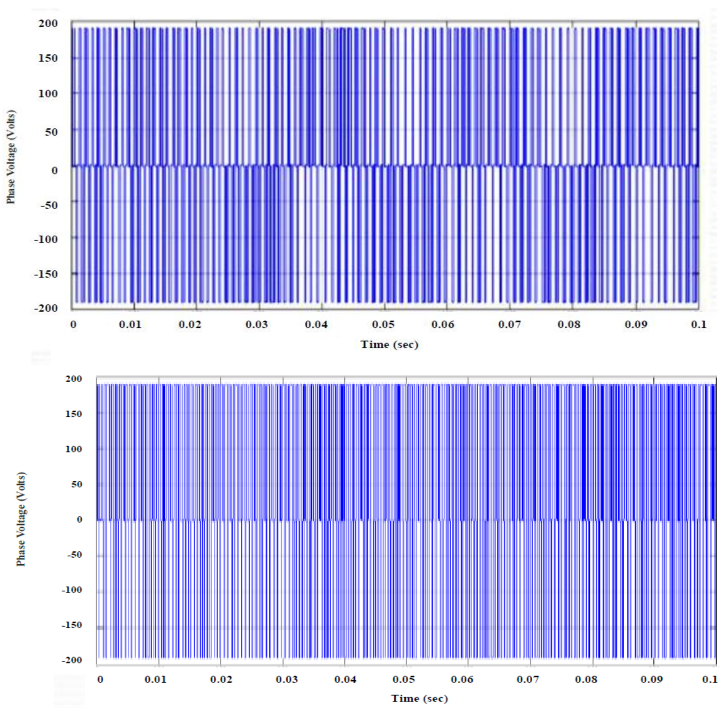


Fig. 3. Output phase current waveform of NPC inverter using SVM,&CBSVM.

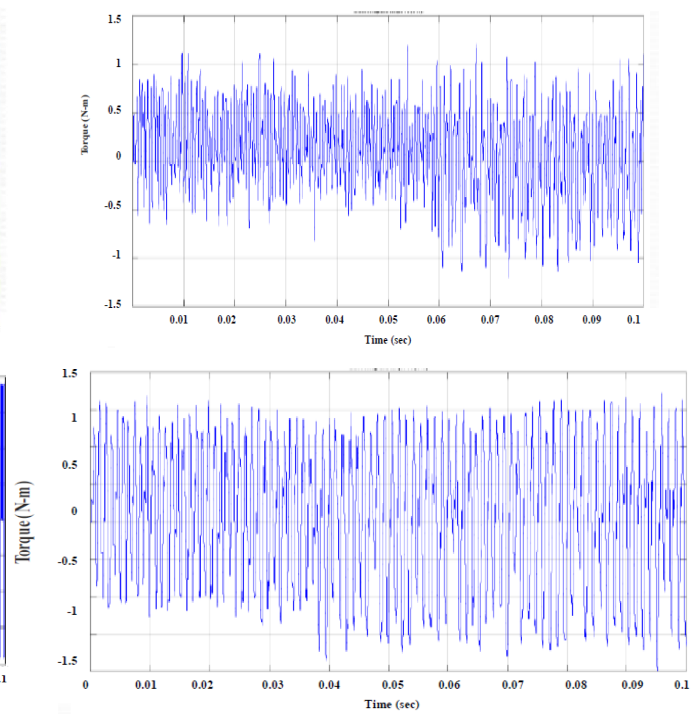
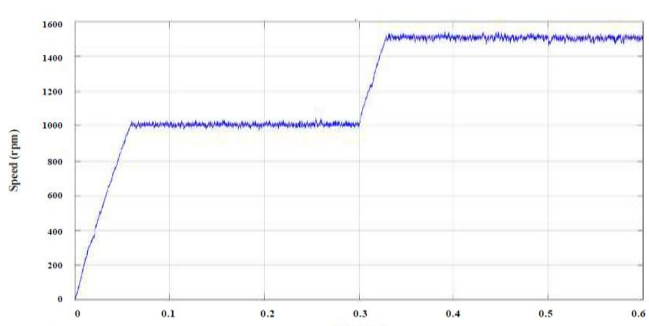
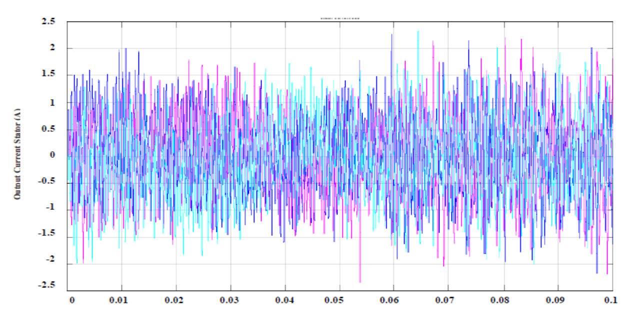


Fig. 5. Output torque response of PMSM drive.





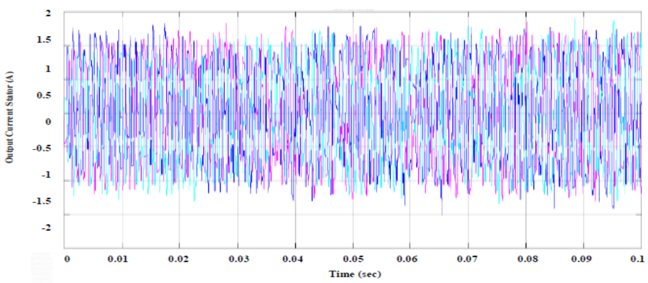


Fig. 6. Output current waveform of PMSM drive.

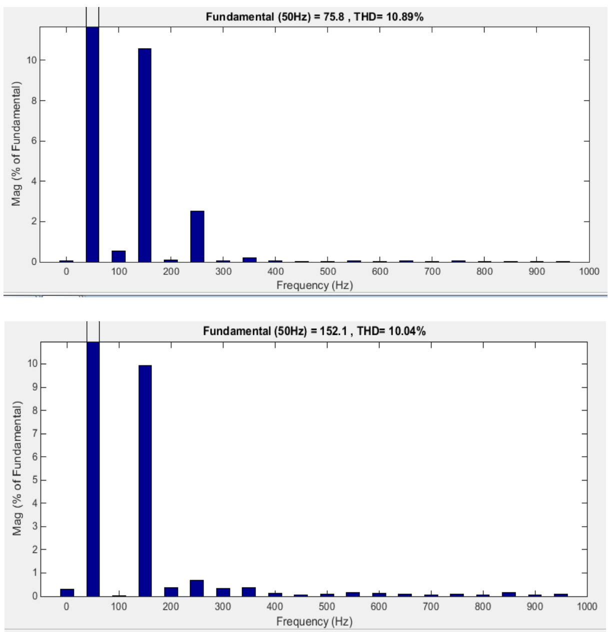


Fig. 7. THD voltage analysis of NPC inverter.

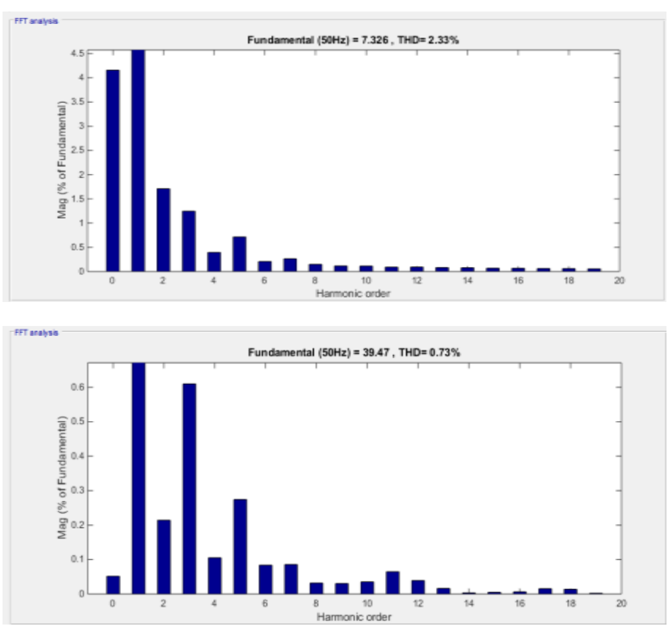


Fig. 8. THD current analysis of NPC inverter.

TABLE I. THD COMPARISON OF VOLTAGE AND CURRENTS USING, SVM AND CBSVM (16)

Voltage and current	THD using SVM	THD using CBSVM
Line Voltage	10.895%	**10.042%**
Line Current	2.339%	**0.736%**

TABLE II. TORQUE RIPPLE ANALYSIS OF NPC INVERTER FED PMSM DRIVE

% Torque Ripples	FOC based SVM	FOC based CBSVM
	10.84 %	**7.38%**

V. CONCLUSION

Modeling and simulation investigations on NPC inverter fed PMSM drive system is presented. Both SVM and CBSVM modulation methods are demonstrated in the present study. CBSVM method provides better steady state response compared to SVM. As seen from its response, the CBSVM is easy and the fastest method. The methods demonstrated the reduction in torque ripple, THD in inverter output with CBSVM and improved driving performance. Due to these characteristics, investigations on NPC inverter fed PMSM drive system is found better suited for EV application.

FUTURE SCOPE

The paper deals with investigations on NPC inverter fed PMSM drive. Many researchers design and implemented two level and three level inverters for the EV application. However there is ample scope to reduced the THD and torque ripples using n level inverters. The current simulation work will be extended to investigations on five levels NPC inverter fed PMSM drive system.

REFERENCES

[1] M. Ehsani, "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles Fundamentals, Theory and Design," CRC Press, 2009.

[2] C. C.Chan,"Modern Electric Vehicle Technology," Oxford University Press, 2001.

[3] M. Ehsani,"Propulsion system design of electric and hybrid vehicles," IEEE Transactions on Industrial Electronics,vol. 33, pp. 19-27, Feb. 1997.

[4] W. P. Jung, "Improvement of control characteristics of interior permanent-magnet synchronous motor for electrical vehicle,". IEEE Transactions on Industry Application, vol. 37, pp.1754-1760, Nov. 2001.

[5] GW Chang, G Espinosa-Perez, E Mendes, R Ortega, "Tuning rules for the PI gains of field-oriented controllers of induction motors," IEEE

Transactions on Industrial Electronics,Vol. 47, No. 3, pp. 592-602, Jun. 2000.

[6] RC Dorf, RH Bishop, Modern Control Systems, Tenth Edition, Prentice Hall, 2005.

[7] J Espina, A Arias, J Balcells, C Ortega. "Speed anti-windup PI strategies review for field oriented control of permanent magnet synchronous machines." Compatibility and Power Electronics, 2009; 279-285.

[8] C Jong-Woo, L Sang-Cheol. "Antiwindup Strategy for PI-Type Speed Controller," IEEE Transactions on Industrial Electronics. 2009; 56(6): 2039-2046.

[9] Z Ibrahim, E Levi. "A comparative analysis of fuzzy logic and PI speed control in high-performance AC drives using experimental approach." IEEE Transactions on Industry Applications. 2002; 38(5): 1210-1218.

[10] S Kuo-Kai, S Hsin-Jang, "Variable structure current control for induction motor drives by space voltage vector PWM." IEEE Transactions on Industrial Electronics. 1995; 42(6): 572-578.

[11] K Satyanarayana, P Surekha, P Vijaya Prasuna."A new FOC approach of induction motor drive using DTC strategy for the minimization of CMV." International Journal of Power Electronics and Drive Systems. 2013; 3(2): 241-250.

[12] 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).

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

[14] 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.

[15] 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.

[16] R.G.Shriwastava,M.B.Daigavane,S.R.Vaishnav, "Simulation analysis of 3-level diode clamped multilevel inverter fed PMSM drive using carrier based space vector Pulse Width Modulation (CB-SVPWM)", 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.

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