Indirect Field Oriented Control Based Five Phase NPC Multilevel Inverter for Reducing Torque Pulsation in PMBLDC Drive

M.Simon Darsingh

[1]*Research Scholar, Department of EEE, Maharishi University of Information Technology, Lucknow, Uttar Pradesh, Email: simonphd123@gmail.com*

Dr. Sanjay S Chaudhary

[2]*Asst Professor, Department of EEE, Maharishi University of Information Technology, Lucknow, Uttar Pradesh.*

Abstract - This paper presents a three level based five phase Neutral Point Clamped (NPC) inverter fed Permanent Magnet Brushless DC drive application. The performances of motor are enhanced depend upon mathematical model. Thus, the parameter variation such as noise, flux variation, common mode voltage and harmonic level of the motor or inverter. The voltage saturation is one of the major problems of a motor due to the more current fluctuations and speed oscillations. This issue can be resolved by using PWM technique based on the reference motor torque and flux. In this paper indirect field oriented control (IFOC) based NPC inverter is used to minimize the torque ripple and also reduce the voltage saturation. Generally, the three level neutral point clamped inverter is used for medium and high level applications. Compared with conventional two level type of inverter, this type of NPC inverters have more advantages. It is used to generate the greater number of levels output waveform in lower harmonic content at the same switching frequency and less voltage stress throughout the semiconductor switches. At last the motor performance and control schemes are analyzed and verified by using Matlab/Simulink software environment.

Keywords: Multilevel Inverter, Five phase BLDC motor Drive, Indirect Field Oriented Control (IFOC), Neutral Point Clamped (NPC) Inverter, PMSM drive, Pulse Width Modulation

1. Introduction

Recently, the most rapid development of power switches, microelectronics and most variable speed drives are now recognized with AC machines. The Permanent Magnet Synchronous Motor (PMSM) with brushless DC (BLDC) motor and sinusoidal shape back-EMF with trapezoidal shape back-EMF drives have been extensively used in more applications, ranging from servo to traction drives due to several decided advantages such as better controllability, high power density, high efficiency and large torque to inertia ratio. In Brushless DC motor (BLDC) fed by two phase conductivity scheme has higher power Vs weight, torque Vs current ratios and also it is less valuable due to the focused windings which contract the end windings compared with the three phase permanent magnet synchronous motor [1]- [6].

Inverter (MLI) topologies have been widely used in the electric motor drive industry to run induction machines for high voltage and high power configurations. In conventional

multilevel topologies consider such as Flying Capacitor (FC) MLI, Neutral Point Clamped (NPC) MLI and Cascaded H-Bridge (CHB) MLI have created to a wide variety of applications. This cascaded type of MLI might be the only kind of multilevel inverter where the energy sources like as capacitors and batteries. It can be completely with isolated the DC sources. The construct of a multilevel inverter is used to achieve the higher power. Also, it is used to a series of power semiconductor switches with various lower voltage dc sources to execute of the power conversion by synthesizing staircase voltage waveforms.

The PMBLDC motor arrives under the family of three Phase Synchronous motors (SM). The PMBLDC motors uses by regular position feedback from the rotor position and devoted to the 3 phase inverter [3]. The 3 phase PMBLDC motor is contributed the supply from 3 phase rectangular current blocks and the corresponding Back EMF is Trapezoidal. The multilevel DC link inverter consists of five voltage cells. This number of cells is referred by n. Because the number of cells values n is increases with the output voltage value touches by fundamental value of AC voltage waveform. If the number of cells reductions such as (n-1) (n-2) (n-3) (n-4) (n-5) then the speed of system configuration is also reduces from the highest point to the lowest point.

However, the multilevel NPC inverters have an unbalance dc link voltage, the device underutilization problems and imbalanced ratings of the clamped diodes and so on, which are not very terrible harms for inverters with three levels or compared to lesser than others. The voltage of capacitor value is imbalance for a five level. It is introduced in which put forward the involve of extra hardware in the form of DC choppers or back to back connection of multilevel rectifier. Presently, the lots of research works are being done in order to reduce the harmonics in the BLDC motor. The torque ripple reduction and harmonics using cascaded H bridge multilevel inverter is talked about for the electric vehicles which requires high power is flowed by cascaded multilevel inverter and the results are measured. A relative analysis study of fuzzy logic based speed control of multilevel inverter fed Brushless DC motor drive is discussed in [3].PMBLDC drives are utilized in a wide range of residential and commercial applications such as heating, domestic appliances, ventilating and air conditioning equipment referable to their possible for highest efficiency. The ability of speed controller using by Hybrid fuzzy controller is capable to allow for the operation at their higher efficiency. The designs of more machine and control schemes have been formulated to improve the performance of BLDC motor drives. The dynamic model of PMBLDC motor drives has to be recognized in order to carry out an effective control in simulation. Mostly, the some simulation models based on the Fourier series, state space equations, d-q axis model and variable trying out have been purposed for the analysis of BLDC motor drives [11-14]. Detailed simulation analyses of the proposed structure with five levels are carried out using indirect field oriented control (IFOC).

2. The Multilevel Inverter (MLI) Configuration

Multilevel inverters are considering the power conversion systems indicted by an array of power semiconductors and voltage capacitive sources, while the properly connected and

controlled. It can be generate a multiple step voltage waveform with variable and controllable frequency, amplitude and phase of the system. Here, the stepped waveform is synthesized by selecting dissimilar voltage levels. Also, it can be generate the variable frequency and voltage amplitude waveform.

The numbers of levels of an inverter is determined as the number of steps that can be returned by the inverter between the output terminal and any reference node. By within the converter is usually represent by N and called as neutral. To be called as multilevel inverter, each phase of the inverter has to generate the at least three different voltage levels. This separates of the classic two level voltage source converters (2L-VSC) carried out from the multilevel family. The most common and well established topologies are consider such as Cascaded H-Bridge (CHB), Diode Clamped or Neutral Point Clamped (NPC) and Capacitor Clamped or Flying capacitor (FLC).

2.1 Five Phase NPC Multilevel Inverter Topology

The diode clamped inverter is also known as the neural point clamped inverter. The basic architecture of this inverter talked about in above survey reference paper. This neural point clamped inverter used to found the staircase output voltage.

Table 1. Switching Format For Five Levels

Terminal Voltage Switching state								
	SA1	SA2	SA3	SA4	SA5	SA6	SA7	SA8
2VDC	ON	ON	ON	ON	OFF	OFF	OFF	OFF
-VDC	OFF	ON	ON	ON	ON	OFF	OFF	OFF
0	OFF	OFF	ON	ON	ON	ON	OFF	OFF
-VDC	OFF	OFF	OFF	ON	ON	ON	ON	OFF
-2VDC	OFF	OFF	OFF	OFF	ON	ON	ON	ON

There are some advantages like consider as the phases share common DC link, which can be reduce the capacitance requirement of the converter. Based on this reason, the configuration of back to back is represent by used for high voltage and variable speed drive applications. The efficiency of the system can be obtained high for fundamental frequency switching. While, it have some weakness like as the Real power flow is unmanageable for a single inverter between the intermediate DC levels will be given to the discharge or overcharge without monitoring and control. The number of clamping diodes are called for qualify related to the number of levels which can be cumbersome for unite with a high number of levels.

2.2 Operating Principle of Three Level NPC Inverter

The three level based five phase inverter topology is proposed for the high power motor drive application and the corresponding circuit configuration is shown in fig.1, which is built by using series connected two dc link voltages. The centre of the two DC link voltages is represent as 'n' which is known as neutral point. Here, the Complementary switch pairs consists of (S1, S1'), (S2, S2') and two clamping diodes (D1, D1') are introduce in each leg which is linked in series. Thus, the one half of voltage source flows through by the two level inverting arrangements.
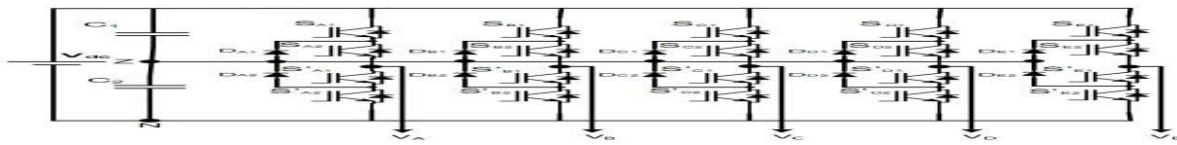
Fig 1. Three Level Based Five Phase NPC Inverter

The above figure mention the NPC inverter can be produce three voltage levels on the output side include such as the DC bus positive voltage, DC bus negative voltage and zero voltage. Only, the two level inverter used connect the output to either the positive bus or the negative bus. The operation of first phase contains the IGBTs S1 and S2 are turned on, while the output is connected to VP. Similarly, the S2 and S1' are switched on, when the output is connected to V0 and also S1' and S2' are turned on, the output voltage is linked to negative side. By obtaining the system efficiency is high in fundamental switching frequency.

2.3 Modulation Techniques for MLI

The multilevel topology requires the various modulation techniques. Each and every technique regards the different modulation methods. These are consists of sub harmonic natural or sinusoidal pulse width modulation, Programmed waveform or selective harmonic eliminated pulse width modulation and stepped waveform based optimized harmonic pulse width modulation. The most effective method of controlling the output voltage is used to integrate by the pulse width modulation control (PWM control) within the inverters. This method contains the fixed DC input voltage is provided to the inverter and a controlled AC output voltage is found by adjusting the on and off time periods of the inverter configuration. The popularized stepped voltage waveform is shown in figure 2.
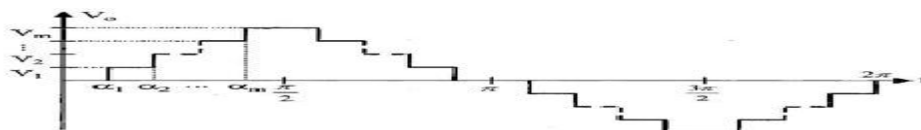

Fig 2. Stepped Voltage waveform

3. Permanent Magnet Brushless DC Motor Modeling

The most of traditional inverter consider as conventional inverter which is fed directly by a single voltage cell or single voltage source. The single phase AC voltage is converted into dc voltage by constructing use of Diode Bridge Rectifier (DBR). This kind of dc voltage is converted into AC by means of the three phase inverter and flowed by the PMBLDC motor drive. The PMDC motors commonly use for the mechanical commutate and brushes to achieve the commutation. However, it is provided with Hall Effect sensors in order to sensation of the rotor position with mechanical commutate and brushes are substituted by the electronic commutation which is considering an inverter. The stator of BLDC motor is constituted of concentrated wound coils and the rotor is made of permanent magnet. In this stator originate the magnetic field used to build the rotor accomplish motion. Here, the Hall Effect sensors used to detect commutates and position through signals to the control circuit. The phasor diagram of five phases PMBLDC Drive is shown in figure 3.

Fig 3. Phasor Diagram for five phase motor

The PMSM model is depicted by using 20-slots 18-poles which is shown in figure 2. The present motor has been planned to obtain a high speed with transient torque and maintain the fault tolerance capability. The concept of physical separation between phases and mutual inductance values are very low. Hence, the number of phases is considered in PMSM, where n denoted and derived from (360˚/n). It procedures of five phase stator windings are displaced with a phase difference of 72˚ degree for all individual. Because, by increasing the number of phases in stator side, when machine has developed by the lower space harmonic content with field. Thus, the efficiency of system is high and in multiphase inverter fed PMSM has equal stator windings and number of each phase. The dynamic model of PM brushless DC motor is expressed by,

$$V_x = R_s i_x + pL_{ls} \tag{1}$$

$$V = R_s i_y + pL_{ls} \tag{2}$$

$$V_0 = R_s i_0 + pL_{ls} \tag{3}$$

$$V_q = R_s i_q + p\lambda_q + \omega\lambda_m + \omega L_d i_q \tag{4}$$

$$V_d = R_s i_d + p\lambda_{qd} - \omega L_q i_d \tag{5}$$

Eventually, the electromagnetic torque equation is deduced as,

$$T_e = \frac{5}{2}\frac{p}{2}\{\lambda_d i_q - \lambda_q i_d\}$$

The dynamic model of five phases PMSM in abcde transformation can be inferred as follows directly in terms of circuit based model.

Stator voltage is expressed as below equation,

$$V_s = R_s I_s + p\lambda_s \tag{6}$$

Air gap flux linkages are showed in equation below,

$$\lambda_s = \lambda_{ss} + \lambda_m \tag{7}$$

$$\lambda_s = L_{ss} i_s + \lambda_m \tag{8}$$

4. Design of Control Strategy

The indirect field oriented is a technique that controls the dynamic speed of PMBLDC motor. Dissimilar from the direct vector control, this indirect vector control contains the unit vectors are returned by an indirect mode of operation. Figure 4 is representing the phasor diagram that explicates the fundamental principle of indirect field oriented control.
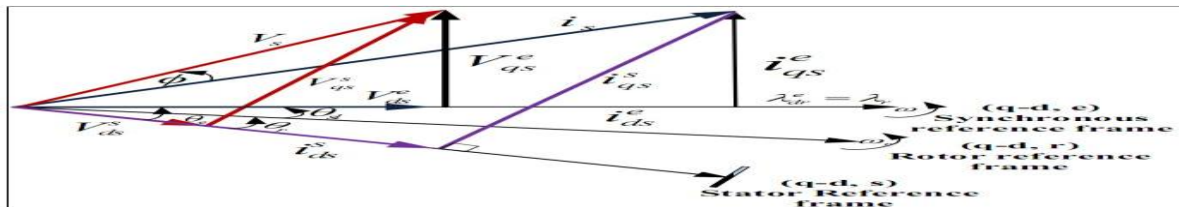
Fig 4. Phasor Diagram of indirect field oriented control

Figure.5 instances the schematic block diagram representation of IFOC control scheme based on NPC multilevel inverter fed five phases PMSM drive is studied and investigated. The most common indirect vector principle is based on the independently control of torque and flux in PMSM motor drive. Here, the actual rotor speed is compared with the reference speed and also with help of speed controller, when is develop by the reference q-axis current I_q^*. This indirect field oriented control method consists the different type of coordinate transformation has create stator current or stator voltage in rotating reference frame at the angular velocity. Here, the d&q axis are responsible for stator current made the torque and flux. These kinds of field and torque currents are orthogonal with two vector dq axis. In D-axis reference current i_d^* may be calculated by using the reference torque. Ultimately, the variable PWM pulses generations are yielded for NPC inverter arrangement.
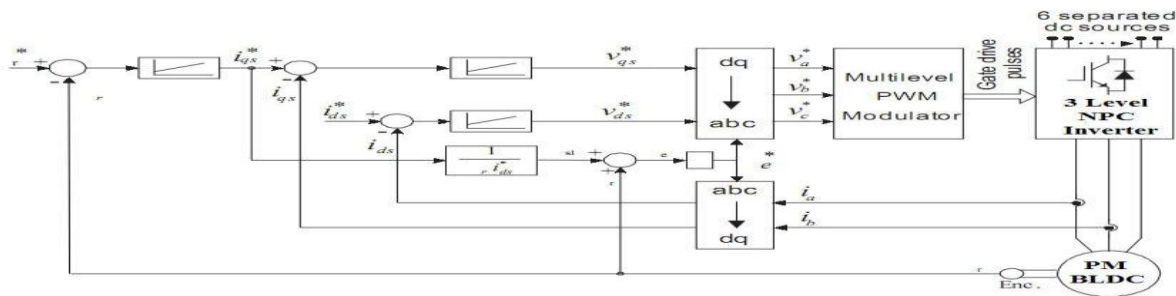
Fig 5. IFOC Based Five phase NPC Multilevel Inverter

D-axis pertain the stator reference current i_{ds}^* is given by;

$$i_{ds}^* = \frac{\Psi_{ref}}{L_m}$$

By using rotor speed ω_r and the slip frequency ω_{sl}, this is given in below equation,

$$1 \quad i_{ds}^*$$

Angle of the rotor flux θ_e is expressed by,

$$\theta_e = \int (\omega_{sl} + \omega_r) dt$$

5. Simulation Result

The performance analysis of the indirect vector control based five phases NPC three level inverter fed PMSM has been verified under MATLAB/SIMULINK environmental. Here, SimPower system is used for design the simulation work. The specifications of motor parameters are listed in table 2. The vector control based IFOC topology is used to carry out the constant speed at transient torque condition. Also, the effective stator side current variant can be found. The overall proposed simulation circuit is shown in figure.6.
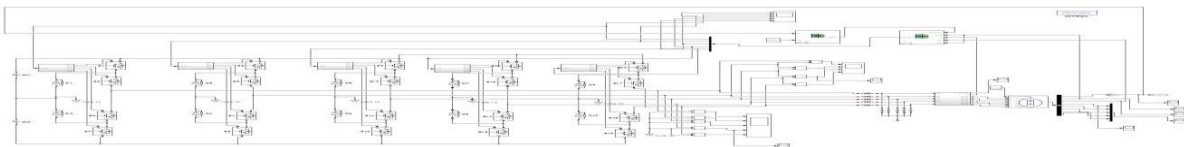

Figure 6. Simulink diagram of proposed overall system configuration

The above diagram represent the three level based NPC inverter directly fed with five phase PMSM for minimization of torque ripple. The starting process with proper load condition, a transient load torque T= 7.6 Nm is attained at 0.2 sec and at the same period of constant speed has been carried out under N= 1400 rpm. These corresponding waveforms are shown in figures 7 and 8.
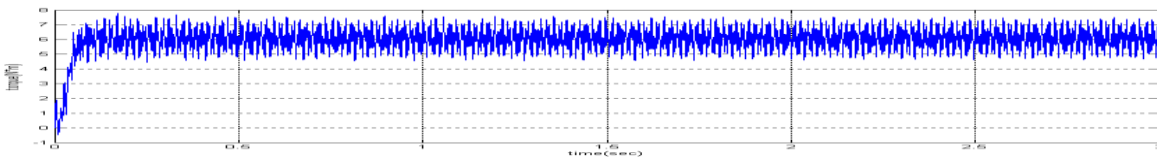

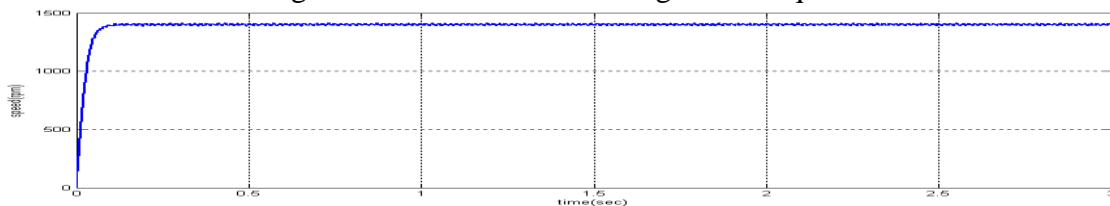
Fig 7. Waveform of Electromagnetic Torque

Fig.8 Waveform of Speed

Therefore, the above analysis results show the indirect vector control scheme can allow for the same performance. It can be also achieved from a separately excited DC machine and done by formulating the stator current phasor. By using the two axes synchronously rotating reference frame, considering the two components include such as the magnetizing current component and torque producing current component. The performance of PMBLDC drive is shown in figure 9.
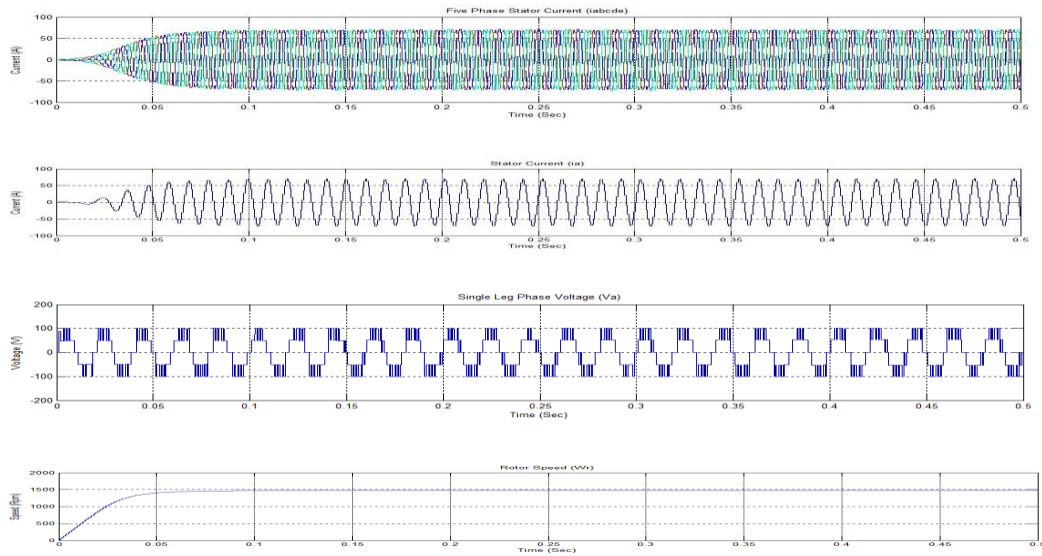
Fig 9. Permanent Magnet Brushless DC motor Performance

The torque of the generated motor is defined as the product of both two. By maintaining the magnetizing current component at rated constant value of the motor torque is linearly proportional to the torque producing component. It is quite like control of separately excited DC motor drives. The three level based phases to ground voltage is shown in figure .10. Similarly, the corresponding line to line voltage is shown in figure 11.
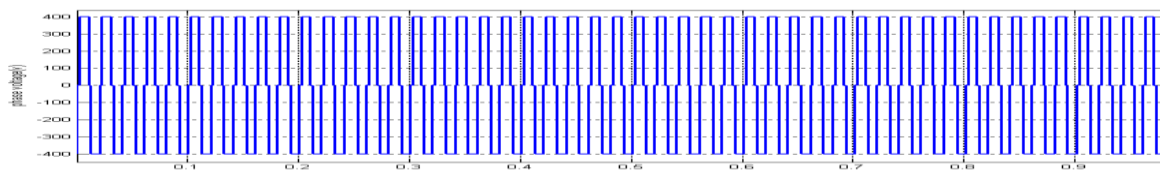

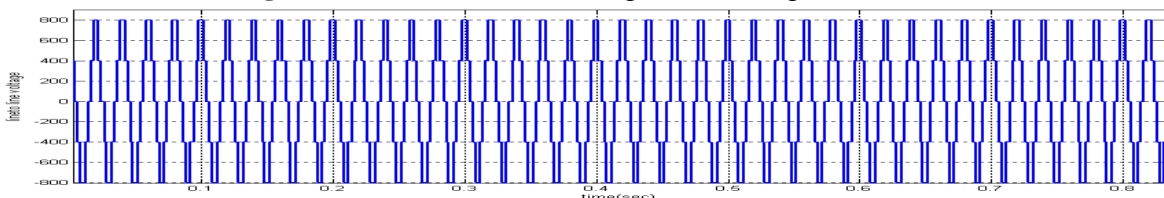**Fig 10.** Three Level Phases to ground voltage waveform

Fig 11. Line to Line Voltage for NPC inverter

Table 2. Parameters Specification for Simulation Circuit

Parameter	Value
d-axis inductance	6.6 mH
q-axis inductance	5.8 mH
Resistance	1.4 Ω
Stator inductance	6.6 mH
Inertia	$0.00176 N.m.S^2/rad$
Rated flux	0.1546 Wb
Pole pairs	3
Friction Factor	0.000388 N.m.s/rad

5. Conclusion

The Three Level Neutral Point Clamped (NPC) five phase inverter based on IFOC controlled by using PMBLDC (Permanent Magnet Brushless DC Motor) drive is implemented. In

general, the stator current is pretended by the harmonic components. Also, it can be affect the torque to develop high torque ripple in PMBLDC at maximum in low speed operation. This NPC based inverter is used to reduced the torque ripples and voltage saturations. The levels are increased and current harmonics has reduced by using IFOC controller based PWM modulation technique. In order to achieve and provide the better dynamic performance under several operating conditions by using three level five phase based NPC. In this paper, the five phases based three levels NPC inverter is implementing used to eliminate the voltage saturation. The torque ripples can be reduced by using PWM technique depends on the reference motor flux and torque. The corresponding simulation results have allowed for the excellent transient torque and constant speed response for the proposed system. This proposed controller IFOC PWM has developed for constant speed and torque response of the PMBLDC motor drive.

Reference

[1]   Soorya, K., & Steffy, S. A. (2014, March). Analysis and simulation of speed control of PMBLDC motor by PI controller. *IEEE International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE),* pp. 1-4.

[2] Parsa, L., & Toliyat, H. A. (2005). Five-phase permanent-magnet motor drives. *IEEE Transactions on Industry Applications, vol. 41, no.*1, pp. 30-37.

[3] Mecrow, B. C., Jack, A. G., Atkinson, D. J., Green, S. R., Atkinson, G. J., King, A., & Green, B. (2004). Design and testing of a four-phase fault-tolerant permanent-magnet machine for an engine fuel pump. *IEEE transactions on Energy conversion, vol.19, no.*4, pp. 671-678.

[4] Levi, E. (2008). Multiphase electric machines for variable-speed applications, *IEEE Transactions on Industrial electronics, vol. 55, no.*5, pp. 1893-1909.

[5] Vakil, G. I., & Rajagopal, K. R. (2010, December). Performance comparison of sinusoidally fed PM BLDC motors having different rotor topologies. *Joint International Conference on IEEE in Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India,* pp. 1-5.

[6] Bianchi, N., & Bolognani, S. (2007). Influence of rotor geometry of an IPM motor on senserless control feasibility. *IEEE Transactions on Industry Applications, vol. 43, no.* 1, pp. 87-96.

[7] Pillay, P., & Krishnan, R. (1989). Modeling, simulation, and analysis of permanent-magnet motor drives. I. The permanent-magnet synchronous motor drive. *IEEE Transactions on Industry Applications, vol.25, no.*2, pp. 265-273.

[8] Porselvi, T., & Muthu, R. (2011, December). Comparison of cascaded H-Bridge,

neutral point clamped and flying capacitor multilevel inverters using multicarrier PWM. *2011 Annual IEEE in India Conference (INDICON),* pp. 1-4.

[9] Prathiba, M. T., & Renuga, D. P. (2010). Multi Carrier PWM Based Multi Level Inverter For High Power Applications. *Int. Journal of Computer Applications*, vol.*1, no.*9, pp. 67-71.

[10] Rodriguez, J., Lai, J. S., & Peng, F. Z. (2002). Multilevel inverters: a survey of topologies, controls, and applications. *IEEE Transactions on Industrial Electronics, vol. 49, no.* 4, pp. 724-738.

[11] Peng, F. Z., Lai, J. S., McKeever, J. W., & Van Coevering, J. (1996). A multilevel voltage-source inverter with separate DC sources for static var generation. *IEEE Transactions on Industry Applications, vol. 32, no.*5, pp. 1130-1138.

[12] Mannan, M. A., Murata, T., Tamura, J., & Tsuchiya, T. (2003, June). Indirect field oriented control for high performance induction motor drives using space vector modulation with consideration of core loss. *IEEE 34th Annual in Power Electronics Specialist Conference, PESC'03.* Vol. 3, pp. 1449-1454.

[13] Singh, G. K., Nam, K., & Lim, S. K. (2005). A simple indirect field-oriented control scheme for multiphase induction machine. *IEEE Transactions on Industrial Electronics, vol. 52, no.*4, pp. 1177-1184.

[14] Abdelsalam, A. K., Masoud, M. I., Hamad, M. S., & Williams, B. W. (2012). Modified indirect vector control technique for current-source induction motor drive. *IEEE Transactions on Industry Applications, vol. 48, no.*6, pp. 2433-2442.

[15] Dwari, S., & Parsa, L. (2011). Fault-tolerant control of five-phase permanent-magnet motors with trapezoidal back EMF. *IEEE Transactions on Industrial Electronics, vol.58, no.* 2, pp. 476-485.

[16] Magzoub, M. A., Saad, N. B., & Ibrahim, R. B. (2013, November). Analysis and modeling of indirect field-oriented control for PWM-driven induction motor drives. *2013 IEEE Conference on Clean Energy and Technology (CEAT),* pp. 488-493.