International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 7, No. 2, June 2016, pp. 531~542
ISSN: 2088-8694 ❒ 531

An Improved DTFC based Five Levels - NPC Inverter Fed Induction Motor for Torque Ripple Minimization

P. Rajasekaran [*], V. Jawahar Senthilkumar [**]
*Department of Electrical and Electronics Engineering, Jawaharlal Nehru Technological University, Hyderabad, Telangana - 500085, India
**Department of Electronics and Communication Engineering, Anna University, Chennai – 600025, India

Article Info

Article history:

Received Sep 30, 2015
Revised Apr 19, 2016
Accepted May 2, 2016

Keyword:

Direct torque and flux control
Field oriented control
Induction motor
Five levels NPC
Space vector modulation
Torque ripple minimization
Voltage source inverter

ABSTRACT

This paper presents a five level Neutral Point Clamped (NPC) inverter fed IM (Induction Motor) drive for variable speed application. In general the stator current is very highly affected by the harmonic components. It can be affecting the torque to produce high torque ripple in IM at maximum to low speed region. Since the drive performances are depends on mathematical model contains the parameters variations, noise, common mode voltage, flux variation and harmonic levels of the machine. Torque ripples and voltage saturations are the most significant problems in drive application. To overcome this problem the DTFC (direct torque and flux control) technique based five-level neutral-point-clamped (NPC-5L) approach is used. The proposed control scheme uses to stator current error as variable. Through the resistance estimated PI controller rules based the selection of voltage space vector modulation technique is optimized and motor performance level has been improved. The torque & speed are successfully controlled with less torque response. The results are compared and verified with conventional three phases VSI under different control technique by Matlab/Simulink.

Corresponding Author:

P Rajasekaran
Department of Electrical and Electronics Engineering,
Jawaharlal Nehru Technological University, Hyderabad,
Telangana - 500085, India.
E-mail: rajasekaranphd123@gmail.com

1. INTRODUCTION

The recent years, induction motors has widely preferred for most industrial low to high speed application due to their reliability, affordable price, the rugged construction and efficiency in comparison with DC motors which suffer from the drawbacks of the brushes-collector, corrosion and necessity of maintenance. However, induction motors are considered as nonlinear, multivariable and highly coupled systems [1, 2]. For this reason, induction motors have been used especially in closed-loop for variable speed application. Even the induction motor is possible for high precision torque and speed control through highly preserved control technique [3].

Generally, the adjustable-speed drive operation should meet following requirement such as highly sinusoidal output waveforms, which has associated with reduced voltage/current harmonic distortions, lower electromagnetic interference (EMI), lower common-mode voltage, lower switching losses and higher efficiencies [5]. Those requirements are not fully satisfied in common VSI, CSI type of inverters. So the multilevel inverters are preferred for high power drive application. Commercially three basic multilevel converters are presented in the literature as diode-clamped converters cascaded H-bridge converters and flying-capacitor converters.

Among the various MLI topologies, the neutral point clamped (NPC) topology is most used one. Even if the conducting power switches and the dc-link capacitors have to endure only one-half of the dc-link voltage. As a result, the converter can be deal with the double voltage and power value compared to standard two-level VSI with the same switching frequency. In general the NPC topology has been constructed by higher number of power switches so thus additional control scheme required. Dc link neutral point clamping is need for maintaining balanced voltage [4-6].

High number of five level NPC inverter fed with high performance IM drives which is requires decoupled torque and flux control. DTFC technique is avoiding the stator current decoupling problem [13]. Additionally DTFC provides very fast torque and speed response without any complex in inner current regulation loop. DTFC–SPWM scheme has enhanced the fundamental output voltages by extend the linear modulation range.

In this paper, stator resistance estimation based DTFC by incorporating SPWM scheme has proposed to uses stator current error as variable through PI controller. Five levels NPC inverter has been equated the DC link voltage into inverting AC voltage. Space vector estimated NPC inverters have been minimized the torque ripples and voltage saturations. The voltage balancing capability is also improved.

2. FIVE LEVEL NPC INVERTER

The five-level neutral-pointed clamped (NPC-5L) topology is shown in figure (1). Each leg of the NPC has constructed by eight active switches (Q1, Q2, Q3, Q4, Q5, Q6, Q7 and Q8) and converter [7-8]. The switching states are given in table 1. An inverter stage connected to an MV induction machine (IM). Generally a standard direct-on-line (DOL) method can be followed for control purpose. Since the value of leakage inductance is xσ, range of 0.18 p.u.

The NPC can be able to minimize the harmonic distortion of the stator current. Further the active switches of the converter are operated at low frequency. The SPWM scheme has overcomes the limitations of the modulation index range of PWM methods. The SPWM controller is suitable to achieve the current harmonics [9-10]. The 5L-NPC inverter derived from 3L-NPC inverter. The Three phase NPC-5L voltage is derived from phase capacitor C_{ph} feed series connected capacitor output voltage.

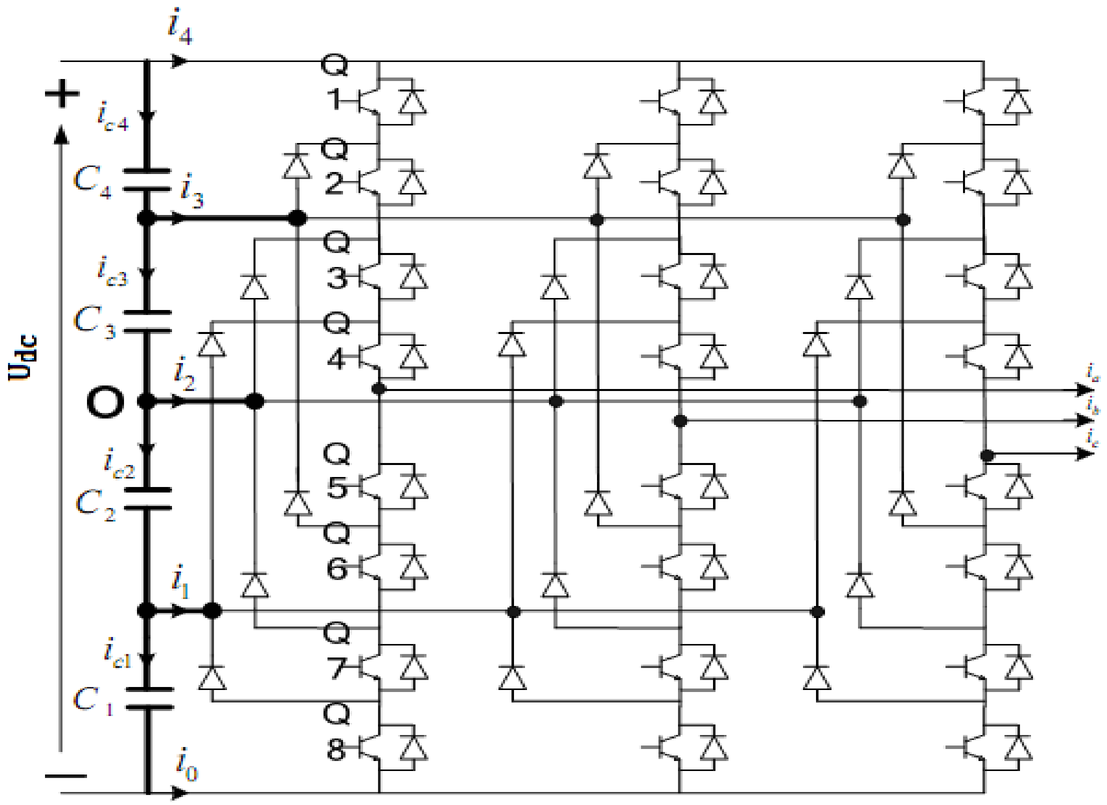

Figure 1. 5L-NPC inverter circuit diagram

Table 1. Switching Table

SWITCHING STATES								OUTPUT VOLTAGE
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	
1	1	1	1	0	0	0	0	Vdc/2
0	1	1	1	1	0	0	0	Vdc/4
0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	-Vdc/4
0	0	0	0	1	1	1	1	-Vdc/2

The desired dc link voltage is Vdc, each capacitor (C1, C2, C3, C4) has been splits voltage (1/4) Vdc. The dc link capacitor currents are flows through the active switches by named as ic1, ic2, ic3 and ic4. This converter ac voltages and currents of the each phase are derived by var, vbr and vcr (ia, ib & ic) connected to the induction drive.

3. MODEL OF INDUCTION MOTOR

The three phase induction motor has constructed by n number of stator windings that are displaced by (360˚/n). It can process at every 120˚. A typical isolated neutral five-leg inverter configuration is used to drive a star-connected five-phase squirrel-cage induction motor. Since the considered squirrel-cage stator and rotor can be represented by a short-circuited three-phase rotor winding in induction motor [11-12]. The state equation of induction motor written by stator reference frame (α, β) coordinates, can be given follows such as stator and rotor laminated model shown in figure 2.

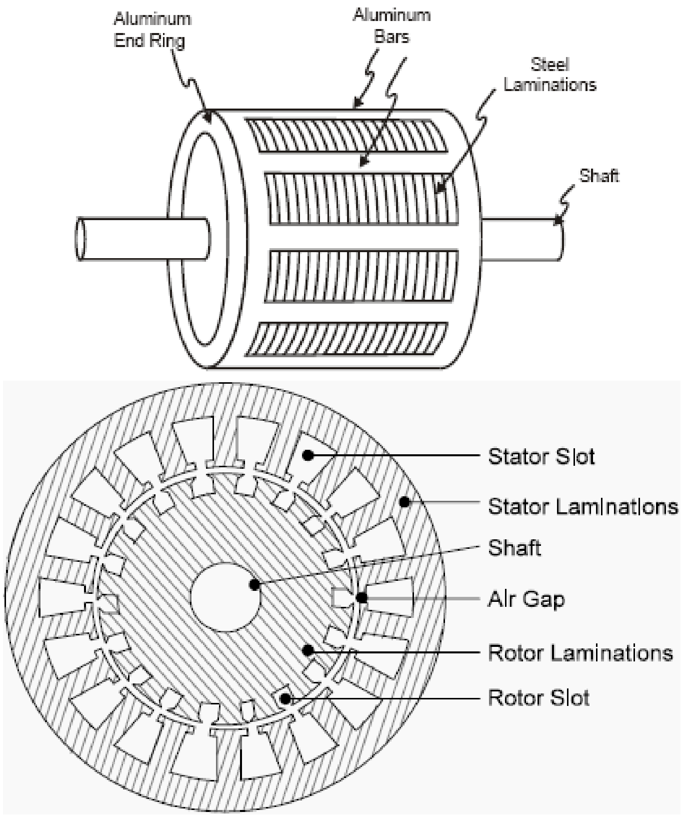

Figure 2. Stator and rotor lamination

$$X = A(\omega).X + B.U \tag{1}$$

$$Y = C.X \tag{2}$$

Where A, B and C are the evolution of the control and observation matrices respectively.

$$X = \left[i_{s\alpha}\, i_{s\beta}\, \phi_{r\beta\alpha}\, \phi_{r\beta} \right]^t ; \; U = \begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} \quad Y = \begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \end{bmatrix} \tag{3}$$

$$A = \begin{bmatrix} -\left(\frac{1}{\sigma T_S} + \frac{1-\sigma}{\sigma T_r} \right) & 0 & \frac{1-\sigma}{\sigma M T_R} & \frac{1-\sigma}{\sigma M}\omega \\ 0 & \left(\frac{1}{\sigma T_S} + \frac{1-\sigma}{\sigma T_r} \right) & \frac{1-\sigma}{\sigma M}\omega & \frac{1-\sigma}{\sigma M T_R}\omega \\ \frac{M}{T_r} & 0 & \frac{1}{T_r} & -\omega \\ 0 & \frac{M}{T_r} & \omega & -\frac{1}{T_r} \end{bmatrix} \tag{4}$$

With, ω Rotor speed and the machine's parameters are Rs, Rr, M, Ls, Lr and p are given by,

$$T_r = \frac{Lr}{Rr}, T_s = \frac{Ls}{Rs} \tag{5}$$

The mechanical equation is derived in equation (7)

$$J.\frac{d}{dt}\Omega = C_e - c_r - f.\Omega \tag{6}$$

J is the inertia coefficient and using the Laplace transform, the equation (8) shows that the relation between the stator flux and the rotor flux represents a low pass with time constant σT_r. The electromagnetic torque can be expressed as,

$$\phi_r = \frac{M}{L_S}\frac{\phi_S}{1+\sigma T_r s} \tag{7}$$

$$C_e = \frac{3}{2}\frac{p}{2}\left(\phi_{sa} i_{s\beta} - \phi_{sa} i_{s\alpha} \right) \tag{8}$$

4. IMPROVED DTFC SCHEME FOR INDUCTION MOTOR

The DTFC method is proposed for induction motor controlling purpose since it can be provide a very accurate and fast decoupled control of the stator flux linkage and the electromagnetic torque without help of any current regulators [14]. The DTFC with stator resistance estimator is shown in figure 3. This strategy of control competitive compare to the rotor flux oriented method [15]. The lookup table can be derived by based on the selected torque error signal in input comparator side.

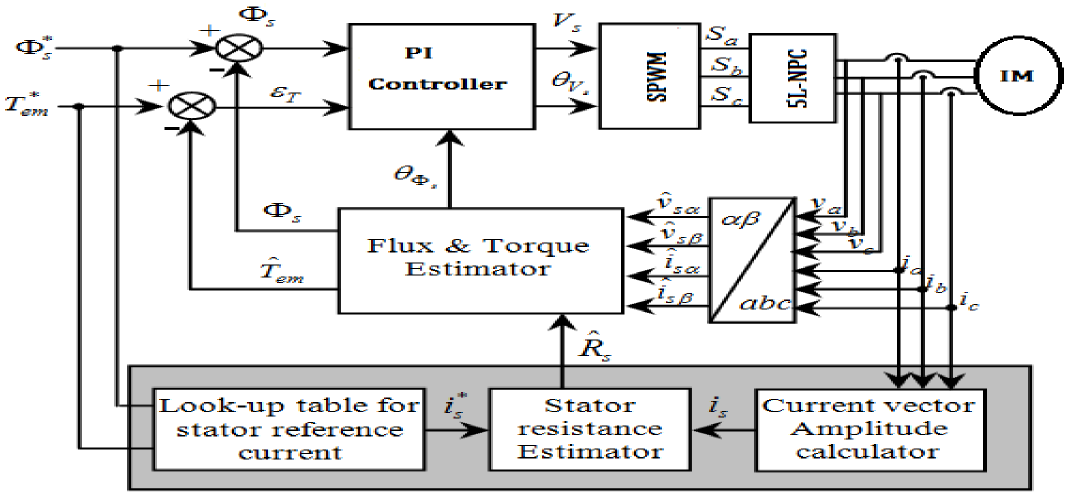

Figure 3. Improved DTFC block diagram with stator resistance estimator

This control technique is fully depends upon the converter active switching operating level. The selection of controlling parts are generally based on the use of hysteresis regulators and SPWM technique, amplitude of the stator flux and electromagnetic torque can be controlled by this modified state of system. The stator flux is derived in equation (1), can be approximately simplified in equation (2) the stator resistance is ignored since it can be derived in short period.

$$\phi_S = \phi_S + \int_0^t (V_S - R_S I_S) dt \tag{9}$$

$$\phi_S \approx \phi_{SO} + \int_0^t (V_S) dt \tag{10}$$

During sampling time Te period the vector tension applied to the machine remains constant, and thus one can be written as,

$$\phi_S(k+1) \approx \phi_S(k) + \int_0^t (V_S . T_e) \tag{11}$$

Therefore to increase the stator flux, we can apply a vector of tension that is co-linear in its direction and vice-versa. Figure 4 shows the stator flux increment and spatial positions of the voltage vectors keeping the flux inside of the strip hysteresis.

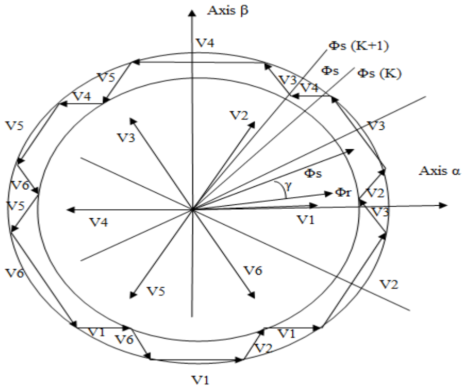

Figure 4. Stator flux increment and spatial positions of the voltage vectors

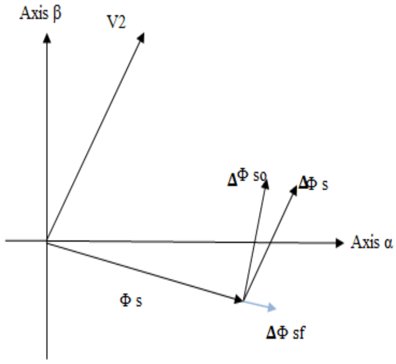

Figure 5. Components of the error of flux at the time of the application of the vector V2 voltage

If the error of flux is estimate on the direction of stator flux and on a perpendicular direction shown in figure 5, one puts in evidence the components acting on the torque and on the flux. The component sf ΔΦ gives the electromagnetic Torque of the Induction motor while the component sf ΔΦ modifies the magnitude of stator flux. The torque is produced by the induction motor can be expressed as equation:

$$Ce = \frac{3}{2} p \frac{M}{\sigma L_S L_r} \overline{\phi_S} \overline{\phi_r} \sin \gamma \tag{12}$$

The torque depends on the amplitude of two vectors such as stator flux Φ_s, rotor flux Φ_r and their relative position γ. If one succeeds in perfectly controlling the flux Φ_s(starting with Vs) in module and in position, one can subsequently control the amplitude and the relative position of Φ_r.

5. PI RESISTANCE ESTIMATORS FOR DTFC DRIVE

Based on the relationship between change of resistance and change of current, a PI resistance estimator can be constructed in equation (10) as shown in Figure.6.

$$\Delta R_S = \Delta i \left(K_P + \frac{K_I}{s} \right) \tag{13}$$

Wherek_P and k_i are the proportional and integral gains of the PI estimator.

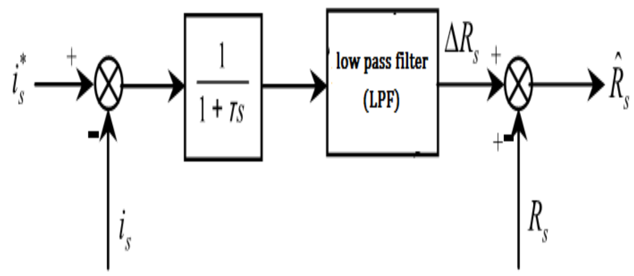

Figure 6. Block diagram of PI resistance estimator

When the stator resistance changes, the compensation process can be depicted as the change of stator resistance will change the amplitude of the current vector [16]. The error of the amplitude of current vector and that of the reference current vector will be used to compensate the change in stator resistance until the error in current becomes zero. Therefore, the steady state error of this resistance estimator is zero and the reference current vector can be derived from the reference torque and reference flux as,

$$i_S^* = \sqrt{\left(i_{s\alpha}^*\right)^2 + \left(i_{s\beta}^*\right)^2} \tag{14}$$

$$i_{s\beta}^* = \frac{2}{3}\frac{2}{p}\frac{C_{eref}}{\left|\phi_{sref}\right|} \tag{15}$$

i_s^* is derived from the following equation, which is equated into zero expressed as,

$$LS\left(i_{sa}^*\right)^2 - \frac{1+\sigma}{\sigma}\left|\phi_{sref}\right| \cdot i_{sa}^* + L_S\left(i_{sa}^*\right)^2 + \frac{\left|\phi_{sref}\right|^2}{\sigma LS} = 0 \tag{16}$$

The filter time constant should be small compared to the stator resistance estimator time constant because to overcome its effect on the stator resistance adaptation. The final estimated stator resistance $\widehat{R_s}$ is again passed through a low pass filter to have a smooth variation of stator resistance value. This updated stator resistance can be used directly in the controller. A PI controller is used to regulate the output voltage to achieve the reputed stator current and also torque. The PI controller limits the transient response of the torque controller. DTFC uses an induction motor model to achieve a desired output torque by using stator resistance estimator.

An induction motor model is used to predict the voltage required to drive the flux and torque to demanded values within a fixed time period. This calculated voltage and current are synthesized using space vector modulation (SVM).

6. RESULT AND ANALYSIS

This section evaluates the performance of the direct torque flux control strategy (DTFC) based NPC five level inverter for induction motor operation. The results are verified and compared with conventional VSI under different control techniques in MATLAB /SIMULINK. Induction motor specifications of proposed topology are listed in table 1. If the level of inverter increased means, current harmonics could be reduced. The conventional VSI based induction motor has been implemented by using field oriented control and Direct Torque control.

The dynamic performance of the IM drive system for various operating conditions has been studied with the uses of DTFC controller. The proposed NPC interfaced IM drive arrangement is shown in fig: 7. three phase NPC inverter stator voltages are illustrated in fig: 8. DTFC based induction motor has achieves superior controlled constant speed, reduced ripple content in stator current and minimized torque ripples.

This is illustrated in fig: 9 & 10 respectively. Fig: 11 and 12 shows the stator current and torque waveform and difference between the signals of torque.

The Different kind of harmonic order of the torque signals are shown in figure 13. The performance of conventional VSI based induction motor under DTC and FOC control techniques are shown in figures 14 & 15. Figure 16 shows the THD in phase current for elimination of harmonics. The Proposed topology Simulation results have shows the smooth and improved performance of the motor compared to Conventional VSI based structure. The total harmonic distortion can be obtained such as 22.91% for FOC control scheme and 78.87% for DTC control scheme. The current harmonic would be reduced as 8.29% by using DTFC based five levels NPC of induction motor.

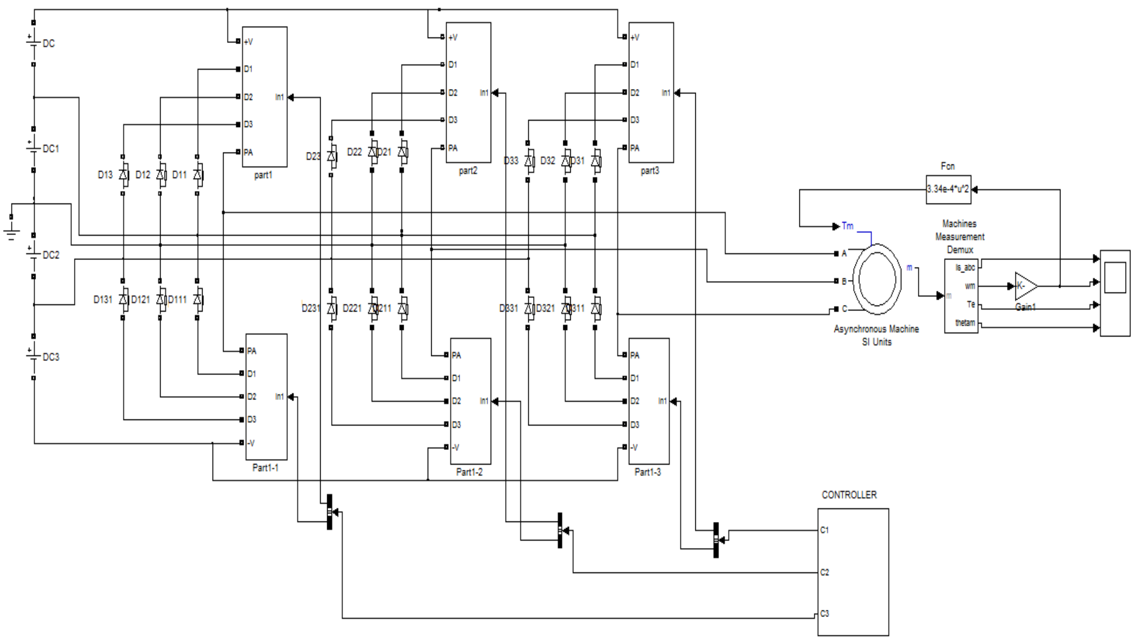

Figure 7. Simulation circuit diagram for NPC-IM

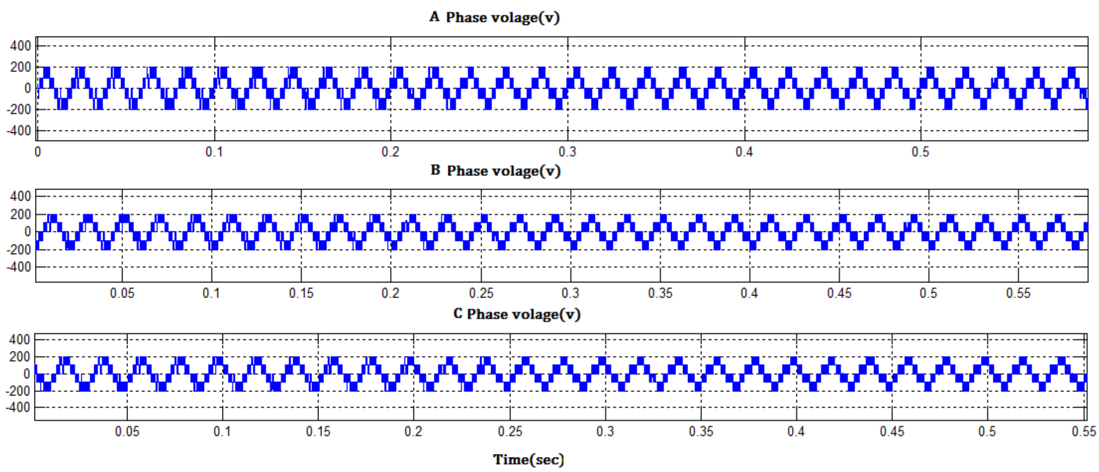

Figure 8. Five Level-NPC inverter voltage

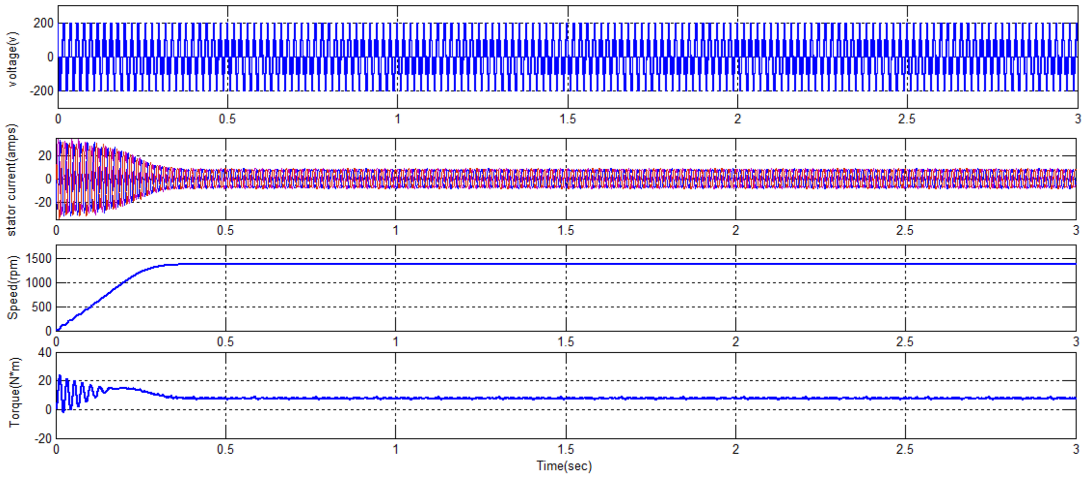

Figure 9. IM drive performance at starting time

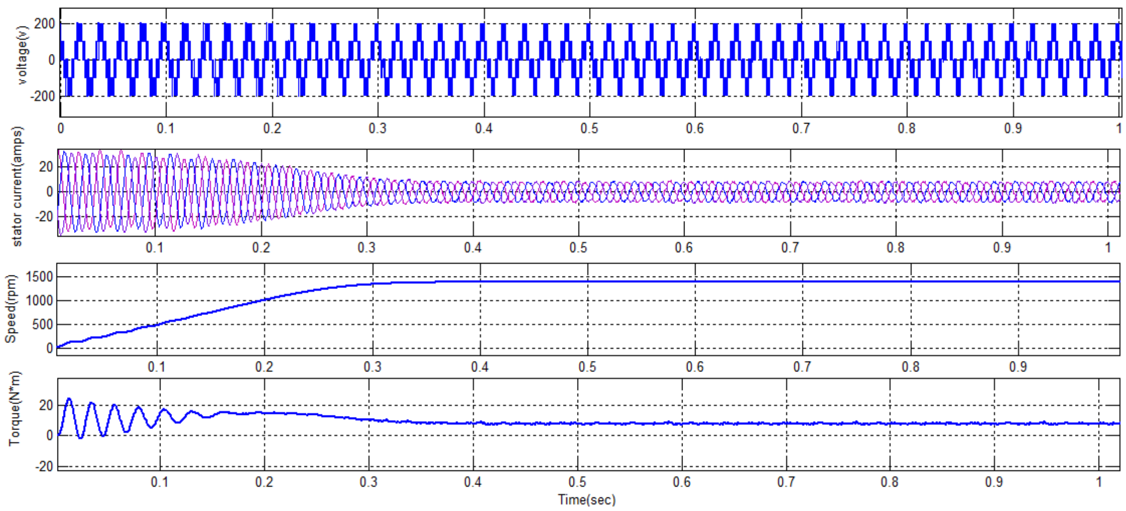

Figure 10. IM drive performance at running time

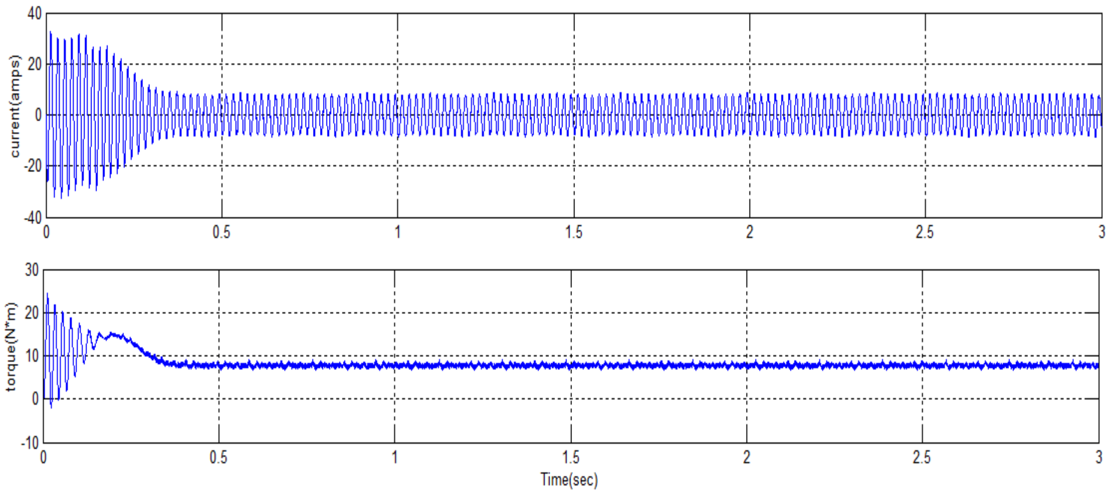

Figure 11. Stator current and torque waveform

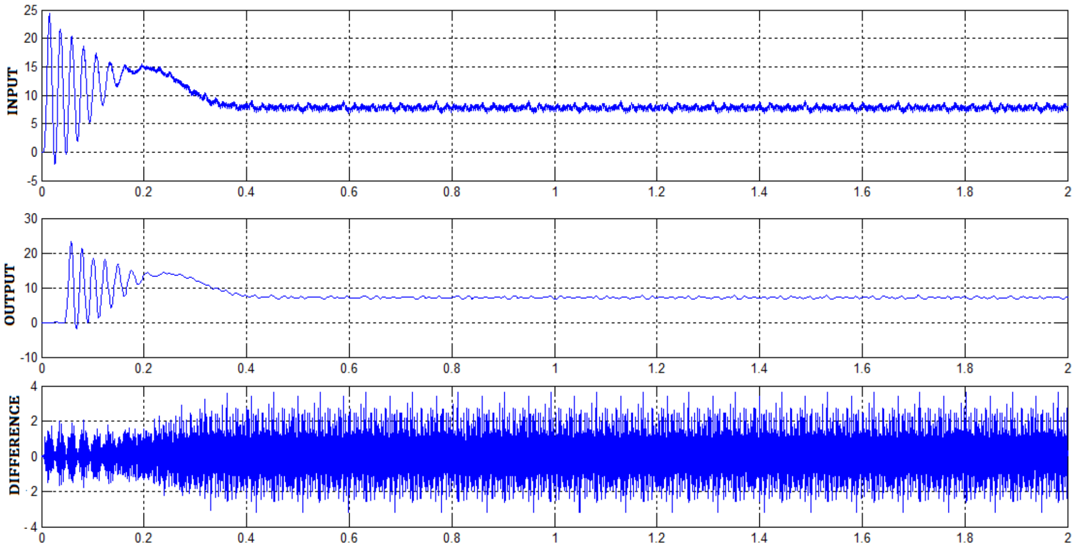

Figure 12. Error Signal of Torque

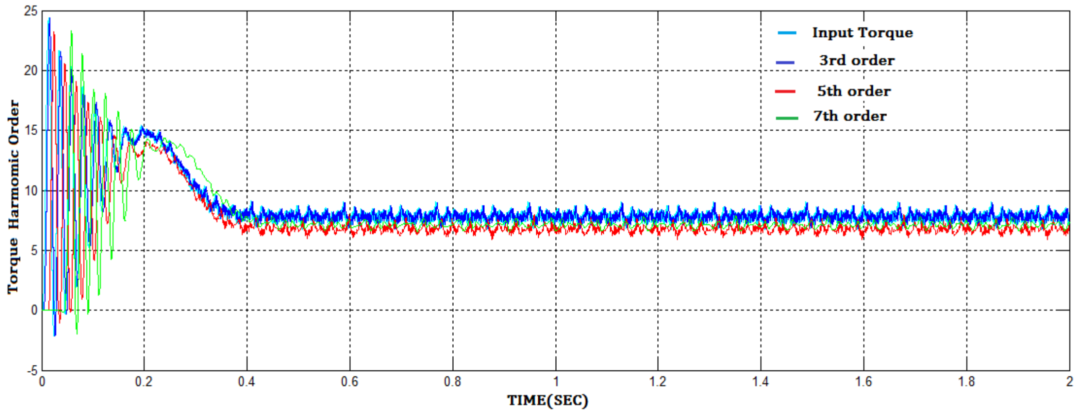

Figure 13. Torque waveforms for different harmonic order

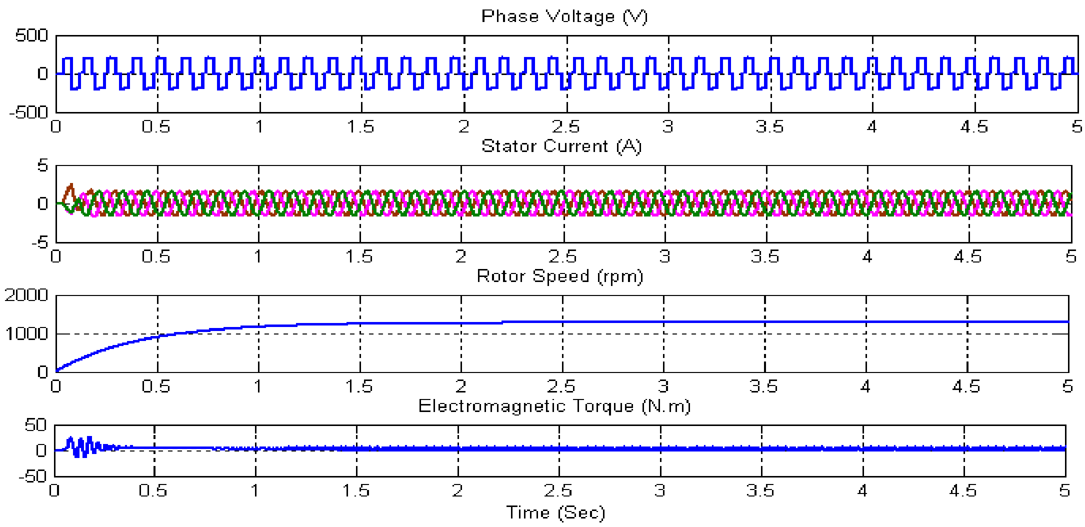

Figure 14. DTC based induction motor performance

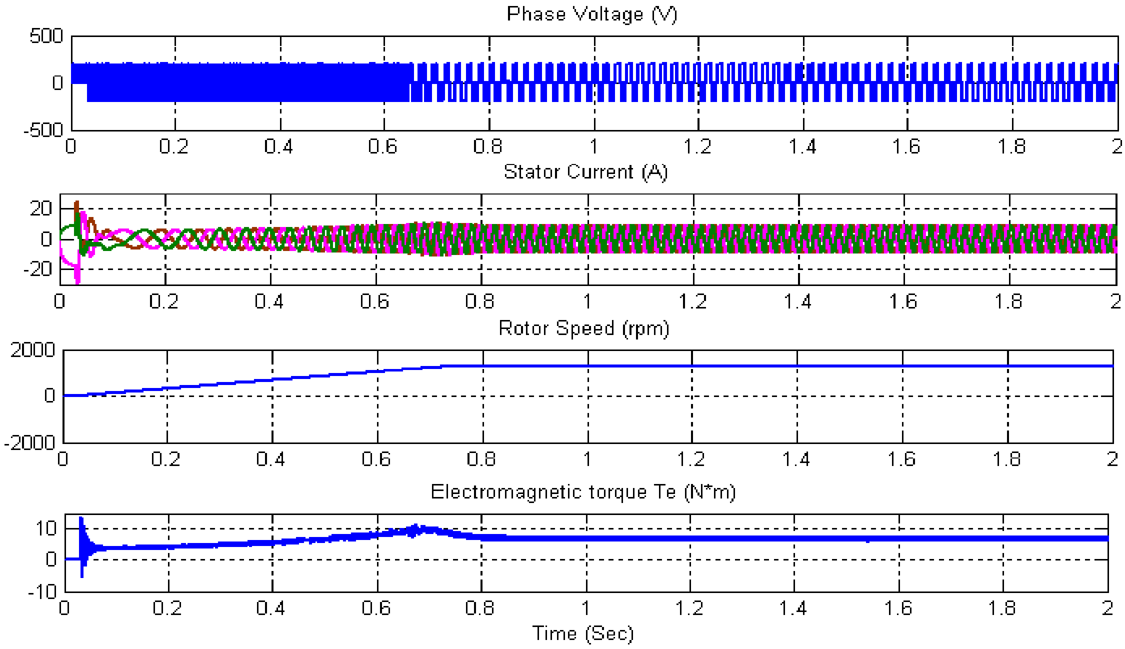

Figure 15. FOC Based induction motor performance

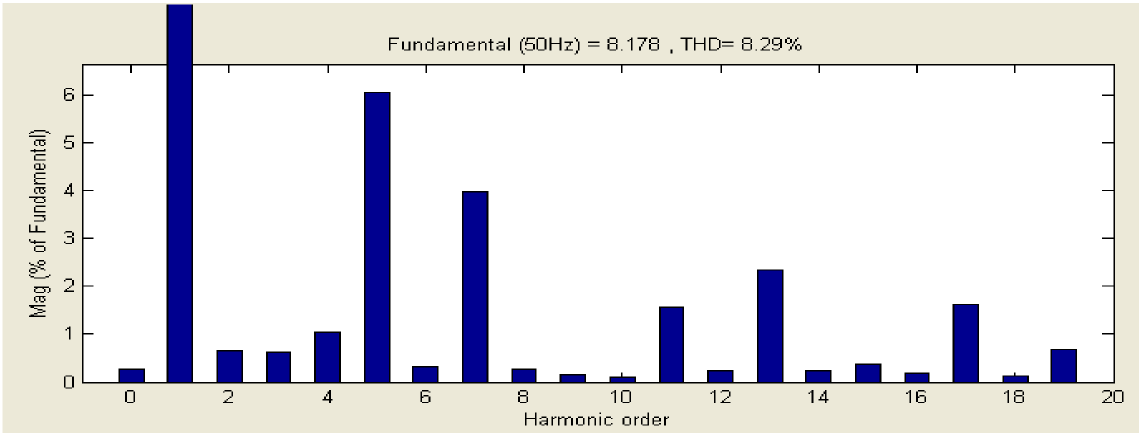

Figure 16. FFT Analysis for proposed topology

Table 2. Simulation Parameter

Name	Values
Rated Power	1kw
Rated Speed	1500 rpm
Rated Voltage	220 V
Stator and Rotor Resistance	6.8 Ω-5.43 Ω
Stator and Rotor Inductance	0.3973 H-0.3558 H
Mutual Inductance	0.3558 H
Number of pole pairs	2
Motor Load-Inertia	0.02 Kg.m2

7. CONCLUSIONS

A five level Neutral Point Clamped (NPC) inverter based DTFC controlled IM (Induction Motor) drive is presented. Generally the stator current is very highly affected by the harmonic components. It can affect torque to produce high torque ripple in IM at maximum to low speed region. The NPC inverter has reduced the torque ripples and voltage saturations. The levels are increased and current harmonics has minimized. DTFC controller based space vector modulation technique has optimised and achieved better dynamic performance under various operating conditions. The conventional VSI based topology has been implemented and the results compared with 5L- NPC based induction motor for torque ripple minimizations. Thus the proposed inverter has achieved better torque and constant speed under simulink environment.

REFERENCES

[1] A. Larabi and M.S. Boucherit, "Vector Control of asynchronous machine Taking into accont discretisation problems of the command as well as the Park reverse Transformation", *Electromotion. Marrakesh*, vol. 10, pp. 489–493, November 2003.
[2] Abbou, A.; Mahmoudi, H., "Real time implementation of a sensor less speed control of induction motor using DTFC strategy", *ICMCS. International Conference on Multimedia Computing and Systems.* April 2009; 2(4); 327-333.
[3] Bennassar, A., A. Abbou, M. Akherraz, and M. Barara. "Sensorless back stepping control using an adaptive Luenberger observer with three levels NPC inverter", *WASET, International Journal of Electrical Science and Engineering.* 2013; 7(8), 1102-1108.
[4] Bose BK, Power electronics and Ac drives, New-Jersey, USA, Prentice Hall, and Englewood Cliffs, 1986; 122-152.
[5] Byeong-Seok Lee; Krishnan, R., "Adaptive stator resistance compensator for high performance direct torque controlled induction motor drives", *Thirty-Third IAS Annual Meeting IEEE on Industry Applications Conference.* Oct. 1998; 12(15); 423-430.
[6] Celanovic, N.; Boroyevich, D., "A comprehensive study of neutral-point voltage balancing problem in three-level neutral-point-clamped voltage source PWM inverters", *IEEE Transactions on Power Electronics.* Mar 2000; 15(2); 242-249.
[7] Colak, Ilhami, Ersan Kabalci, and Gokhan Keven. "Comparison of multi-carrier techniques in seven-level asymmetric cascade multilevel inverter", *Fourth International Conference on Power Engineering, Energy and Electrical Drives (POWERENG).* 2013; 1619-1624.
[8] Franquelo, L.G.; Napoles, J.; Guisado, R.C.P.; Leon, J.I.; Aguirre, M.A., "A Flexible Selective Harmonic Mitigation Technique to Meet Grid Codes in Three-Level PWM Converters", *IEEE Transactions on Industrial Electronics.* Dec. 2007; 54(6); 3022-3029.
[9] Gupta, A.K.; Khambadkone, A.M., "A Simple Space Vector PWM Scheme to Operate a Three-Level NPC Inverter at High Modulation Index Including Over modulation Region, With Neutral Point Balancing," *IEEE Transactions on Industry Applications.* May-June 2007; 43(3); 751-760.
[10] Holtz, J.; Oikonomou, N., "Neutral Point Potential Balancing Algorithm at Low Modulation Index for Three-Level Inverter Medium-Voltage Drive,," *IEEE Transactions on Industry Applications.* May-June 2007; 43(3); 761-768.
[11] Khajehoddin, S.A.; Bakhshai, A.; Jain, P.K., "A Voltage Balancing Method and its Stability Boundary for Five-Level Diode-Clamped Multilevel Converters", *IEEE on Power Electronics Specialists Conference, PESC.* June 2007; 17(21); 2204-2208.
[12] Kyung-Seo Kim, Sung-Hoon Byun "Auto-Measurement of Induction Motor Parameters," *Journal of Electrical Engineering & Technology,* 2006; 1(2); 226-232.
[13] Leonhard W, Control of electrical drives, Berlin, Germany: Springer-Verlag, 1990.
[14] Mini R, Saranya C, Satheesh BH, Dinesh MN. Low Speed Estimation in Sensorless Direct Torque Controlled Induction Motor Drive using Extended Kalman Filter. *International Journal of Power Electronics and Drive Systems (IJPEDS).* 2015; 6(4), pp. 819-830.
[15] Mohsen Hosseinzadeh Soreshjani, Ahmad Ghafari and Reza Heidari," The Application of Classical Direct Torque and Flux Control (DTFC) for Line-Start Permanent Magnet Synchronous and its Comparison with Permanent Magnet Synchronous Motor," *J Electr Eng Technol.* 2014; 9(6); 1954-1959.
[16] Patel, Hasmukh S.; Hoft, R.G., "Generalized Techniques of Harmonic Elimination and Voltage Control in Thyristor Inverters: Part I--Harmonic Elimination", *IEEE Transactions on* Industry *Applications.* May 1973; 9(3); 310-317.
[17] Satyanarayana K, Anjaneyulu B, Prasad KS. Performance Improvement of Multi Level Inverter fed Vector Controlled Induction Motor Drive for Low Speed Operations. *International Journal of Power Electronics and Drive Systems (IJPEDS).* 2014; 4(1): 51-60.
[18] Z. Boulghasoul, A. Elbacha, E. Elwarraki, "intelligent Control for Torque Ripple Minimization in Combined Vector and Direct Controls for High Performance of IM Drive", *Journal of Electrical Engineering & Technology.* 2012; 7(4); 546-557.