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Analysis and Design of Multicarrier PWM Based Multilevel Z-Source Inverter Fed Induction Motor Drives with DTC

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Abstract: This paper presents the simulation as well as prototype model for design and analysis of 5-level neutral point clamped (NPC) inverter fed medium voltage induction motor drive. The development of prototype model shows the flexibility of the multilevel z-source inverter to establish an ideal AC voltage from more than a few levels of DC voltages with lesser harmonic content. The z-source network is placed to unite the input DC source and the inverter to accomplish the buck-boost capability. Three different multi-carrier PWM techniques are analyzed and several fascinating characteristics are revealed. The Direct Torque Control (DTC) is the most well-liked approach to control the performance parameters of induction motor drive is also presented in this paper. The effect of this paper illustrate that, this developed prototype model will bridges the existing research gap between theoretical and practical execution of multilevel z-source inverters for medium voltage industrial applications. Satisfactory and improved performance of multilevel z-source inverters is demonstrated through test results under various operating circumstances and the effort has been made to validate the effectiveness the simulation and hardware implementation of the proposed inverter topology.

Keywords: Multicarrier PWM Technique; Multilevel Inverter; Neutral Point Clamped (NPC) Inverter; Total Harmonic Distortion (THD); Z-Source Inverter; Direct Torque Control (DTC).

1. Introduction

Multilevel z-source inverters are promising as an innovative sort of power converter choice for medium voltage industrial applications. The field of multilevel inverter has been one of the most dynamic spot in research and development of power electronics in the previous decades. Many engineering process enlarged their power level requirements, production of novel power semiconductor devices, converters and control strategies to minimize the cost of production [1]. Presently, the revolution of multilevel inverters has lots of gorgeous features. In particular, lesser switching losses, THD, voltage stress, EMI, output voltage step higher power quality and efficiency [2]. Moreover the multilevel inverter extends its use to renewable energy system like PV cells, wind and fuel cells for high power applications [3]. The NPC inverter has widely acknowledged and investigated for various medium, high Power and high voltage industrial automotive drives.

The proposed z-source inverter defeats the conceptual hurdles and restrictions of the conventional voltage source inverters and current source inverters. An additional X-shaped LC impedance network has the buck-boost capability, which links the isolated dc sources and NPC topology [4] as shown in figure 1. The 'L' denotes the number of levels, the number of capacitors required on the DC bus are (L-1), the number of power semiconductor switches per phase are 2(L-1) and the number of clamping diodes per phase are 2(L-2). These design prescription are almost frequent for any level of NPC inverters. Table1. shows the switching sequences of five level proposed inverter.

Figure 1. 5-Level neutral clamped multilevel z-source inverter.

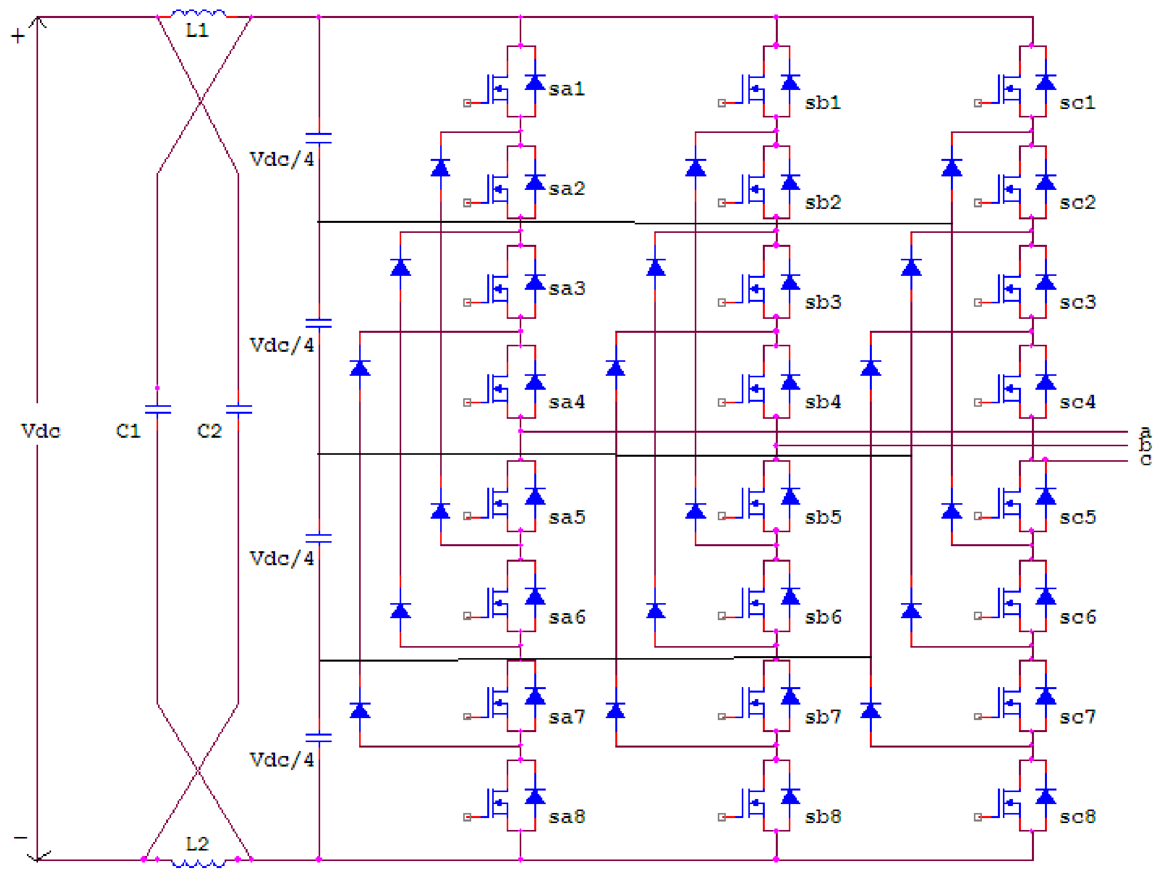


Table 1. Five-level switching sequences.

Switching sequences								Terminal Voltages
Sa1	Sa2	Sa3	Sa4	Sa5	Sa6	Sa7	Sa8	
1	1	1	1	0	0	0	0	2Vdc
0	1	1	1	1	0	0	0	Vdc
0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	-Vdc
0	0	0	0	1	1	1	1	-2Vdc

Now a day's several modulation strategies used for multilevel inverters and are broadly called fundamental frequency switching, space vector PWM (SVPWM) and multicarrier PWM techniques. In this way, multicarrier PWM is the finest strategy to reduce the common mode voltage generated by inverter switches for voltage source type medium voltage variable speed drives [5]. In the past decades, plenty of schemes have been proposed to control the induction motor drives. The conventional control schemes have the problem of torque ripples, flux ripples, uneven switching frequency and acoustic noise.

This paper presents the Direct Torque Control (DTC) techniques to provide more effective response by means of a very low power induction motor control. The proposed DTC can minimize the torque and flux ripples considerably, at the same occasion it maintaining the simplicity and robustness of the conventional control scheme. The DTC scheme has implemented for PMSM and PMBLAC drives and verified total harmonic distortion and torque ripple factor in [6]. Instead of predictable three phase six switch inverter, three phase four switch inverter with DTC technique is used for PMBLAC motor [7]. The DTC is involved for doubly fed induction motor drive with conventional voltage source converter has been discussed in [8], also achieved reduced torque and flux ripples at short steady switching frequency.

The DTC employed for PMSM drives with the use of space vector pulse width modulation have proposed in [9]. Recently multilevel inverters with minimum number switches creates the high impact to the cascaded H-bridge inverters are revealed in [10] to reduce the switching losses. The various control strategies for 5-level SVPWM current rectifier is presented in [11]. This paper presents the five level NPC z-source inverter fed induction motor drive with Direct Torque Control techniques (DTC) to achieve the better performance parameters.

2. Design and Analysis of MCPWM

There are three different Multicarrier PWM (MCPWM) techniques namely phase disposition PWM (PDPWM), phase opposition disposition PWM (PODPWM) and alternate phase opposition disposition PWM (APODPWM) techniques. The proposed modulation techniques give the excellent response compared with conventional single carrier PWM; it desires L-1 carriers are demand for L-level inverter if L be the number of level.

Here carriers are aligned in vertical shifts in uninterrupted bands defined by the levels of the inverter. All L-1 carriers have the identical frequency and amplitude. A distinct voltage reference wave is compared to the carrier arrangement and the generated pulses are tied to each switching device. The different multicarrier PWM technique is enumerated as follows, *2.1. PDPWM*

The PDPWM incorporate L-l carriers, which all in phase consequently. The proposed five level topology take account of four carriers are settle in phase with one another and compared to reference wave. In accordance with that, the gate pulses are activated and so are tied with each switching device.

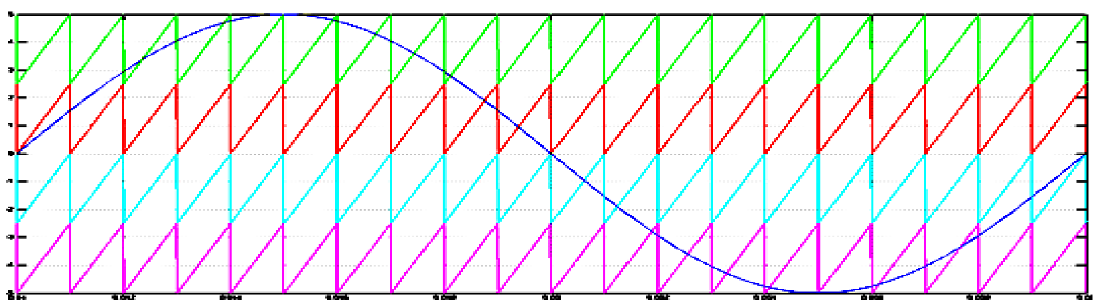
2.2. PODPWM

The PODPWM utilize L-l carriers which might be every carrier in phase above and below the zero position. At this point, all the carrier waves are phase shifted by 180° between the ones above and below zero position.

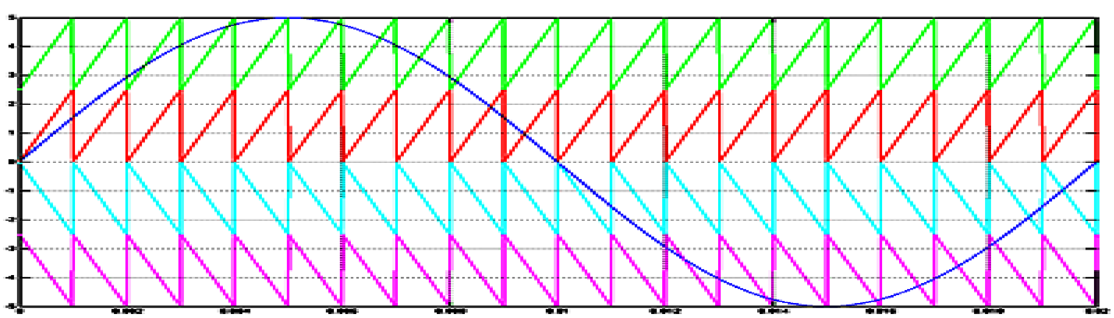
2.3. APODPWM

It requires (L-1) number of carriers which are all phase displaced from each other by 180° alternatively [2-3]. The figure 2. reflects the variety of multicarrier PWM for 5-level inverter. Among such three techniques the PODPWM seems to have the least quantity of harmonics compared over others under all circumstances and therefore PODPWM is the perfect choice for proposed multilevel z-source inverter fed induction motor drives. Figure3. shows comparison chart for all multicarrier PWM approaches, in fact it is evident that PODPWM has got not as much of harmonics hence it is the obvious choice for the proposed system.

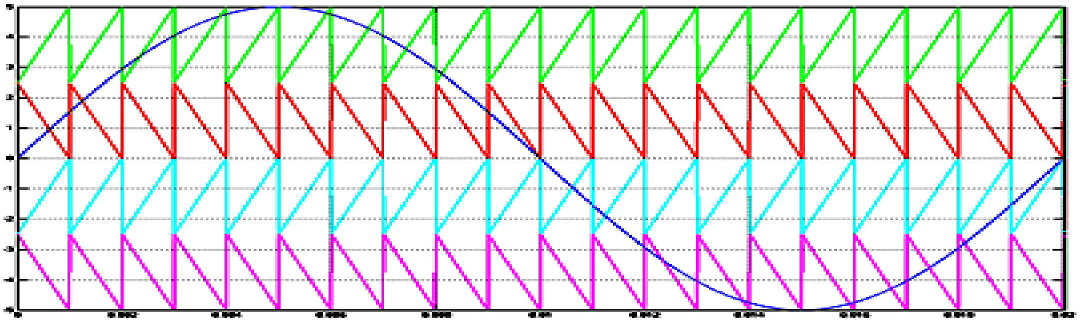
Figure 2. (a) PD (b) POD (c) APOD PWM techniques.



(a)

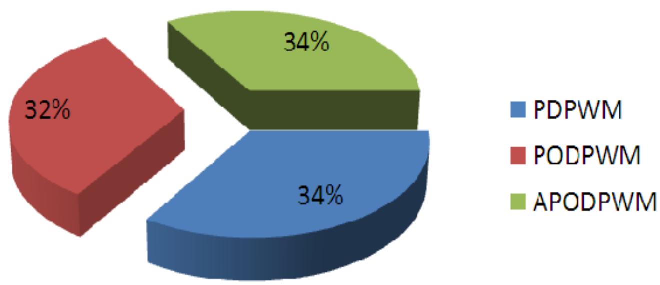


(b)



(c)

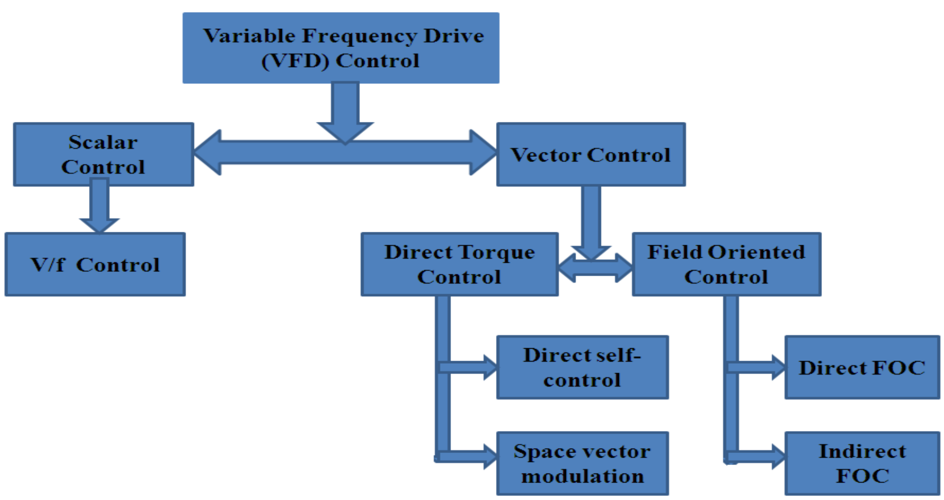
Figure 3. %THDs of different multi-carrier PWM methods.



3. Variable Frequency Drive (VFD) Control

The variable frequency drive (VFD) control method which controls three phase AC electric motor output by means of two controllable VFD inverter output variables such as voltage magnitude and frequency. The figure 4. shows the classification of variable frequency drive. This paper primarily focuses on the vector control methods such as direct torque control and field oriented control strategies. From this the torque and flux can be changed rationally fast, in not as much of 5-10 milliseconds, via altering the references.

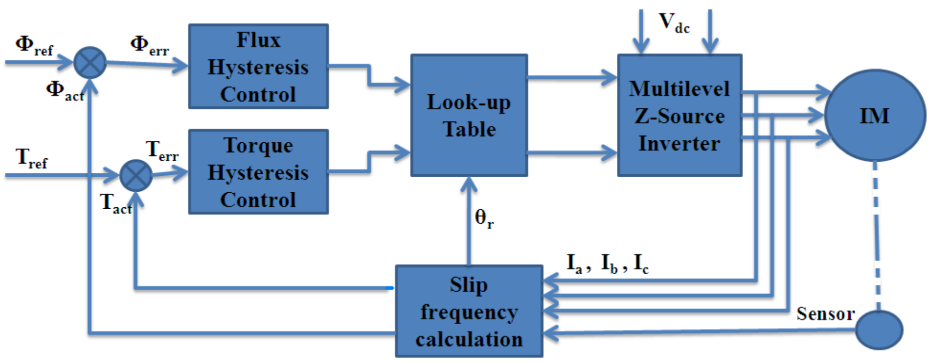
Figure 4. Classification of variable frequency drive.



3.1. Direct torque control

Direct Torque Control (DTC) is the approach utilized for variable frequency drives to control the torque in addition eventually the speed of three-phase induction motors. This necessitates calculating an estimate of the motor's magnetic flux and torque in accordance with the adequate voltage and current of the motor. DTC employs two hysteresis comparators and a heuristic switching table to get hold of quick dynamic response [6-9]. The DTC be supposed to have the knowledge of stator flux, which is often quite simply acquired from the current model by integrating the back electromotive force behind the stator resistance as shown in figure 5.

Figure 5. Direct torque control.



The three phase stator currents are given by,

$$I_{as} = I_s^s \sin\theta_s \quad (1)$$

$$I_{bs} = I_s^s \sin(\theta_s - \frac{2\pi}{3}) \quad (2)$$

$$I_{cs} = I_s^s \sin(\theta_s + \frac{2\pi}{3}) \quad (3)$$

Where,

T_{act} ,T_{ref}, T_{err}- Actual, reference, error valve of torque

I_{as}, I_{bs}, I_{cs}- Stator phase currents

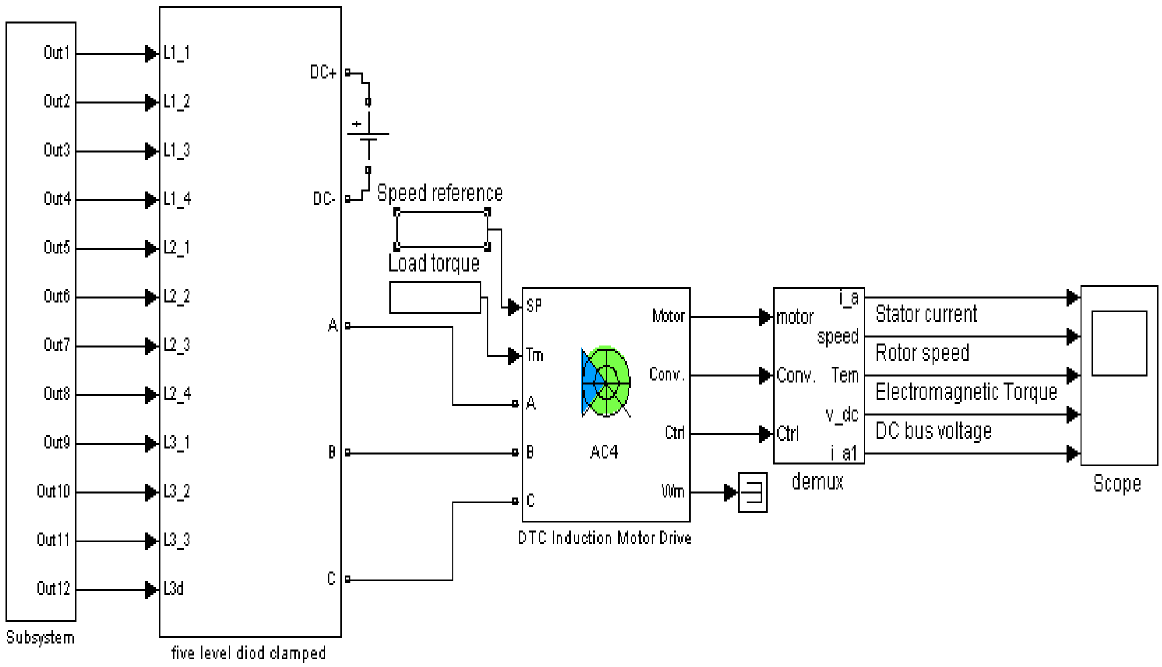
Φ_{act}, Φ_{ref}, Φerr- Actual, reference, error valve of flux and

θr- Rotor Angle.

4. Simulation Results and Discussion

The versatility of the proposed schemes is well established by simulation making use of MATLAB/SIMULINK software as shown in figure 6. and prototype has been built to further verify the operation of the proposed system. A three-phase MOSFET based multilevel inverter model has been built. The inverter accommodates three limbs and each bearing 8 switches, all of which is directed by a voltage signal. MOSFET and internal diode are parallel with a series RC snubber circuit. The moment a gate signal spread over the MOSFET, it conducts and plays the role of a resistance on either side. As gate signal dips to zero when the current is negative, the current is relocated to anti parallel diodes. The amplitudes of DC voltage sources are believed 100V.

Figure 6. Simulink model for proposed system.



It is assumed that the inverter is adjusted to yield a 50Hz, 5-level staircase waveform. An induction motor of 3 HP has been used. The stator and rotor resistances are 0.435 Ω and 0.819 Ω respectively. Figure 7.exhibits to the three phase current of DTC and Figure 8.denotes the speed, torque and DC bus voltage of DTC scheme. Figure 9. shows the stator voltage of DTC scheme. Figure 10. and Figure 11.are the THD value of V_{ab} and filtered V_{ab} for DTC scheme. Through this comparison and review, it has been proven that the DTC seems to have sensibly enhanced outcome under all aspects. The DTC possesses enhanced voltage sticking with the same level of THD.

Figure 7. Phase current of DTC.

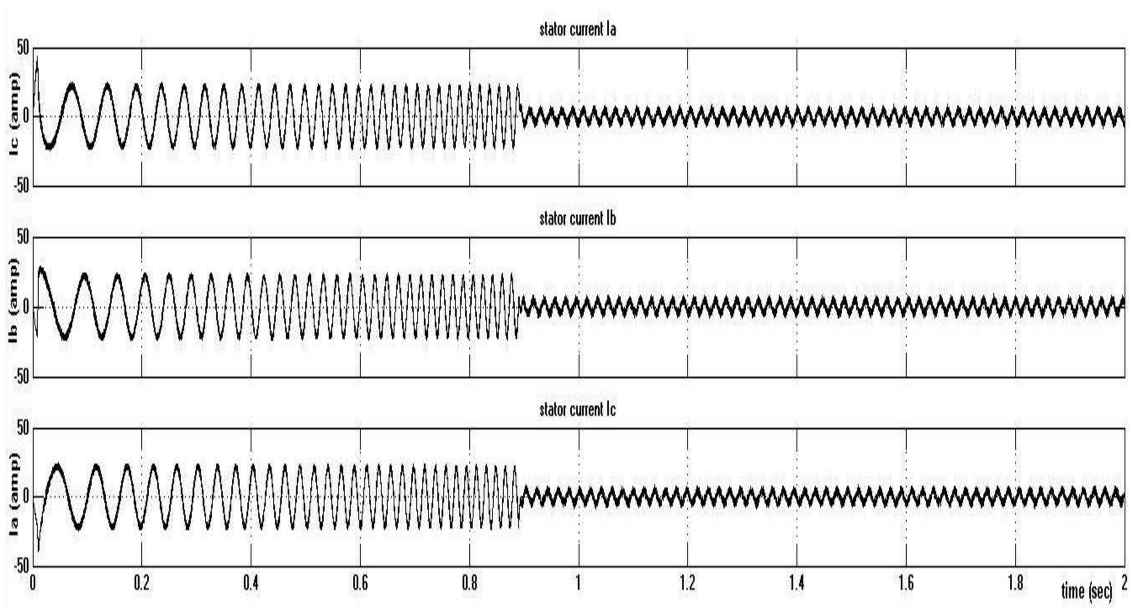


Figure 8. Parameters of DTC induction motor drive.

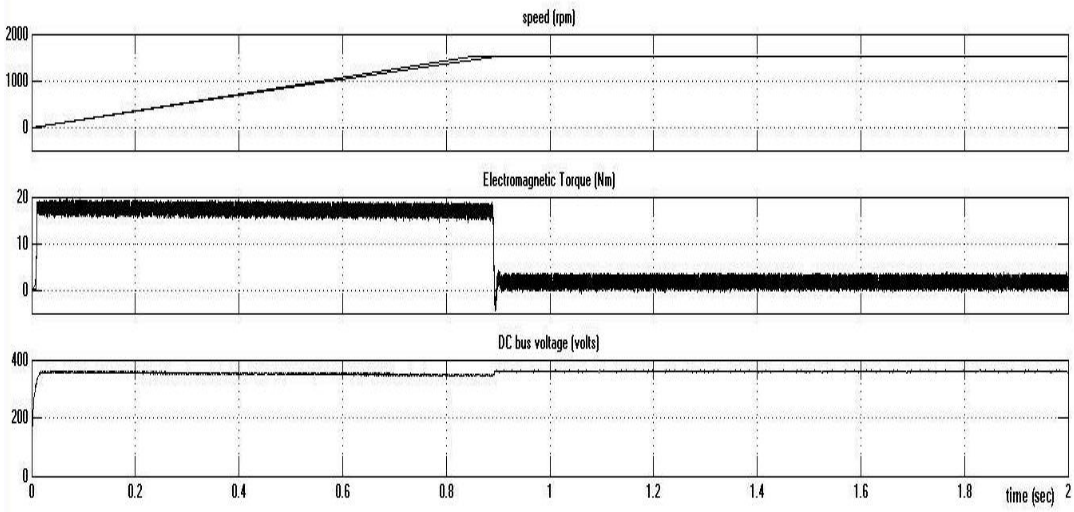


Figure 9. Stator voltage of DTC scheme.

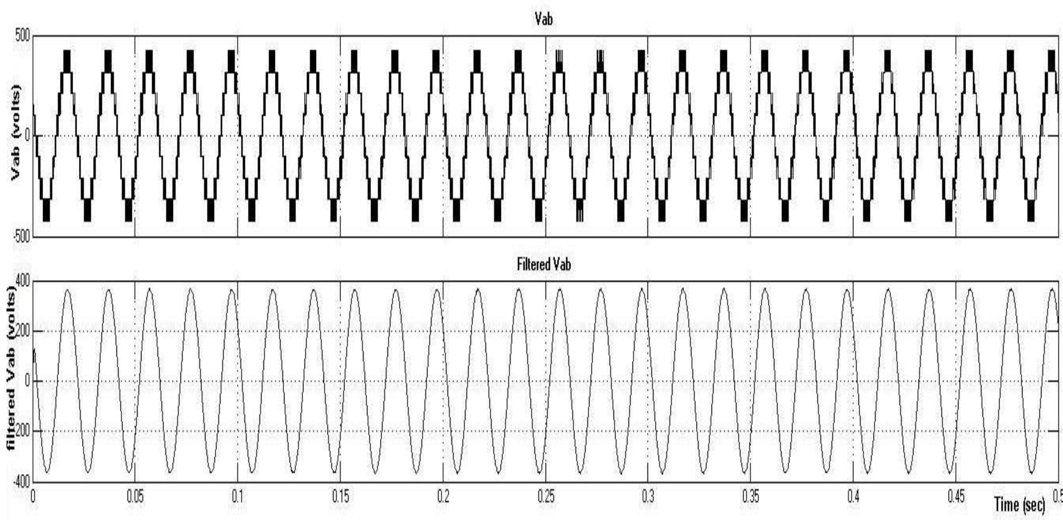


Figure 10. THD value for V_{ab} of DTC scheme.

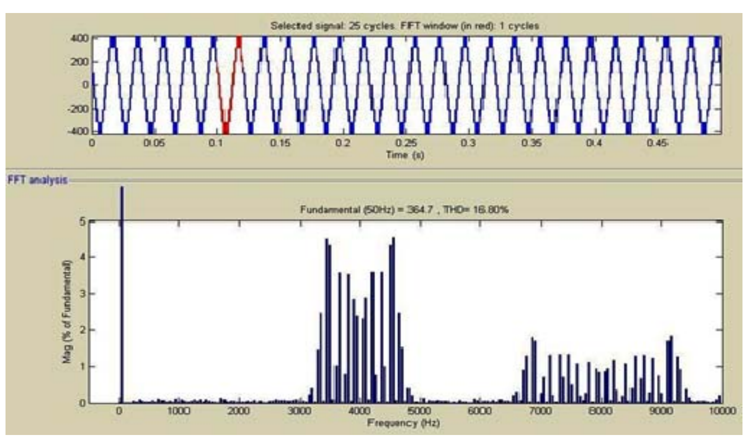
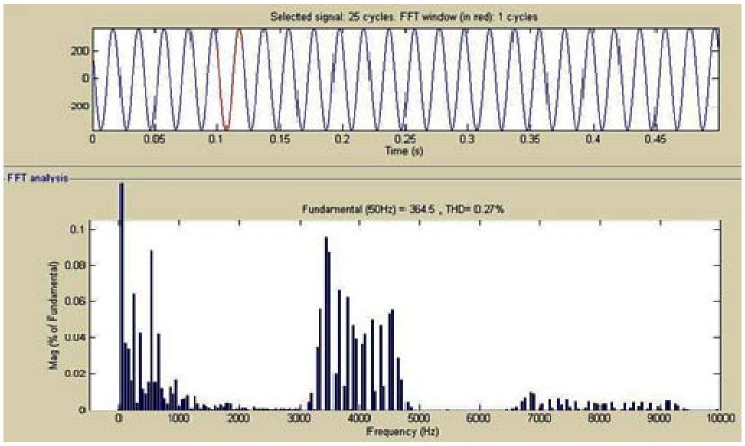


Figure 11. THD value for filtered V_{ab} of DTC scheme.



5. Experimental Section

Figure 12.shows the development of prototype model for the proposed five level z-source Inverter fed induction motor drive. Figure 13.is illustrated the experimental line voltage waveforms.

Figure 12. Experimental setup of multilevel z-source inverter fed induction motor drive.

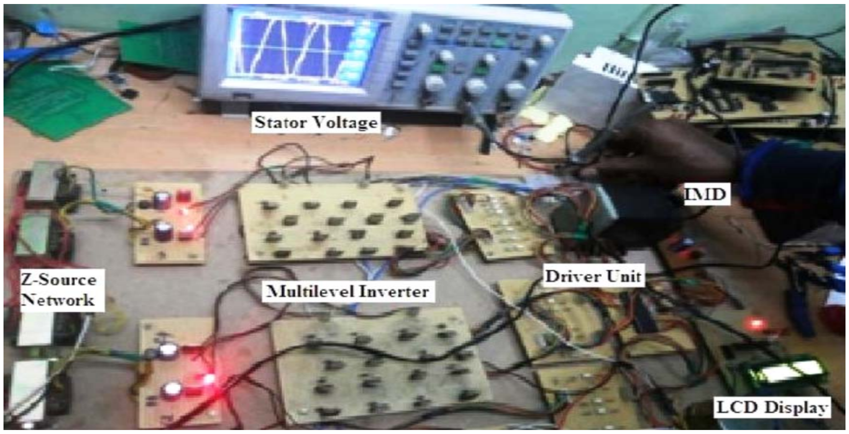
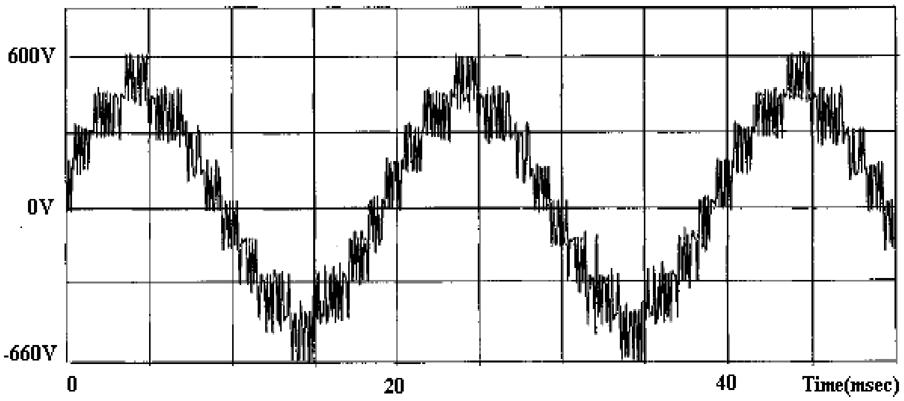


Figure 13. Experimental line voltage waveforms.



6. Conclusions

This paper presents an approach to evaluate the comparative performance analysis of 5-level neutral point clamped z-source inverter fed induction motor drives by simulation as well as building a development of prototype model. The constraint of prototype model is constructed to make flexibility and adaptability to the practical environment. Various performance parameters of induction motor like phase currents, stator voltage, speed, torque and DC bus voltage has been investigated using DTC strategy by simulation and prototype model.

The PD, POD, APOD PWM approaches are reviewed for the proposed inverter and acknowledged that POD PWM gives lot better test results over others. From the above results DTC could tremendously reduce current, torque and flux ripples. The DTC only needs the information of torque and flux errors, while excellent steady performance is achieved and also dynamic response can be elevated. Moreover, switching losses are minimized simply because the transistors are switched only when it is needed to keep torque and flux within their hysteresis bands.

The experimental results show that, developed prototype model is effective for induction motor drive and proved that, design is accurate, good performance for reduction in THD. Thus the developed prototype model bridges the existing research gap between theoretical and practical execution of multilevel z-source inverters for medium voltage industrial applications.

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Conflicts of Interest

The authors declare no conflict of interest.

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