Transient Analysis of Z-Source Inverter Fed Three-Phase Induction Motor Drive by Using PWM Technique

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Abstract- This paper presents Z-Source inverters which have recently been proposed as an alternative power conversion concept for adjustable speed AC drives (ASD). It has both voltages buck and boost capabilities as they allow inverters to be operated in the shoot through state. It utilizes an exclusive Z-Source network (LC component) to dc-link the main inverter circuit to the power source (rectifier). By controlling the shoot-through duty cycle, the inverter system using IGBTs, reduces the line harmonics, improves power factor, increases reliability and extends output range. When this proposed strategy considers like the inverter as a single unit, it greatly reduces the complexity and cost when compared with traditional systems. It has reduced harmonics, low switching stress power and low common mode noise.

Keywords: Induction Motors (IM), Input Filter, Pulse Width Modulation (PWM), Shoot- through state, Z-source inverters.

I. INTRODUCTION

In this paper, a functional model of Z-source inverter and PWM modulated Z-source inverter (PWM VSI) using switching function based on PWM approach concept is studied and the Simulation of the developed model is proposed with the help of MATLAB/Simulink.

The Traditional Inverters are voltage source inverter (VSI) and current source inverter (CSI) which consists of a diode rectifier front end, dc link and Inverter Bridge. In order to improve power factor, either an ac inductor or dc inductor is normally used. The dc link voltage is roughly equal to 1.38 times the line voltage. The voltage source inverter is a buck converter that produces only an ac voltage, which is limited by the dc link voltage. Because of this nature, the voltage source inverter and current source inverter are characterized by relatively low efficiency because of switching losses and considerable EMI generation. Inverter presents negligible switching losses and EMI generation at the line frequency. The voltage source inverter requires an output RLC filter to provide sinusoidal voltage compared with current source inverter. The RLC output filters causes additional power loss and control complexity. The voltage source converter is widely used.

The switching function concept is a powerful tool in understanding and optimizing the performance of the static power converter/inverters. With the developed functional model, the simplification of the static power circuits can be achieved so that the convergence and long run-time problems.

II. Z-SOURCE ASD SYSTEM

Z-Source inverter based induction motor drives provides a low cost and highly efficient two stage structure for reliable operation. It consists of voltage source for the supply of rectifier section, impedance network, which consist of two equal inductors and two equal capacitors, three phase inverter and three phase induction motor. The rectification of ac voltage is done by rectifier section to obtain dc voltage for further supply. The rectifier output dc voltage is now fed to the impedance network. The network inductors are connected in series arms and capacitors are connected in diagonal arms as shown in fig.1. Depending upon the boosting factor capability of impedance network the rectified dc voltage is buck or boost upto the voltage level of the inverter section (not exceed to the dc bus voltage) [7]. This network also act as a second order filter and it should required less inductance and less capacitance.

This paper addressed an efficient PWM based z-source inverter approach for the control of adjustable speed drive polyphase Induction motor. The Z-source inverter advantageously utilizes the shoot through states to boost the dc bus voltage by gating on both the upper and lower switches of the same phase leg [6]. Shoot through mode allows simultaneous conduction of devices in same phase leg. Therefore, On behalf of boost factor of dc-link, a Z-Source inverter can boost or buck to the voltage to a desired output voltage that is greater / lesser than the dc bus voltage[7][12].

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The voltage buck and boost capability cannot be achieved by the conventional converters, but it is easily achieved by the proposed model. As shown in fig. (1), the inverter main circuit consists of six switches. These inverters use a unique impedance network (LC), coupled between the rectifier and inverter circuit, to provide both voltage buck and voltage boost properties [17]. The unique feature of the Z-Source inverter is that the output ac voltage can be any value between zero and infinity regardless of dc voltage. However, three phase Z-Source Inverter Bridge has one extra zero state when the load terminals are shorted through both the upper and lower devices of any one phase leg, any two phase legs, or all three phase legs. This shoot-through zero State is forbidden in the traditional voltage source inverter, because it would cause a shoot-through. The Z-Source network makes the shoot-through zero state efficiently utilized throughout the operation. The Z-Source inverter Adjustable Speed Drive (ASD) system has many ASD applications such as:

- Steel mills machines, Paper machines (winder, tension reels, mill stands)
- Cement mills, rubber mills, mixers, crushers
- Conveyors
- Cranes and elevators cars
- Variable Torque applications:
- Centrifugal pumps
- Centrifugal fans

B. Current Source Converter: Barriers and Limitations

- The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage produced is always smaller than the ac input voltage. Therefore, the current source inverter is a boost inverter for dc-to-ac power conversion and the current source converter is a buck rectifier for ac-to-dc power conversion. For applications where a wide voltage range is desirable, an additional dc-dc buck converter is needed.
- At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the dc inductor would occur and destroy the devices. Overlap time for safe current commutation is needed in the current source converter, which also causes waveform distortion, etc. In addition, both the voltage source converter and the current source converter have the following common problems.
They are either a boost or a buck converter and cannot be a buck-boost converter. That is, the output voltage range is limited to either greater or smaller than the input voltage.

III. MATHEMATICAL ANALYSIS OF IMPEDANCE NETWORK

The impacts of the phase leg shoot through on the inverter performance can be analyzed using the equivalent circuit shown in Fig. 4 and Fig. 5. Assume the inductors (L1 and L2) and capacitors (C1 and C2) have the same inductance and capacitance values respectively; the Z-source network becomes symmetrical.

The following equations can be written.

\[ V_{i} = V_{dc} - V_{e} \]
\[ V_{i} = V_{dc} \]
\[ V_{i} = V_{e} - V_{dc} \]

Alternatively, when in non shoot through active or null state current flows from Z-Source network through the inverter topology to connect ac load during time interval T1. The inverter side of the Z-source network can now be represented by an equivalent circuit as shown in Fig. 5.

The output voltage can be stepped up and down by choosing an appropriate buck-boost factor \( B_{B} = B.M \) (it varies from 0 to \( \alpha \)).

IV. MODULATION METHOD

Averaging the voltage across a Z-source inductor over a switching period \( (0 \text{ to } T) \),

\[ V_{i} = \frac{T_{1}}{(T_{1} - T_{0})} V_{dc} \]  

Using equations (1) and (2)

The peak DC-link voltage across the inverter bridge is

\[ V_{i} = 2V_{C} - V_{dc} = \frac{1}{1 - \frac{2T_{0}}{T}} V_{dc} \]  

where,

\[ B = \frac{T}{T_{1} - T_{0}} \text{ i.e. } B \geq 1 \]

B is a boost factor, T-Switching period The peak ac output phase voltage, For Z-source

\[ V_{ac} = \frac{MV_{dc}}{2} \]

In the traditional sources

\[ V_{ac} = \frac{MV_{dc}}{2} \]

where M is modulation index.

The Buck-Boost factor BB is determined by the modulation index M and the Boost factor B. The boost factor B can be controlled by duty cycle of the shoot through zero state over the non-shoot through states of the PWM inverter. The shoot through zero state does not affect PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot through period is limited by the zero state periods that are determined by the modulation index.
PWM inverters can be of single phase as well as three phase types. Their principle of operation remains similar and hence in this paper the emphasis has been put on the more general, 3-phase type PWM inverter. These inverters are capable of producing ac voltages of variable magnitude as well as variable frequency. The PWM inverters are very commonly used in adjustable speed ac motor drive loads where one needs to feed the motor with variable voltage, variable frequency supply. For wide variation in drive speed, the frequency of the applied ac voltage needs to be varied over a wide range. The applied voltage also needs to vary almost linearly with the frequency.

Carrier-based PWM methods are preferred in implementing modulators for inverters as they are simple and easy to realize. To date, there are three types of carrier-based modulation schemes proposed to modulate single-stage Z-source inverters [4], [5], [16].

In simple boost modulation method, the shoot-through period is fully inserted within the traditional null period, and this is achieved simply by comparing a constant reference value with a carrier signal. With the second method, the total null period is occupied by shoot-through period and is known as maximum boost controlling. Although this method does not increase the total number of switching’s per half cycle, it is found to be producing poor dynamic performance under transient conditions [17], [19]. The modulation method proposed in [15], has shot-through period carefully inserted between the state changes from active to active and active to null. This minimizes the number of switching’s per half carrier cycle and achieves improved spectral characteristics. In this topology, two inverters are connected to a single dc source through a common Z-source impedance network. These techniques are commonly used for the control of ac induction, Brushless Direct Current (BLDC) and Switched Reluctance (SR) motors. As a result, PWM converter powered motor drives offer better efficiency and higher performance compared to fixed frequency motor drives [2].

Hence, modulation schemes may need to be modified to suit the proposed topology. There are two possibilities in deriving the modulation signals. The first and obvious method is to modulate the two inverters from a common carrier signal with careful insertion of shoot-through time with simple boost or minimum switching [4], [15] methods proposed for a single Z-source inverter. This pulse is used to switch ON or OFF the power switches. The width of the pulse or duty cycle can be varied by varying the frequency of the reference wave. Since the Z-source inverter bridge can boost the dc capacitor (C1 and C2) voltage to any value that is above the average dc value of the rectifier, a desired output voltage is always obtainable regardless of the line voltage. Here inverter bridge switching is provided by pulse width modulation generator. In order to show clearly the output voltage obtained from inverter an RLC filter is placed between the Inverter Bridge and induction motor. Simulation parameters for z-source are given as follows:

\[ L_1=L_2 = (100e-9) \text{ H} \]
\[ C_1=C_2 = (1000e-6) \text{ F} \]

V. SIMULATION RESULTS AND DISCUSSION

Fig. 8 shows the main circuit configuration of the z-source fed pwm induction motor drive, similar to that of the traditional ASD system. The z-source ASD system’s main circuit consists of three parts: a diode rectifier, dc link circuit and inverter bridge.
To confirm the operating principle of the new ASD system, simulations have been carried out on simulink modeling. In order to show clearly the output voltage obtained from the inverter, an output RLC filter is placed in between the inverter bridge and the motor. Different cases are considered for showing the parameter variation in the value of load.

Case 1: full load, \( T_f = 11.9 \text{N-m} \)
Case 2: under load condition, \( T_f = 8 \text{N-m} \)
Case 3: Free acceleration condition, \( T_f = 0 \text{N-m} \)

Fig. 10. Waveforms of dc –link voltage of Z –Source.

Fig. 11. Inverter output voltage before filter is \( V_{\text{peak rms}} = 307.00 \text{V} \).

Fig. 12. Inverter output voltage after filter is \( V_{\text{rms}} = 220 \text{V} \).

Fig. 13. Inverter Load voltage after output filter \( V_{\text{peak rms}} = 304.5 \text{V} \).

Fig. 14. Inverter Load voltage after output filter is \( V_{\text{rms}} = 220 \text{V} \).
Case-2) Response of Induction motor for under load condition \((T_{\text{under load}} = 8 \text{ N-m})\)

The result for the speed estimation are shown in figure 19-22. It can be observed that speed reaches at steady state value that is 1745 rpm with in 0.714 second when motor is subjected to constant load 8 N-m. So when the motor is fed by z-source inverter then its speed increases and setting time decreases.

Also the waveform for Rotor speed (rpm), input voltage, per phase rotor current, per phase stator current and also the waveform of electromagnetic torque is shown in fig. 19-22.

Case-3) Response of Induction motor at No load condition \((T_{\text{nl}} = 0 \text{ N-m})\)

The result for the speed estimation are shown in fig. 23 - 26. It can be observed that speed reaches at steady state value that is 1799.4 rpm with in 0.736 second when motor is subjected to constant load 0 N-m. So when the motor is fed by z-source inverter then its speed increases and setting time decreases.

Also the waveform for Rotor speed (rpm), input voltage, per phase rotor current, per phase stator current and also the waveform of electromagnetic torque is shown in fig. 23 - 26.
PWM allows the operation of inverter in over modulation region. This proposed strategy considers the inverter as a single unit and greatly reduces the complexity and cost when compared with traditional systems. It has reduced harmonics, low switching stress power and low common mode noise.

Simulation has been performed for 3 HP, 220 V, 60 Hz, 1725 rpm, induction motor with PWM z-source inverter and the results are show that to verify these new features. By comparison we conclude that z-source fed pwn induction motor drive is more efficient over Traditional variable speed drive system. Because of inverter output voltage is more boost up than that of Traditional variable speed drive system.

VII. REFERENCES


Jaswant Singh was born in Firozabad, (U.P), India in 1987. He received the B.Tech. degree in Electrical Engineering in 2009 from RGEC, Meerut, India, and M. Tech. in Electrical engineering (Power electronics & drive) from the Kamla Nehru Institute of Technology (KNIT), Sultanpur, (U.P.), India, 2011. In 2011, he joined the Department of Electrical & Electronics Engineering, P.K. Institute of Technology & Management, (PKITM), Mathura, U.P., India, as an Asst. Prof. & Head in 2011. He is currently an Asst. Professor & Head in Department of electrical engineering from Shri Ram Group of Colleges (SRGC), Muzaffarnagar (U.P.), India, where he has been since August’2012. He has authored or coauthored 20 publications on power electronics, control and simulation of electrical machines and drives. His areas of interest in research are power electronics & drives and power quality problems.