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RESEARCH ARTICLE

Z-Source Inverter Based Motor Drives for Industrial Medium Voltage Application

Hanuman Prasad[1*], Tanmoy Maity[1]

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Abstract

This paper presents an application of z-source inverter for industrial medium voltage drives. Z-source inverter based drive has advantages like boosting the output voltage during voltage sag, reducing harmonic distortion and improving the input power factor. Adjustable speed drives (ASD's) are interrupted due to voltage sag, reducing the manufacturing and financial losses. The medium voltage ac drives are limited to low value of switching frequency because of dynamic losses of the power devices. Using the proposed technique, it can remove those limitations. In this paper, the performance of traditional voltage source inverter is compared to that of z-source inverter for medium voltage drives under different operating conditions. Simulation results show the dynamic performance of z-source inverter based 225KW, 3.3KV induction motor drives during input supply fluctuation. The proposed closed loop control method provides nearly zero steady state speed error at any operating frequency.

Keywords

Motor drives, z-source inverter, voltage sag, medium voltage drives, PID controller

[1] Department of Mining Machinery Engineering, Indian School of Mines, Dhanbad-826004, India

[*] Corresponding author, e-mail: hpshukla271@gmail.com

1 Introduction

The medium voltage drive has been one of the fast growing areas for industrial applications. There are many applications of medium voltage drives such as winder motor, ventilation fans, pumps, rolling mills etc. The common level of medium voltage drives are 2300 volts, 3300volts, 6600 volts and 13200 volts. Traditionally, current-source inverter (CSI) [1] was used for adjustable speed drive system for medium voltage motor. CSI have following drawbacks like (1) during low load condition, it suffers from stability problems. (2) It is not suitable for multi motors drives from a single motor. (3) It produces more heating and distorted input current waveform. (4) It is more costly per kilowatt than voltage source drives. (5) It can excite torsional resonances in the motor.

The medium voltage drives are both direct and indirect type. For direct conversion, cycloconverter is popular but having complex control. Matrix converter is not useful for medium voltage drives. Indirect drives use voltage source and current source topologies. Traditional voltage source inverter operates in only buck mode and this is quite undesirable for drives system operation. Also, it operates at low input power factor, more harmonic distortion and inrush current.

A Multilevel inverter [2] is a series connection of single phase inverters which makes a high multi-level voltage source inverter. This topology increases the number of voltage source level which makes a large and complex circuit. It cannot boost the output voltage of the inverter during desirable condition for adjustable speed drives. Presently, multilevel-inverter technology has been used for medium voltage drives [3-6]. The Cascade H-Bridge (CHB) also has drawback of separate dc source, required for each cell of the H-bridge making it a heavy and complicated circuit.

Currently, the flying capacitor (FC) multi-level inverter is used for industrial medium voltage drives. The drawbacks of this topology are: (1) Higher level inverter requires large number of capacitors, which makes a bulky and complex circuit for recharging of all the capacitors at same level. (2) Real power transmission efficiency and switching utilization are poor. A 6.6KV transformerless motor drive [7] using a five-level diode-clamped PWM inverter has many advantages but suffer some drawbacks like requirement of additional voltage balancing circuit with three-level inverter which operates in buck and boost mode at any operating condition. Additional voltage balancing circuit increases complexity and losses in the system.

Closed-loop hybrid direct torque control by rotor reference frame quadrature axis current is introduced [8] instead of conventional DTC. Though the proposed control technique has dynamic response, it is not suitable for adjustable speed drives. A new medium-voltage PWM inverter topology [9-12] is proposed for adjustable speed drives. But existing topology cannot boost the output voltage during voltage sags condition. It has required additional transformer.

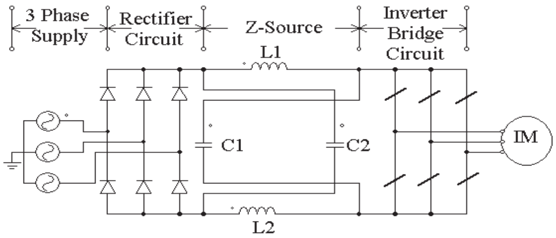


Fig. 1 Z-source inverter system based induction motor drives

Z-source inverter proposed for motor drives [13] is employed for low voltage drive only. Voltage sag problems can be eliminated using shoot-through duty ratio i.e. boosting of the output voltage of inverter. Z-Source inverter drive system improves input power factor of the circuit and reduces the line harmonics distortion. This paper presents a new a motor drive system with the z-source inverter for medium voltage drive application.

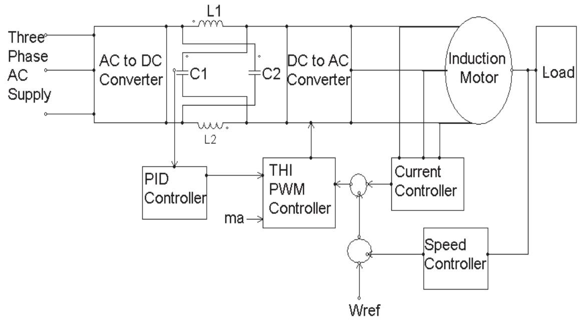


Fig. 2 Closed loop controlled Z-source inverter system induction motor drives

For the adjustable speed drives system, the z-source inverter is controlled the same way as the traditional voltage source inverter without adding one extra shoot-through switching state. During voltage sag condition, system requires output voltage higher than the line voltage and then shoot-through zero state is employed to boost the voltage. The regulating shoot-through zero state, we can maintain the desired output voltage level and steady state speed of the induction motor. Assuming that the inductors L1 and L2 and capacitors C1 and C2 of the z-network have the same inductance (L) and capacitance (C), respectively, the output peak phase voltage of z-source inverter can be expressed as

$$\hat{V} = M \times B \times \frac{V_{dc}}{2} \tag{1}$$

Where M is modulation index of the inverter and B is boost factor of the inverter. Vdc is dc link voltage of uncontrolled rectifier fed from three phase ac supply.

2 Proposed System

The Figure 2 represents the proposed closed loop control system of z-source inverter used for adjustable speed drives. Z-source inverter utilizes the shoot-through zero state to boost the output voltage, while this state is forbidden in traditional voltage source inverter.

The voltage across the capacitor is directly proportional to the input variation. It is sensed by the voltage sensor and fed to a PID controller. The PID controller output is compared with a high frequency triangular signal to generate shoot through pulses. It is ORed with six third harmonic injected sine PWM pulses and finally fed to the switches of the inverter. The third harmonic injection circuit improves the output voltage of the inverter at low modulation index. During voltage sag condition, the speed of the induction motor is compensated by increasing shoot-through pulse of z-source inverter and maintains steady state output voltage.

The induction motor current is sensed for drive system because it depends on the load characteristics of the system. The current controller is used to reduce the distortion in input current of induction motor. During voltage sag condition, input current is distorted due to the load variation, which is compensated by PID controller and provide smooth input current to the induction motor.

3 Results and discussion

To verify the proposed technique of z-source inverter for induction motor drives simulation is carried out under MATLAB-SIMULINK environment.

For the simulation, three phase 3.3KV, 6 pole, 225KW induction motor is selected. A comparison is made between the conventional drive and z-source converter drive. Switching frequency for the converter is selected as 5 KHz. Z-source network is made with L1=L2=10mH, C1=C2 =100µF. The L-C filter for each phase is selected with parameters L= 5mH, C = 10 µF. PID tuning parameters are chosen as K_p=0,1, K_i=5, K_d=1,5.

The specification of the induction motor is given in Table 1.

Table 1 Motor parameters 3.3KV, 6 pole, 225 KW

Motor parameters	Selected Value
Stator resistance	0.50832 Ω
Stator leakage inductance	0.0002588 H
Rotor resistance	0.50832Ω
Rotor leakage inductance	0.0002588H
Mutual inductance	0.158536 H
Moment of inertia	4 kg-m^2

Performance of traditional voltage Source inverter drive system under open-loop condition is shown in Table 2. By varying the modulation index, the inverter output voltage changes whereas variation in the shoot-through duty ratio, z-source inverter drive produces the variable output voltage at its terminal. Performance of z-source inverter drive system at different shoot-through duty ratio is shown in Table 3.

Performance of the proposed closed loop system are investigated in two operating conditions such as at variable supply voltage under constant load torque (2170 N-m) and variable load torque during constant input supply voltage (3.3kV) and results are presented in Table 4 and Table 5 respectively. Input supply voltage is suddenly varied from 3.3kV to 2.3kV imposing 30% voltage sag. During voltage sag, terminal voltage, stator current, speed of the induction motor are recorded and shown in Fig. 3. There is small variation in the inverter output voltage, motor current and speed of induction motor which may be assumed approximately constant. The closed loop control method is provided with PID controller, which maintains steady state speed of the induction motor during voltage sag condition.

In second operating condition, load torque is varied at constant supply voltage. Performance of closed loop z-source inverter drive system at constant supply voltage and variable

Table 2 Performance of traditional voltage Source inverter drive under variable modulation index

S. No.	Modulation index(ma)	Frequency (Hz)	Simulated Inverter output voltage (Volts) Line to line	Stator Current (A)	Speed(N) RPM
1	1.0	50	2650	58	982
2	0.95	47	2541	59	922
3	0.90	45	2393	60	882
4	0.85	42	2194	61	823
5	0.80	40	1996	63	782
6	0.75	37	1800	63	722
7	0.70	35	1657	64	683
8	0.65	32	1550	64	623
9	0.60	30	1452	65	580

Table 3 Performance of the drive under variable shoot-through duty ratio

S. No.	Frequency(f) (Hz)	Shoot-through duty ratio(D)	Boost factor (B)	Simulated Inverter output voltage (volts)	Stator current (A)	Speed (N) RPM
1	50	0.12	1.32	3000	55	990
2	49	0.11	1.28	2930	55	972
3	48	0.10	1.25	2900	56	950
4	47	0.09	1.22	2839	57	920
5	46	0.08	1.19	2735	57	900
6	45	0.07	1.16	2700	58	880
7	40	0.06	1.13	2635	59	775
8	35	0.05	1.11	2490	60	685
9	30	0.04	1.08	2395	61	590

Table 4 Performance of the drive at rated torque and variable supply voltage

S. No.	Input voltage (rms) line-to-line (Volts)	Inverter output voltage (rms) (Volts)	Speed N (RPM)	Stator Current (A)
1	3300	3000	990	55
2	3000	2980	985	55
3	2700	2965	979	56
4	2500	2942	975	57
5	2300	2935	970	58

Table 5 Performance of the drive system at constant supply voltage and variable load torque

S. No.	Load Torque (N-m)	Inverter output voltage (rms) Volts	Speed (N) RPM	Stator current (A)
1	1870	3033	995	52
2	1970	3026	992	53
3	2070	3015	990	54
4	2170	3000	990	55
5	2270	2975	980	57
6	2370	2982	975	58
7	2470	2995	970	59

load torque is shown in Table 5. The inverter output voltage, speed and stator current of the induction motor are observed. Closed loop control system with PID controller is provided small variation in the output voltage of the inverter, speed and stator current of the induction motor.

Z-source inverter output voltage without and with filter at modulation index 1 and boost factor 1.32 is shown in Fig. 4 (a) and (b) respectively. For the same voltage rating of the induction motor, z-source inverter boosts the dc link capacitor voltage and maintains the desired level voltage while this is

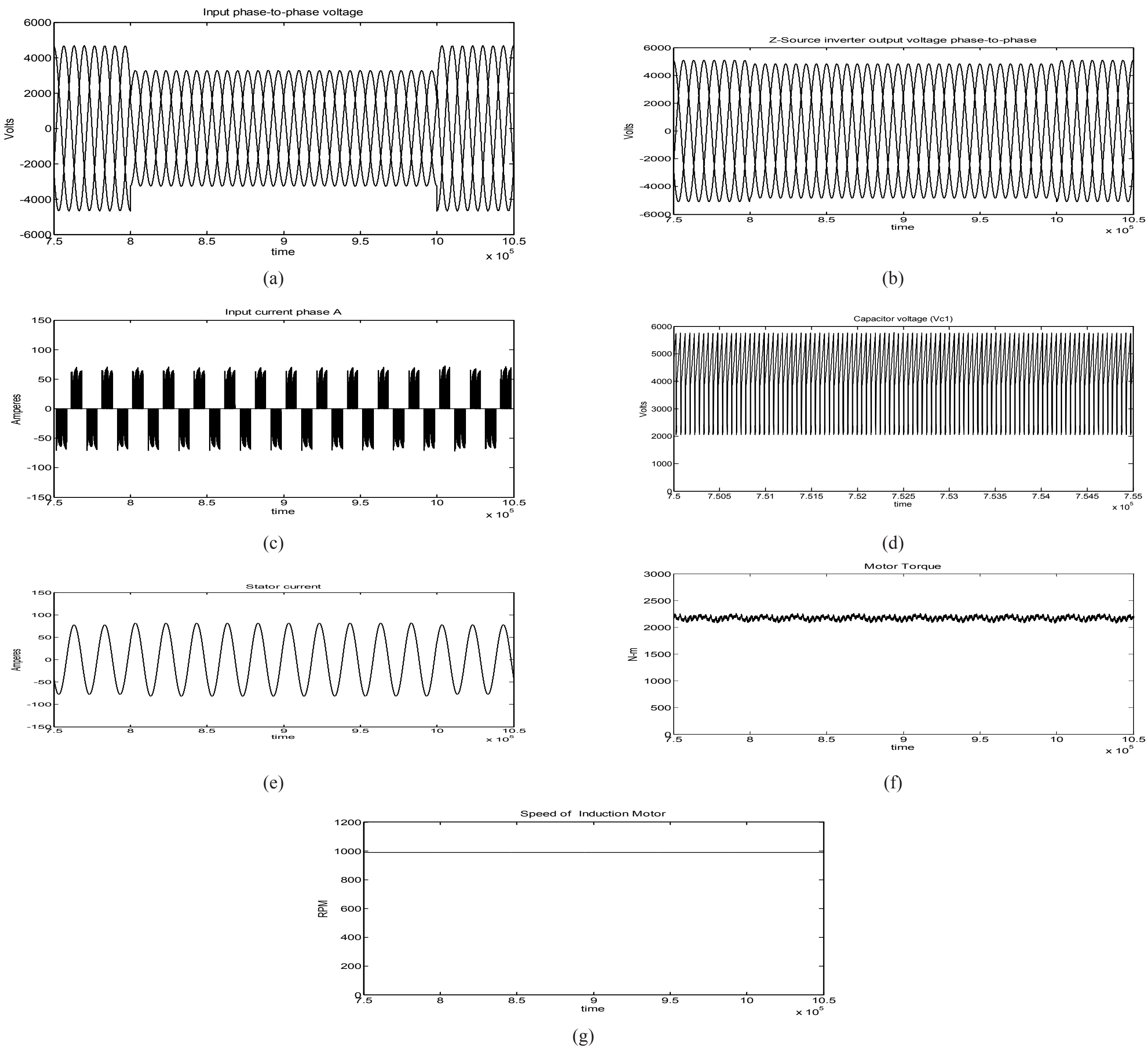
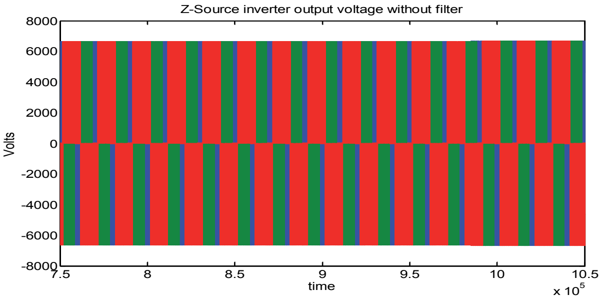
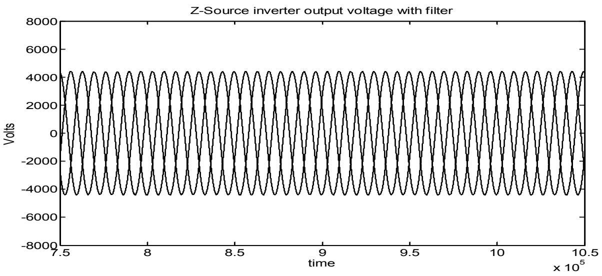


Fig. 3 The voltage sag condition the following simulation graphs (a) Three phase input voltage (b) Inverter output voltage (c) Input current phase A (d) Capacitor voltage (e) Stator current (f) Motor torque (g) Speed of induction motor.



(a)



(b)

Fig. 4 Simulation waveforms of Z-source inverter output voltage (a) without filter (b) with filter

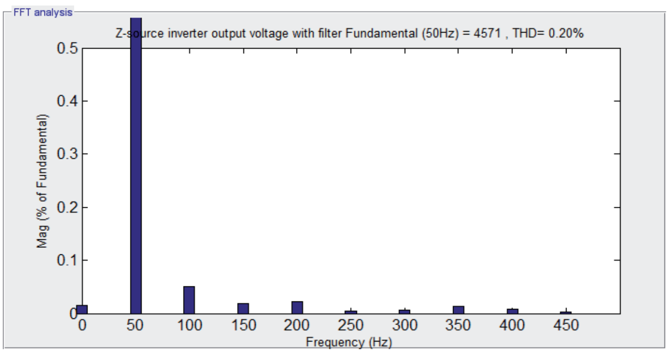


Fig. 5 FFT analysis of Z-source inverter output voltage without filter

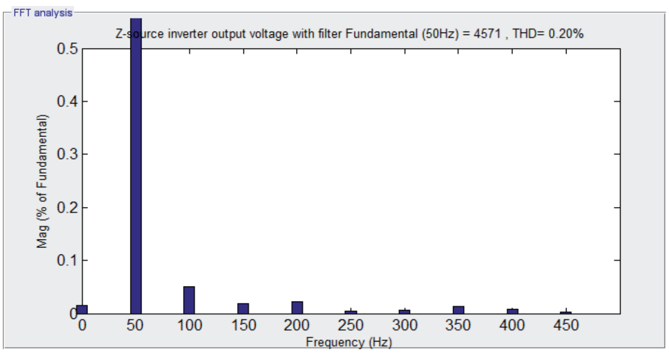
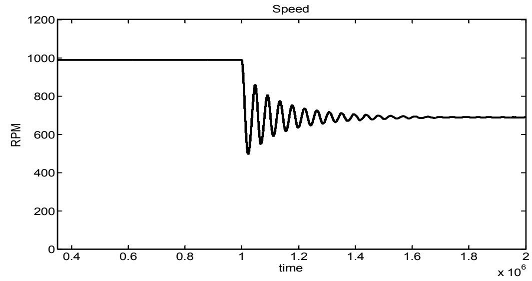
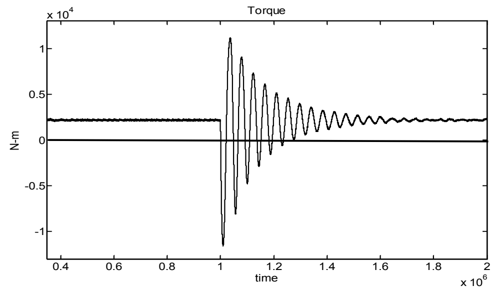


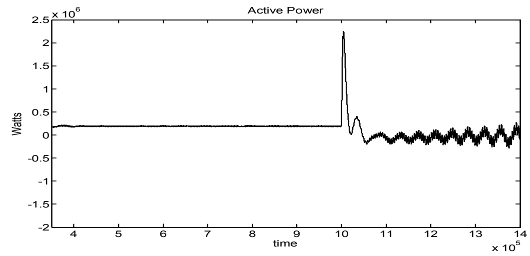
Fig. 6 FFT analysis of Z-source inverter output voltage with filter



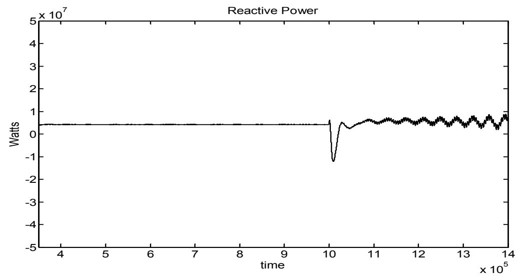
(a)



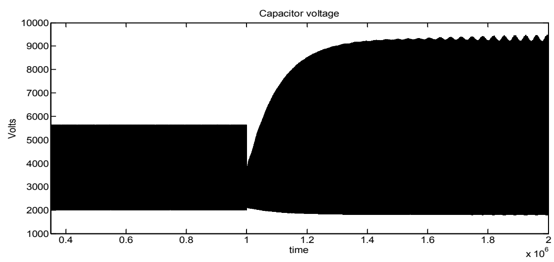
(b)



(c)



(d)



(e)

Fig. 7 The braking condition of the induction motor the following simulation graphs (a) Speed (b) Torque (c) Active power (d) Reactive power (e) Capacitor voltage of Z-source network.

not possible in traditional voltage source inverter. During voltage sag, traditional voltage source inverter contain much harmonic distortion waveform of input current and output voltage of inverter as compared to z-source inverter.

FFT analysis of the z-source inverter output voltage without and with filter are shown in Fig. 5 and Fig. 6. The total harmonics distortion (THD) in the z-source inverter output voltage without and with filter are 74.14% and 0.20% respectively.

The voltage sag problems can be removed by controlling the boost factor of the z-source inverter easily. By controlling the boost factor, the z-source inverter maintains the steady state speed for the induction motor.

The V/f control method is very efficient for induction motor drives during motoring and regenerative braking operations. Regenerative braking method is energy saving method as compared to dynamic braking. The braking torque developed negative shaft power which is produced by the motor and fed to the dc-link circuit. The regenerated energy fed to the capacitor can be utilized for other purposes. Regeneration is imposed in the Motor which is operating at 50 Hz with 990 rpm by suddenly reducing the modulation index and frequency by 15%. The braking torque is negative, motor operates as generators as shown in Fig. 7. The dynamic behavior is recorded for speed and torque at Fig. 7 (a), (b) respectively. The nature of variation in active power, reactive power and capacitor voltage are also shown in Fig. 7 (c), (d) and (e) respectively.

4 Conclusion

In this paper, z-source Inverter based motor drives for industrial medium voltage application is presented. MATLAB-SIMULINK simulation results validate the theoretical concept of z-source inverter for induction motor drives both motoring and regenerative conditions. The shoot-through zero state is employed to boost the input voltage and provide ride-through during input voltage fluctuations. The closed loop control system with PID controller automatically maintain steady state output voltage and constant speed of the induction motor during voltage sag condition. Traditional voltage source inverter drive system has a limitation to remove the voltage sag problems. For the same rating of the induction motor drives, we now require less supply voltage as compared to traditional voltage source inverter. Z-source inverter drive system contains less harmonics distortion in output voltage as compared to traditional voltage source inverter drive system.

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