

Simulation and Analysis of Z-Source Inverter Fed PMBLDC Motor

Honey Sharma¹, C. S. Sharma²

¹Department of Electrical Engineering, Samrat Ashok Technological Institute, Vidisha, India
honey.sharmaer@gmail.com

²Department of Electrical Engineering, Samrat Ashok Technological Institute, Vidisha, India

Abstract: This paper deals with the simulation and operation of PMBLDC Motor drive system with Z-Source Inverter. The z-source inverter employs a unique impedance network coupled with inverter and rectifier. It overcomes the conceptual barriers and limitations of the traditional voltage-source inverter such as V-source inverter and current-source inverter such as I-source inverter. By controlling the shoot-through duty cycle, the z-source inverter system provides ride-through capability. Simulation results are presented to demonstrate the features. The result shows that the Z-source inverter is very promising for BLDC motor drive. For applications with a variable input voltage, this inverter is a very competitive topology.

Keywords: Z-Source Inverter, Shoot through state, Motor Drive, PMBLDC Motor.

1. Introduction

There exist two traditional converters: voltage-source (or voltage-fed) and current-source (or current-fed) converters (or inverters depending on power flow directions).

1.1 Voltage Source Inverter

The traditional system is based on the voltage-source inverter (V-source inverter), which consists of a diode rectifier front end, dc link capacitor, and inverter bridge. In order to improve power factor, either an ac inductor or dc inductor is normally used [1]. VSI topology is used as it gives good output voltage with low harmonic levels. The main disadvantage of VSI topology is its buck type output voltage characteristics limiting the maximum voltage.

Figure 1.1 shows the traditional three-phase voltage-source inverter is a buck (or step-down) converter that can only produce an ac voltage limited by the dc link voltage. Because of this nature, the V-source inverter based ASD system suffers the following common limitations and problems [1].

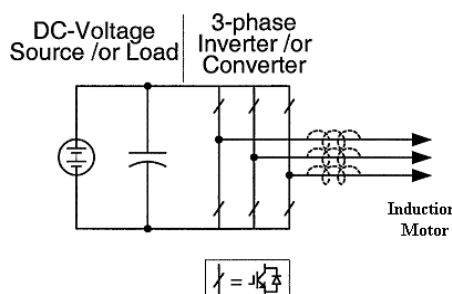


Figure 1.1 Voltage source inverter

- Limited output voltage is obtained.
- Inverter cannot output a voltage higher than the dc bus voltage.
- Input dc voltage is not always constant. That is why; dc-dc boost converter is required.

- Increase complicity, cost and decrease reliability.

1.2 Current Source Inverter

The current source inverter is shown in Figure 1.2. The input to the inverter is a current source or a voltage source with an inductor in series. The inverter bridge consists of six switches with a reverse blocking diode in series or switches with reverse blocking ability. Three capacitors are connected at the ac side of the inverter to provide a leading power factor load. The C-source inverter system suffers the following common limitations and problems.

- DC voltage produce is always smaller than the AC 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 (or buck converter) for ac-to-dc power conversion.
- At least 1 upper & 1 lower device have to be gated ON.
- They are either a boost or a buck converter and cannot be a buck-boost converter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.
- Their main circuits cannot be interchangeable. In other words, neither the voltage-source converter main circuit can be used for the current source converter, or vice versa.
- They are vulnerable to EMI noise in terms of reliability.

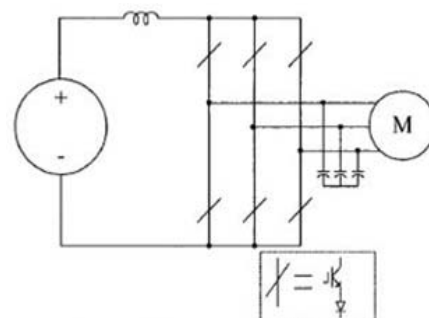


Figure 1.2 Current source inverter

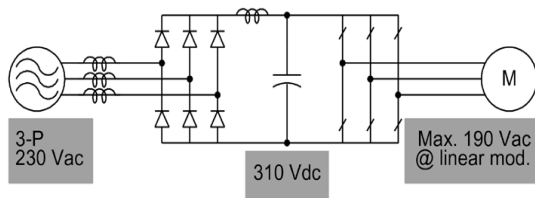


Figure 2. Proposed Z-Source Inverter

2. Introduction

The Z-source inverter is a buck boost inverter and having wide range of obtainable voltage. To overcome the above problems of the traditional V-source and I-source inverters this paper presents an impedance-source power inverter (which is abbreviated as Z-source inverter) for implementing DC-to-AC, AC-to-DC, AC-to-AC, and DC-to-DC power conversion. Figure 3 shows the general Z-source inverter structure. The Z-source inverter has been an alternative to the existing inverter topologies with many inherent advantages. The Z-source inverter is very simple to describe two ports X shape LC network between the input voltage and the inverter bridge. With the unique LC network, we can intentionally add the shoot through state to boost the output voltage. By utilizing this switching state to boost the output voltage, we can output voltage higher or lower than the DC link voltage. Therefore, the inverter is a buck-boost type converter and can output whatever voltage desired, and overcome the voltage limitation of the traditional inverters [2].

In summary, the Z-source inverter has several unique features:

- The inverter can boost and buck the output voltage with a single stage structure
- The shoot through caused by EMI can no longer destroy the inverter, which increases the reliability of the inverter greatly.
- Because of no dead time is required, perfect sinusoidal output waveform is obtainable.

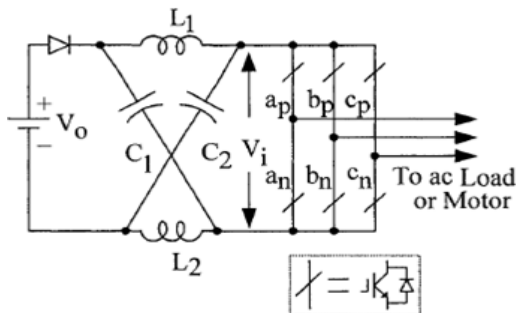


Figure 2.1 Z-Source inverter

Fig.2.1 show the topologies of voltage type three phase Z-source inverter, where a dc voltage source and a conventional VSI with three phase legs are connected at opposite ends of the Z-source impedance network. A diode is connected in series with the power source to block the reverse flow of current. A voltage type Z-source inverter can assume all active and null switching states of VSI. Unlike conventional VSI, a Z-source inverter has a unique feature of allowing both power switches of a phase leg to be turn ON

simultaneously (shoot-through state) without damaging the inverter.

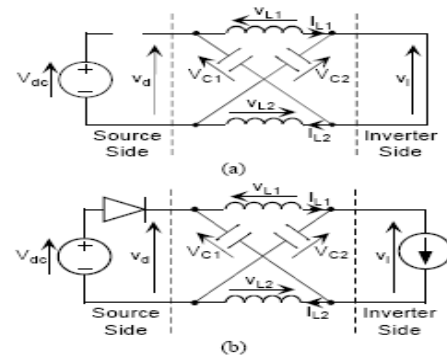


Figure 2.2 Z-Source Inverter equivalent circuits when in (a) shoot-through state and (b) non-shoot-through state.

The impact of the phase leg shoot-through on the inverter performance can be analyzed by considering the equivalent circuits shown in Fig.2.2 When in a shoot-through state during time interval T_0 , the inverter side of the Z-source network is shorted as in Fig.2.2 (a). Therefore (assuming $L_1 = L_2 = L$ and $C_1 = C_2 = C$):

$$\begin{aligned} V_{L1} &= V_{L2} = V_L = V_{C1} = V_{C2} = V_C \\ V_d &= V_L + V_c = 2V_c \\ V_i &= 0 \end{aligned} \tag{1}$$

Alternatively, when in a non-shoot-through active or null state during time interval T_1 , current flows from the Z-source network through the inverter topology to the connected ac load. The inverter side of the Z-source network can now be represented by an equivalent current source, as shown in Fig.2.2 (b). This current source sinks a finite current when in a non-shoot-through active state and sinks zero current when in a non-shoot-through null state. From Fig. 2.2(b), the following equations can be written:

$$\begin{aligned} V_L &= V_{dc} - V_c \\ V_d &= V_{dc} \\ V_i &= V_c = V_L = V_c = V_{dc} \end{aligned} \tag{2}$$

Averaging the voltage v across a Z-source inductor over a switching period (0 to $T=T$) then gives:

$$V_c = T_1 / (T_1 - T_0) * V_{dc} \tag{3}$$

Using 2 & 3 the peak dc voltage V_i across the inverter phase-legs and peak ac output voltage V_x can be written as:

$$\begin{aligned} V_i &= 2V_c - V_{dc} = 1 / (1 - 2T_0/T) * V_{dc} = BV_{dc} \\ V_x &= M \frac{V_i}{2} = B \left\{ \frac{MV_{dc}}{2} \right\} \end{aligned} \tag{4}$$

Where B is the boost factor introduced by the shoot-through state, M is the modulation ratio commonly used for Conventional VSI modulation and the term within $\{ \}$ gives the ac output of a conventional VSI. Obviously, equation (4) shows that the ac output voltage of a Z-source inverter is boosted by a factor of B (always ≥ 1), which cannot be achieved with a conventional VSI.

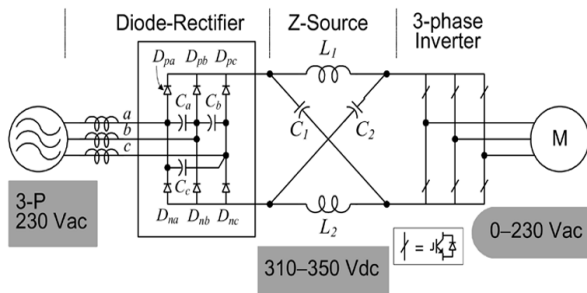


Figure 2.3 Main circuit configuration of proposed Z-source inverter ASD system

Fig. 2.3 shows the main circuit of the proposed Z-source inverter based permanent magnet BLDC motor drive system. A Z-source inverter is utilized, instead of the traditional voltage source inverter or current source inverter [CSI], to feed electric energy from the dc source to the Brushless DC motor. To gain the buck/boost ability, the PWM method is used to control the Z-source inverter to generate shoot through states. Unlike the Z-source inverter based ASD system with induction machines, the output currents of the Z-source inverter in the proposed BLDC motor drive system are composed of square waveforms of 120° electrical degree.

Consequently, the operation principle, the modelling method and the control are all different from the Z-source inverter based ASD system with induction machines. According to the operation principle of BLDC motor, two phases are conducted in the non-commutation stages. The shoot-through states can be generated by shorting either any one arm or both arms in the bridge. During non-shoot-through states two switches in different legs are conducting. Four devices are conducting when shoot-through occurs in one phase leg. And six switches conduct if shoot-through occurs in two phase legs. ZSI fed BLDC motor drive is shown in the following Fig 2.4.

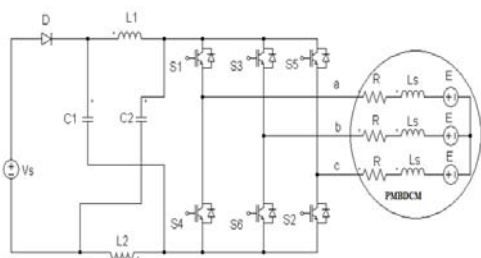


Figure 2.4 Main circuit of Z-source inverter fed BLDC motor drive.

3. Simulation Model of Z-Source fed PMSBLDC Motor

The simulation model of impedance network fed brushless DC motor is shown in Fig 3.1. Fig 3.2 shows the DC voltage, and the improved DC voltage after Z network is shown in Fig 3.3 back emf, speed, torque and current of motor is shown in Fig 3.4

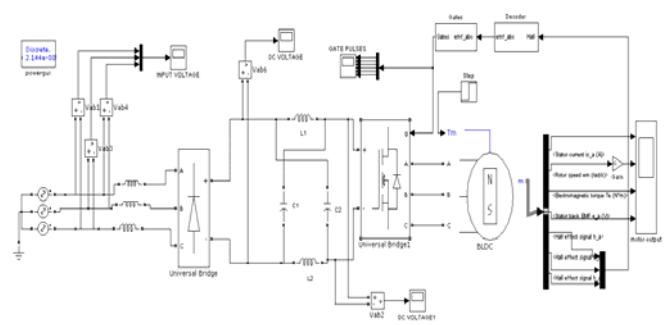


Figure 3.1 Simulation of ZSI fed BLDC motor with three phase AC source

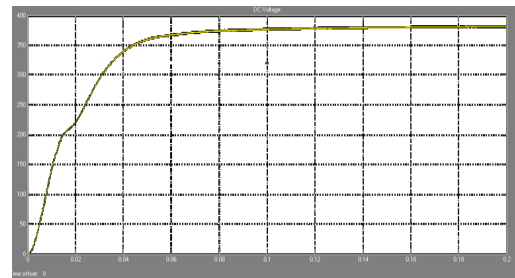


Figure 3.2 DC voltage

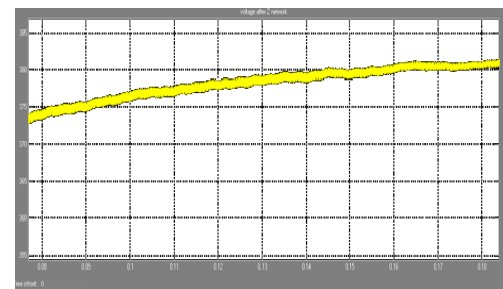


Figure 3.3 DC Voltage after impedance network

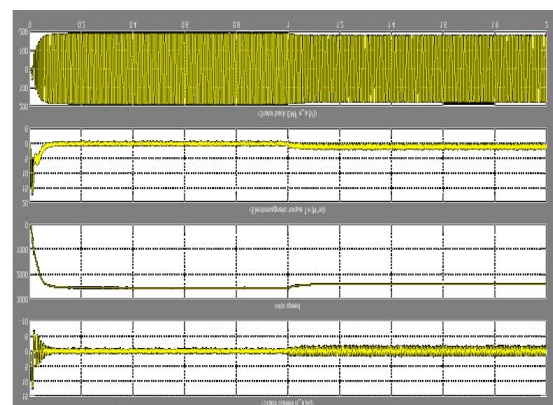


Figure 3.4 Simulation of ZSI fed BLDC motor with three phase AC source

Fig 3.5 shows the close loop PMSBLDC motor fed through impedance network. And the results are shown as DC bus voltage, DC voltage after impedance network, in fig 3.6, fig 3.7 respectively. And the stator current, electromagnetic force, rotor current and electromagnetic torque is shown in fig 3.8 respectively.

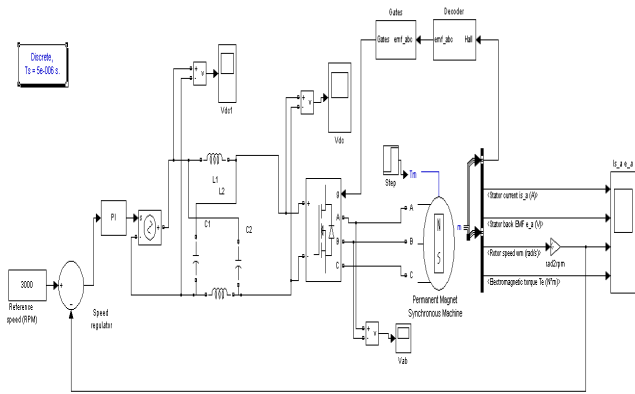


Figure 3.5 Close Loop Control of Z-Source Inverter Fed PMSM Motor

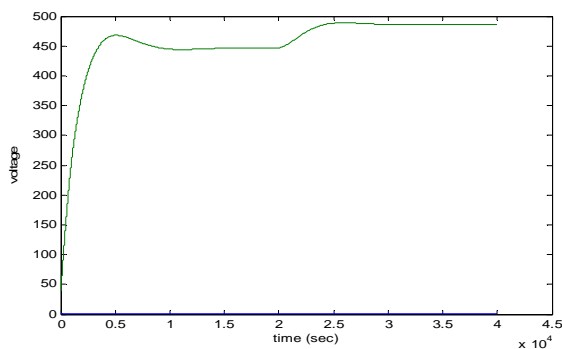


Figure 3.6 DC bus Voltage

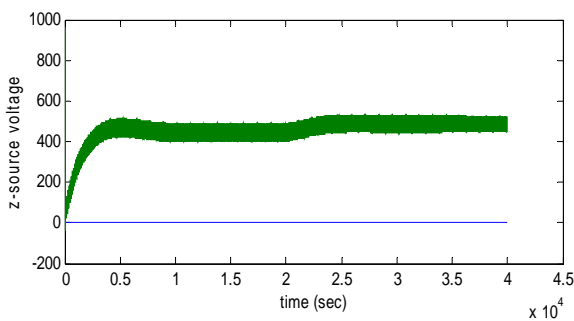


Figure 3.7 DC Voltage after Z network

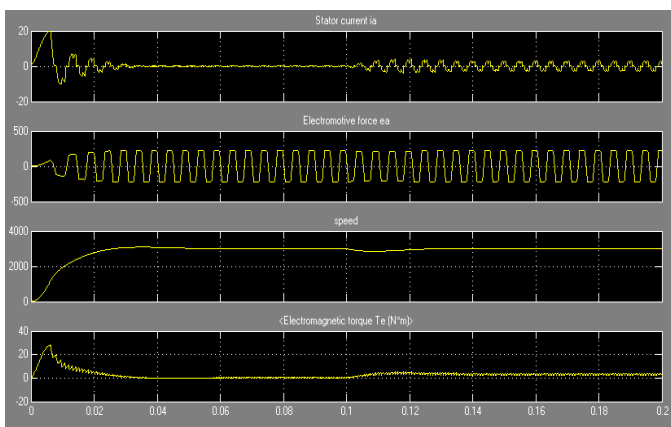


Figure 3.8 a) Stator current, b) back emf , c) Rotor speed and d) Electromagnetic torque

4. Conclusion

This paper has proposed a new electric drive system with permanent magnet BLDC motor fed by Z-source inverter. The drive offers the advantages of both Z-source inverter

and BLDC motor. The existing inverter scheme suffers from shoot-through reliability problem. This topology provides better performance than the traditional inverter topology for an identical load and speed conditions. The feasibility of Z-source inverter fed BLDC motor drive is proved by the simulation results. From the results obtained, it is clear that the Z-source inverter fed PMSM motor drive is very promising for various industrial applications. The drive response can be improved by using space vector PWM technique.

4.1 Application

Z-Source Inverter is used as buck-boost converter, where voltage greater than the input voltage is required. The BLDC motor can be used for various applications such as hybrid electric vehicles.

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