

Design and Simulation of Z-Source Inverter for Brushless DC Motor Drive

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ABSTRACT: This paper presents a Z-source inverter for controlling the speed and reducing the torque ripple of a brushless DC motor. This inverter uses a unique impedance network, coupled between a power source and the inverter circuit, to provide both boost and buck-boost inverters properties, which cannot be achieved by conventional voltage source and current source inverters. The PI controller has been used as a closed loop controller, which improves the speed control of the brushless DC motor for any load. The hysteresis controller has been implemented to control the motor output current and provide suitable switching system for Z-source inverter. As a result, the new Z-source inverter by self boosting brings the output voltage higher value as in a six-switches standard three-phase inverter. Therefore, it expands the motor operating speed range and reduces its torque ripple. Analysis and simulation results are presented in result section to demonstrate these new features.

Keywords: BLDC motor, Z-source inverter

Introduction

Brushless DC electric motor (BLDC motors, BL motors) also known as electronically commutated motors (ECMs, EC motors) are synchronous motors that are powered by a DC electric source via an integrated inverter/switching power supply, which produces an AC electric signal to drive the motor. BLDC motors are rapidly becoming popular in industries, such Appliances as HVAC industry-medical, electric traction, automotive, aircrafts, military equipment, hard disk drive, industrial automation equipment and instrumentation because of their high efficiency, high power factor, silent operation, compact, reliability, low maintenance and ease of control [1-3]. To replace the function of commutators and brushes, the BLDC motor requires an inverter and a position sensor that detects rotor position for proper commutation of current.

Fundamentally, a PMBLDC motors produces torque characteristics very similar to the classical separately excited DC motor. The stator of a PMBLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery or around stator salient poles. In the conventional PMBLDC motor, excitation is provided by permanent magnets mounted on a solid iron rotor. [1]

This structure has some inherent disadvantages such as: Loss of flexibility of field flux control, changing the magnetic properties of permanent magnets when subjected to external magnetic fields and temperature changes, limited operating speed range and high cost of the high flux density permanent magnets. These problems have been addressed by many researchers [2, 3]. Under consideration the assistant dc field BLDC motor has salient-poles in stator and rotor similar to switched reluctance machine. The stator and rotor are constructed with two dependent magnetically layers, in which the two layers are exactly symmetrical. The absence of windings on the rotor helps to keep the majority of the losses within the stator, making the Homopolar BLDC motor relatively easy to cool. [4, 5]

Assistant dc field BLDC motor (Fig. 1) can be used in electric drive applications such as electric vehicles and hybrid electric vehicles along with fuel cell stacks as energy source. The absence of windings and permanent magnets on the rotor support both high rotational speeds and high temperature operation.

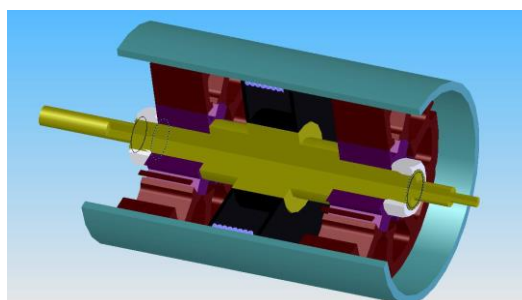


Figure 1. Proposed Field assisted BLDC Motor

It should be mentioned that the output voltage of fuel cell decreases when the output current increases. there are two main solutions for that problem: the traditional dc/dc-boosted Pulse Width Modulation [PWM] inverter and the original Z-Source inverter. Thus to have high power and high speed for the variable speed application motors such as BLDC motor it is necessary to use inverter coupled to the voltage source (fuel cell). There are many kinds of inverters that can be employed to have high voltage but the new kind of inverter, Z-source inverter, has many advantages compare with other inverters [6].

The conventional Voltage Source Inverter [VSI] suffers from the drawback that it cannot boost the voltage of the input source. Many new inverters have been proposed in the recent researches [7]. Comparison of traditional inverters and Z-source inverter shows that the Z-source inverters are very promising for fuel cell vehicle [6]. A new electric drive system with permanent magnet BLDC motor fed by Z-source inverter has been described in [8]. Three-phase induction motor with Z-source inverter has been described in [9]. In All works by today, traditional PWM method has been used to control the switching system, but this paper uses hysteresis current controller to provide switching system, which has many advantages comparing to traditional PWM method. The hysteresis controller can be used for high speed motors, which cannot be controlled well by PWM techniques.

Z-Source Inverter Concept

The Z-source inverter has been invented by F. G. Peng et al [10]. The Z-source inverter concept can be applied to all dc-to-dc, dc-to-ac, ac-to-dc, and ac-to-ac power convention. Fig.2 shows the general Z-source inverter structure. The Z-source inverter employs an impedance network to connect the inverter main circuit to the power source thus providing unique features that overcomes the conceptual and theoretical barriers limitations of the VSI and Current Source Inverter [CSI]. The Z-source inverter can boost the output voltage of the fuel cell without requiring dc-dc boost inverter or step up transformer which is forbidden in traditional VSI. Also, it can output a lower voltage than the input voltage as well as a common PWM inverter uses a modulation index. In general, the input voltage of the BLDC motor can be controlled by the Z-source inverter to have fixed speed with expanded range. The most important feature of the Z-source inverter is its low cost.

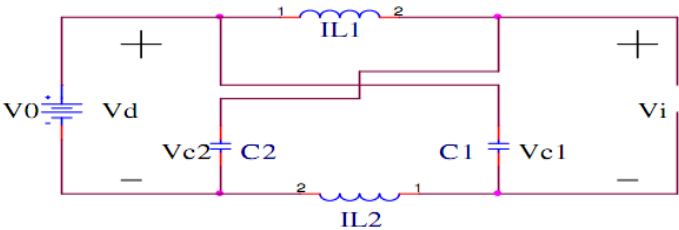


Figure 2. Shows General structure of the Z-source inverter.

The impedance source network includes a combination of two inductors and two capacitors. This combined circuit network woks as the energy storage or filtering element for the impedance source inverter. This impedance network provides a second order filter. This is more effective to repress voltage and current ripples. The inductor and capacitor requirement should be smaller than traditional inverters.

When the two inductors [L1 and L2] are small and approach zero, the impedance decreases to two capacitors [C1 and C2] in parallel and becomes traditional voltage source. Therefore, a traditional voltage inverter's capacitor requirement and physical size are the worst cases for the impedance source inverter. Considering additional filtering and energy storage supplies by the inductors, the impedance source network should needs less capacitance and smaller size compare with the traditional voltage source inverter. Similarly, when two capacitors [C1 and C2] are small and approach zero, the impedance source network decrease to two inductors [L1 and L2] in series and becomes a traditional current source. Therefore a current inverter's inductor requirement and physical size are the worst cases. VSI and CSI are used in only buck or boost operation of inverters while Z-source inverter used in both buck and boost mode operation of the inverter. Both CSI and VSI cannot allow misfiring of switches but for Z-source, sometimes misfiring of switches is allowable [11].

Operation And Control

Fig.3 shows the BLDC motor that is fed by Z-source inverter. The Z-source inverter output provides required voltage by adjusting the shoot through duty cycle with the restriction to keep the voltage across the switches not to exceed its limit [13].

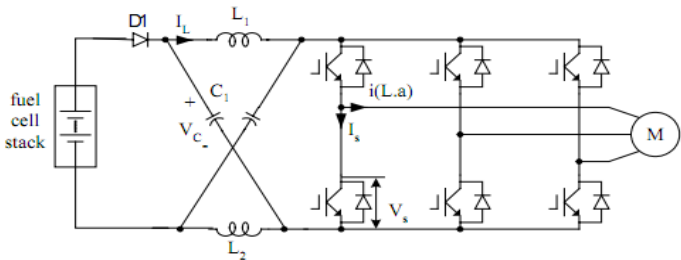


Figure 3. Shows system configuration using the Z-source inverter.

There are six active states (100, 110, 010, 001, 100 and 011) and two through shoot states (111 and 000). When shoot through occurs, the front-end diode D is reverse biased and the output voltage V_i will be zero. But when inverter return back to its active states front-end diode D conducts and the output voltage is nonzero: [12]

$$V_i = \frac{V_d}{1-2d_o} \quad (1)$$

Where d_o is the duty cycle of shoot through state. The value of the d_o cannot be more than 0.5. The output voltage of the Z-source inverter can be boost by $(\frac{1}{1-d_o})$ value.

Design Z-Source Inverter

In proposed Z-source inverter passive components are designed according to switching frequency and their voltage ripple and current ripple requirements. The voltage ripple across the capacitor in the Z-source inverter is [11]:

$$\Delta V_c = \frac{P_o}{V_i} \frac{(1-\frac{\sqrt{3}}{2}M)T_s}{C} \quad (2)$$

Where P_o is the maximum power; V_i is the fuel cell stack output voltage at maximum power; M is the modulation index. The current ripple through the inductor is:

$$\Delta I_L = \frac{V_i\sqrt{3M}}{2L(\sqrt{3M}-1)} (1 - \frac{\sqrt{3}}{2}M)T_s \quad (3)$$

Simulation Results In Matlab

Schematics of the BLDC motor drives have been shown in Fig. 4a and 4b. The BLDC motor that is used in these simulations is 184 (w) with the speed of 300 (rpm). Simulation results show comparison between Six-switches standard inverter and Z-source inverter fed BLDC motor drive.

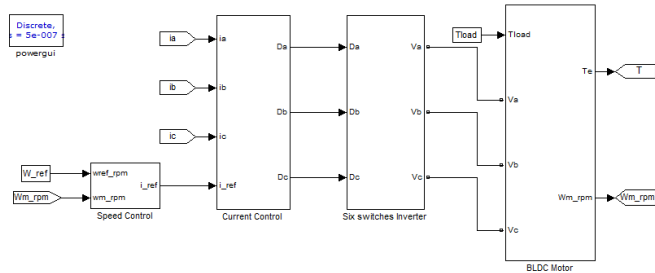


Figure 4a. BLDC drive with six switches inverter.

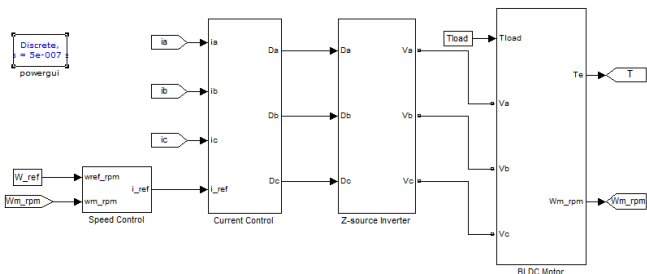


Figure 4b. BLDC drive with six switches Z-source inverter.

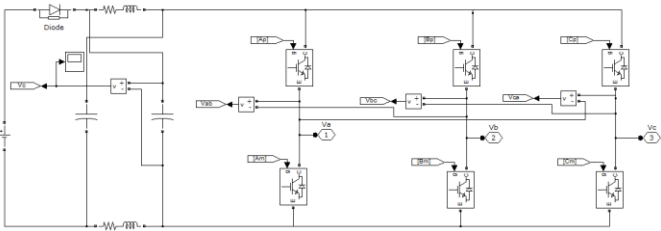


Figure 4c. Six switches Z-source inverter

Fig. 4c shows the schematic of Z-source inverter that has been used in the second simulation (fig. 4b).

Modulation index of the Z-source inverter is 0.92

Current ripple through inductors <10%

Voltage ripple across capacitors <3%

The values of two inductors are the same. Similarly the values of two capacitors are the same. By this consideration inductor value is achieved 400 (μH) and capacitor value is achieved 400 (μF). The input DC

voltage is 60 (volt). The load torque has been set 5.7 (N.M). The Fig. 5 to 7 show the simulation results of the BLDC motor drive fed by six switches standard inverter. The Fig.5 shows the motor speed curve, when reference speed is 400 (rpm), which is higher than the motor nominal speed. The Fig. 6 shows the motor output torque. It can be seen that when the value of the reference speed is higher than the motor nominal speed, torque ripple will be greater. The Fig. 7 shows the inverter output voltage, which its value is same as the DC input voltage. The Fig. 8 to 10 show the simulation results of the BLDC motor drive fed by six switches Z-source inverter. The Fig. 8 shows the motor speed and Fig. 9 shows the motor output torque. By these two figures, it can be obtained that by Z-source inverter the torque ripple has been reduced, when the motor speed increases. The Fig. 10 shows the regulated output voltage from Z-source inverter, which has been shown that the Z-source inverter boosted the input dc voltage to 300 (volt), and it let the motor to have more speed without torque ripple. It can also be seen that the response time has been decreased. In fact the Z-source inverters have more acceptable answers rather than other inverters.

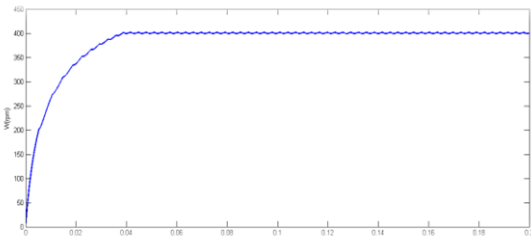


Figure 5. the motor speed (400 rpm).

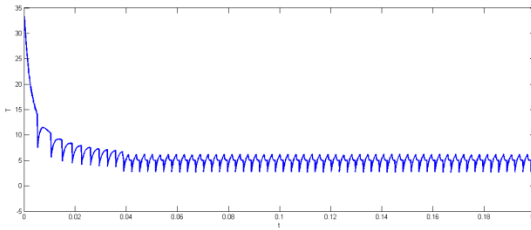


Figure 6. the motor torque (5.7 N.M).

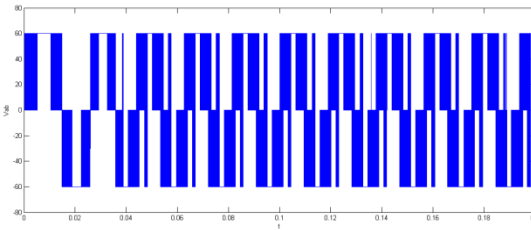


Figure 7. the inverter output voltage (Vab).

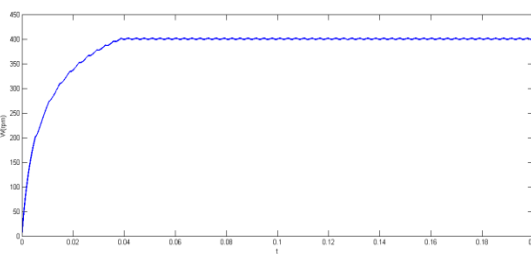


Figure 8. motor speed for a reference of 400 rpm

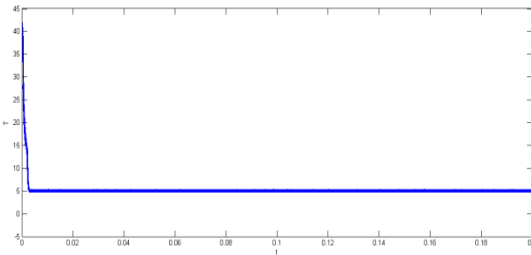


Figure 9. motor electrical torque for a load torque of 5.7 N.m

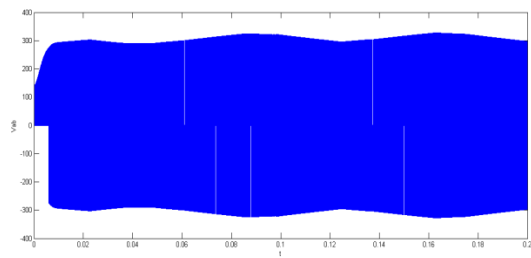


Figure 10. Z-Source output voltage

Conclusion

This paper presents a Z-source inverter system for controlling the speed of the without Permanent Magnet Brushless DC motor. This inverter regulates the input voltage that can be increased. It also reduced the torque ripple. The minimum components are used in this scheme, which decreases the switching loss and stress across the switches, so the harmonic generation can be reduced in the output. These inverters use a unique impedance network, coupled between the power source and inverter circuit, to provide both voltage buck and boost properties, which cannot be achieved with conventional voltage-source and current-source inverters. As a result, the new Z-source inverter system provides ride-through capability during voltage sags, reduces line harmonics, and extends output voltage range. Implementing Z-source inverter has many advantages that have been described in this paper such as:

- It can generate demanded DC voltage, even greater or lower than the output voltage;
- It provides greater operation speed range for BLDC motors;
- It can store energy without any additional circuits and energy storage;
- It reduces the output torque motors ripple;
- It has low cost.

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