Speed Control of SLqZSI FED PMBLDC Motor with Double-Loop Control

Mukhlesur Rahman¹, Pankaj Rai²

¹Department of Electrical Engineering, B.I.T SINDRI, India
²Professor, Department of Electrical Engineering, B.I.T SINDRI, India

Abstract: In this paper, a permanent magnet brushless DC motor drive using switched-inductor quasi Z-source inverter is proposed. This drive system utilizes the advantages of both the PMBLDC motor and SL-qZSI and can be used in high power/medium power electric vehicles and any other adjustable drive applications. The BLDC (Brushless DC) motor is characterized by linear torque to current and speed to voltage. The speed and torque is controlled by applying the armature voltage applied. Desired level of speed performance can be achieved with Double loop control for the speed and torque control. Also, SLqZSI has numerous advantages like low capacitor voltage stress, low current stress on inductors, high voltage gain etc. Thus feeding a high boosted dc voltage to the inverter and obtaining a smooth operating performance and dynamic response of the drive is very fast. Maximum constant boost control method has been used to generate the switching signals for the inverter switches.

Keywords: Switched Inductor Quasi Z source Inverter, BLDC Motor, Double Loop control, Boost factor

1. Introduction

According to various reports, cars and trucks are responsible for almost 25% of CO₂ emission and other major transportation methods account for another 12%. Nowadays, where fuel are on a shortage and the rising issues of global warming led the researchers for some alternative and one of the most discussed technology is the use of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell hybrid electric vehicles (FCHEVs), and electric vehicles (EVs) require power electronics and electrical machines to function. These devices allow the vehicle to use energy from the battery or inverter to assist in the propulsion of the vehicle, either on their own or in combination with an engine. Thus, implementation of Z-Source Inverter with BLDC motor solves the purpose by utilizing superior qualities of Z-Source inverter and BLDC motor. The operation of BLDC motor is similar to DC motor, where speed is directly proportional to input voltage. Unlike the traditional voltage source inverters, it can utilize the shoot-through (ST) state to boost the input voltage, which improves the inverter reliability and enlarges its application field[1]. It can utilize the shoot-through (ST) state to boost the input voltage. Thus, the generation of high ac voltage made the motor to run at higher speed. The rotor current is sensed to limit the torque ripple which is required for quiet operation of the drive system. This paper investigates the input and output performance of BLDC motor drive system with close loop control of speed and torque.

2. Switched Inductor Quasi Z-Source Inverter

A newly proposed topology, which consists of two capacitors(C1 & C2), the inductors (L1,L2 & L3) and four diodes (D1,D2,D3 & D1n). And as the name suggests, it is a set of energy storing elements arranged in such a way to minimize the inrush current at starting up of the switches. Along with it, reduces the current strain on inductor and voltage stress on capacitors. Also reduces the passive components connection and improves system authenticity.

The main advantage of this arrangement is, the boost factor increases from $1/(1-2D)$ to $(1+D)/(1-2D1-D2)$.[2]

![Figure 1: Switched Inductor Quasi Z-Source Inverter](image)

The operating principle of SLqZSI is, it has an extra shootthrough state unlike the traditional inverter which enhances the boosting capability of the inverter.

The operating condition is divided into two states for analysis purpose (i) shoot- through state (ii) non shoot- through state. Fig. 5 shows the equivalent circuits of the proposed SL-qZSI. In the nonshoot-through state, the energy flows from the dc supply to the load through inductors $L_1$, $L_2$, and $L_3$ and capacitors $C_1$ and $C_2$ gets charged. And during the shoot-through state, capacitors $C_1$ and $C_2$ is feeding the energy to the inductors $L_1$, $L_2$, and $L_3$ and stores energy.

3. SLqZSI based BLDC Motor Drive System

Fig.2 shows the proposed model of SL-qZ source inverter based Permanent Magnet Brushless DC motor drive system. The dc
input voltage is either buck/boosted as per the requirement of
the motor drive. The boosted energy from the SLqZSI is
fed to the brushless dc motor. Basically two modes are there
(a) commutation mode (b) non-commutation mode[3].

![Figure 2: SL-qZSI based PMBLDC Motor](image)

According to the operating principle of PMBDCM[4],
only two phases conduct in the non-commutation state which
is shown in fig 2. Thus in that only two switches (IGBT or the
anti-parallel) conducts in different legs of the bridge in non
shoot-through mode. While four devices are conducted in the
shoot-through mode when it occurs in one phase leg shown in
fig 2(c). When stator phase current flows from a-phase to b-
phase. For getting the boost capability, shoot-through states
are generated either by shorting one arm or two arm in the
inverter. Consider that lower switches are arranged so as to
short the bridge whereas upper switches perform the chopper
operation. The operation of various modes can be explained by
the fig 2.

![Figure 4: Equivalent circuit during phase commutation stage](image)

The fig 3 below shows that when switches S1 and S6
conducts, the current flows from phase a to phase b, and
simultaneously switch S4 conducts, which shorts the leg.

![Figure 5: Gating pulse for Switch S1, S6 & S4](image)

4. Proposed Model of Motor Drive System and
its Control Strategy

The voltage buck/boost is done in accordance with a speed and
current feedback system providing precise speed and torque control of the BLDC motor.

![Figure 5: Proposed model of Motor Drive system](image)
The control system consists of speed feedback system, a controller, PMBLDC motor, SLqZ-Source Inverter and a speed. The control system consists of speed feedback system, a controller, PMBDC motor, SLqZ-Source Inverter and a speed setting equipment.

The purpose is to achieve a constant speed and torque characteristics. Here, motor speed controller is designed such as to take a reference signal which represents the demanded speed and this reference signal compared with the rotor speed signal. Now the controller estimates the difference between both the signals which produces an error signal, which is fed to the PI controller. PI controller is the most popular controller, which computes and transmits a controller output signal in every sample time ‘T’ to the final control system i.e., motor drive system. It consists of proportional gain which generates a signal which is proportional to the input error and the integral action empower the controller to remove the offset. Thus the system becomes stable by making the steady state error to zero[5].The control system is properly designed for a precise control of speed and torque which makes it insensitive to any disturbance and changes in the parameters[6]. P which is termed as proportional gain which generates a signal which is proportional to the input error and it correlates with present error whereas I is termed as integral action which empower the controller to remove the offset and I depends on the accrual of past errors, established by current rate of change. There are several methods for tuning a PI loop [7]. The PI Loop is tuned by various methods. The most productive Method is to develop a process model and then choosing the P, I values according to the dynamic model parameters[8]. Here in the proposed model, a feedback loop of speed signal and a feedback loop of current signal is used and is shown in Fig. 6 shown below.

Thus the speed loop comprises of PI controller and the Current loop comprises of hysteresis current loop.

Here the rotor position is sensed with the help of hall sensor and the signal from these hall sensor is used as the modulating signal for the PWM generation. The insertion of shoot-through is done by the use of combinational logic circuit. Maximum voltage gain can be achieved with this switching technique without introducing any lower order harmonics related to the output frequency [10]. Maximum constant boost control method is used for pulse generation and the shoot-through duty ratio is kept at Dth=0.75. By controlling the duty cycle of pulse width modulation (PWM) signal, the amplitude of applied voltage can be controlled, which in turn will control the speed of the motor.

5. Simulation Results & Discussion

To analyze the performance of proposed model of SLqZSI fed BLDC Motor drive system, simulation has been done in MATLAB/SIMULINK. The simulation has been done for two speed frames i.e., (i) constant speed frame and (ii) variable speed frame. The simulation parameters are mentioned in table.1 and 2 and the main simulation circuit performed in MATLAB is shown in fig.5. Also, maximum constant boost control technique has been used for this drive system with constant modulation index, M=0.67.
Case 1: Constant speed drive with low torque
The simulation is done keeping in view of the operation of hybrid EV’s and at first performed for low speed and low torque.

Simulation Parameters for SL-QZSI fed BLDC Motor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Input Voltage</td>
<td>60V</td>
</tr>
<tr>
<td>Carrier Frequency</td>
<td>10KHz</td>
</tr>
<tr>
<td>Z-Source Parameters</td>
<td></td>
</tr>
<tr>
<td>L1=L2=L3</td>
<td>0.5mH</td>
</tr>
<tr>
<td>C1=C2</td>
<td>220uF</td>
</tr>
<tr>
<td>Load Torque ‘T’(Nm)</td>
<td>4 Nm</td>
</tr>
<tr>
<td>Ref. speed ‘N’ (rpm)</td>
<td>2500</td>
</tr>
<tr>
<td>Kp</td>
<td>0.02</td>
</tr>
<tr>
<td>Ki</td>
<td>0.6</td>
</tr>
<tr>
<td>Hysteresis Band</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Figure 11 (a): MATLAB/SIMULINK model of the proposed method

We observed that the PI controller keeps the speed constant and hysteresis controller lower the torque ripple. So, the speed settles fast and it is reaching its desired speed within 0.4s and torque ripple is nearly 1%.

The input dc voltage is 60V but the injection of shoot-through keeps the capacitors to store the charge and which result in boosting the voltage to 420V in dc link. The voltage stress on capacitor is also less and can be utilized practically.

Figure 10 (c): Stator Phase-a current
Figure 10 (d): Input current through L1
Figure 10 (e): Voltage across dc link
Figure 10 (f): Voltage across capacitors C1 & C2
Figure 10 (g): Line Voltage Vab

Case 2: Variable speed drive with high torque
In auto-vehicles where speed frequently varies and torque should have high range. So, keeping in view of operation of auto-vehicles, the parameters have been set. Thus speed varies from 10000 to 15000 rpm and keeping the torque at 41 Nm, the control system keeps the speed constant and settles at new desired speed within 0.5 secs. Also the torque ripple is very low at 2.5%.

The stator phase current is 5 A which is also in fair limit which can be applied to the stator phase winding for safe operation.
Simulation Parameters for variable speed in SL-QZSI fed BLDC Motor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Input Voltage</td>
<td>0-650V</td>
</tr>
<tr>
<td>Carrier Frequency</td>
<td>10KHz</td>
</tr>
<tr>
<td>Z-Source Parameters</td>
<td></td>
</tr>
<tr>
<td>L1=L2=L3</td>
<td>0.5mH</td>
</tr>
<tr>
<td>C1=C2</td>
<td>220uF</td>
</tr>
<tr>
<td>Load Torque</td>
<td>41 Nm</td>
</tr>
<tr>
<td>Ref. speed</td>
<td>15000-10000-12000 rpm</td>
</tr>
<tr>
<td>Kp</td>
<td>0.07</td>
</tr>
<tr>
<td>Ki</td>
<td>0.5</td>
</tr>
<tr>
<td>Hysteresis Band</td>
<td>0.4</td>
</tr>
</tbody>
</table>

From fig 11(a), it is observed that this drive system can attain the speed of 15000 within 1.2s and variation in speed is achieved with a fast speed adjustment to the desired speed. The load torque is directly proportional to the stator current and as with high torque, the stator phase current reaches 50A. The dc link voltage is boosted to 8000V at starting and the voltage across the capacitor is 4000V. The above analysis clearly represents that it can supply heavy loads, when there is a need of high speeds and medium load torque. However, when this motor drive system is used with a load torque more than 70 Nm, then the efficiency decreases and reaches to 50%. When operating at high speed low torque, than the motor drive’s efficiency reaches up to 85%.

6. Conclusion

This paper proposes a new model for speed control of SLqZSI fed BLDC motor. A new switching algorithm has been proposed for SL-qZSI with BLDC motor by sensing the rotor position through Hall sensors and controlling the speed and torque by designing double-loop control. As speed is increased the back EMF also increases. This increase in back EMF, results in a reduced torque. Inverter supplies a high voltage to the BLDC motor when it is required to drive high power load. SL-qZSI helps in increasing the back EMF to a value which is required for attaining the desired speed. Analysis shows that when the modulation index is at 0.83, boost factor is near to 5 times and it is the optimum operating point as the shoot-through current remains in the permissible range. The speed can vary from 0 to 15000 rpm rapidly and settling at desired speed within 1.4s. The control of speed is smooth and the efficiency at high speed low torque is more than 85%. It is basically a constant torque drive hence it can conclude that this drive is best suited for application which needs a variable range of high speed and constant medium/low load torque.

References

[6] Control guru (practical process control) Integral action and pi control

Volume 6 Issue 6, June 2017
www.ijsr.net
Licensed Under Creative Commons Attribution CC BY

