Sensor Less Control of Z-Source Inverter Fed BLDC Motor Using Sliding Mode Observer

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Abstract— Z – source inverters have been recently proposed as an alternative power conversion concept as they have both voltage buck and Boost capabilities. These inverters use a unique impedance network, coupled between the power source and converter circuit, to provide both voltage buck and boost properties, which cannot be achieved with conventional voltage source and current source inverters. This paper deals with sensor less control of Z-source inverter under Direct torque control to get an instantaneous torque control. Sliding mode observer is a parameter for estimating the phase to phase trapezoidal back-EMF in sensor less mode. Z-source inverter is used to boost up the voltage. The simulation results of Z-source inverter is shown.

Key words: BLDC motor, Z-source inverter(ZSI), Sliding mode observer, Direct Torque Control

I. INTRODUCTION

BLDC motors are becoming so popular in industrial applications. Because of its High efficiency, High torque, Low acoustic noise, Less maintenance, longer life time and large inertia ratio when compared to brushless AC motors. BLDC motor is also known as electronically commutated motors are synchronous motors. A BLDC motor is an inside out DC commutator motor with mechanical commutator replaced by an electronic switching converters. The existing two converters are voltage source inverter and current source inverters. In voltage source inverter and current source inverter the reliability is low, complexity is high and the power factor is low with decreasing speed. To overcome these limitations z-source inverter is used.

II. Z- SOURCE INVERTER

Z-Source inverter is a type of power inverter that converts direct current into alternating current. It works as Buck-boost inverter. Z-source inverter eliminates the problems of voltage source inverter and current source inverter. Z-source inverter is a two-port network that consists of inductance and capacitance which are connected in x-shape to provide an impedance source.. With the unique LC network, we can intentionally add the shoot through state to boost the output voltage.. Z-source inverters has some advantages when compared to voltage source inverters and current source inverters. By using z-source inverter the switching losses can be reduced. The z-source inverter is applied to all DC-AC, AC-DC, AC-C and DC-DC power conversion.

A. Operation of z-source inverter

The figure 1 shows the Z-source inverter. It consists of inductor, capacitor and diode which are connected in series with the supply. The function of diode is to block the reverse current. Z-source inverter has the capability of allowing the power switches of a phase leg to be turned on when compared to voltage source inverter.

Fig. 1: Z-Source Inverter

Fig. 2: Non Shoot Through Mode Of Zsi

Z-source inverter can produced the high output voltage even for lower input voltage. The z-source inverter has two operating modes. Due to some additional special structure, the ZSI has an additional switching state, when the load terminals are shorted through upper and lower switching devices of any one phase leg, which is known as shoot through. The input diode is reverse biased during the shoot through mode. There are shoot-through mode and non-shoot through mode. The block diagram of non-shoot through mode is shown in figure 2. The figure 3 shows shoot through mode of Z-source inverter.

Fig. 3: Shoot Through Mode Of Zsi
At that time the input dc source is isolated from the load and two capacitors are discharged the energy to the inductors and to the load. This mode is not allowed to inverter control strategies. In order to reduce the volume and cost of passive elements of Z-source inverter, it is important to keep the shoot through duty ratio constant.

Fig. 4: Block Diagram Of Torque Control Of Blde Motor With Zsi

The input diode turns on during the non-shoot through mode. In this operation the inductor will transfer the energy to the load and the capacitor gets charged which results in the dc link voltage is boosted. The block diagram of Z-Source inverter is shown in figure 4. It consists of Sliding mode observer, BLDC motor, Z-source inverter, PI controller, Rotor flux observer, Torque estimation, Space vector PWM.

1) ADVANTAGES OF ZSI
- The load of ZSI can either be inductive (or) capacitive (or) another z-source inverter.
- The main circuit of ZSI can be either traditional CSI (or) VSI
- The source of Z-source inverter can be either current source (or) voltage source
- The dc source of ZSI can be either battery (or) diode rectifier.
- It provides power factor and reduces the harmonic current and common-mode voltages.

III. DIRECT TORQUE CONTROL

Direct Torque control is used in industries for attaining good dynamic performance. The application of direct torque control to a three phase BLDC drive operating in 120° conduction mode for obtaining instantaneous torque control and it may reduce the torque ripples. In DTC scheme, the torque command is obtained from two level hysteresis controller by comparing the estimated electromagnetic torque with their references value. It is obtained from the speed error Hall sensors are used to sense the rotor position. It may increase the cost, size, weight of the motor and its reliability is low. To overcome these limitations sensor less control is used. By using this control we can estimate the position and velocity. In this paper, DTC scheme in the constant torque region under two-phase conduction based on sliding mode observer with signum and saturation functions for estimating the back-EMF. The torque is calculated which is mainly based on the measured stator voltages and currents. Torque error, stator flux error, and stator flux angles are regularly used to select proper voltage space vector for switching in DTC technique. In this paper flux linkage error is eliminated because of variations of stator flux magnitude regarding changes in resistance, current and voltage, and specifically sharp dips at every commutation. This is due to the presence of freewheeling diode. Therefore the control of stator flux linkage is very complex. Direct torque control method has some advantages when compared to vector control. The following advantages of DTC is given.

A. Advantages Of Direct Torque Control
- Switching losses are reduced.
- Dynamic response is fast.
- It reduces the complexities.

The block diagram of DTC is shown in figure 5. Transforming the state equation of BLDC motor in $\alpha - \beta$ stationery reference frame can be written as:

$$V_{sa} = R_s i_s + L_s \frac{d}{dt} i_s + e_\alpha$$

$$V_{sb} = R_s i_s + L_s \frac{d}{dt} i_s + e_\beta$$

Where $V_{sa}$, $V_{sb}$, $i_{sa}$, $i_{sb}$, $e_\alpha$, $e_\beta$ are the stator voltage, stator current and back-EMF in the $\alpha - \beta$ stationery reference frame.

Fig. 5: Direct Torque Control

Electromagnetic Torque for DTC can be expressed as:

$$T_e = \frac{3P}{4} \left( \frac{d\psi_{ra}}{d\theta_e} i_{sa} + \frac{d\psi_{rb}}{d\theta_e} i_{sb} \right)$$

Where $\psi_{ra}$ and $\psi_{rb}$ are the $\alpha - \beta$ axis rotor flux components, P is the number of poles and $\theta_e$ is the rotor electrical angle. The differential form of the rotor flux components respect to $\theta_e$ can be derived from the ratio of the back-EMF to the electrical angular velocity $\omega_e$ can be written as,

$$\frac{d\psi_{ra}}{d\theta_e} = \frac{d\psi_{ra}}{dt} \frac{dt}{d\theta_e} = \frac{1}{\omega_e} \frac{d\psi_{ra}}{dt} = \frac{e_{\alpha}}{\omega_e}$$

$$\frac{d\psi_{rb}}{d\theta_e} = \frac{d\psi_{rb}}{dt} \frac{dt}{d\theta_e} = \frac{1}{\omega_e} \frac{d\psi_{rb}}{dt} = \frac{e_{\beta}}{\omega_e}$$

Where $\omega_e = \frac{d\theta_e}{dt}$

Then the electromagnetic torque can be written as,

$$T_e = \frac{3P}{4} \left[ e_{\alpha} i_{sa} + e_{\beta} i_{sb} \right]$$

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Rotor angle velocity calculation can be obtained from the estimation of sliding mode observer.

B. ROTOR FLUX OBSERVER

The rotor flux components can be calculated by using rotor flux observer

$$\psi_{sa} = -L_s i_{sa} + \int (V_s a - R s i a) dt \tag{7}$$

$$\psi_{sb} = -L_s i_{sb} + \int (V_s b - R s i b) dt \tag{8}$$

To control the electromagnetic torque in DTC scheme, the rotor flux vector position can be obtained as,

$$\theta_r = \tan^{-1} \left( \frac{\psi_{sb}}{\psi_{sa}} \right) \tag{9}$$

IV. SLIDING MODE OBSERVER

Sliding mode observer is used to estimate the stator flux. It is a non-linear control method that may modifies the system performance. The SMO can be designed with two approaches. In the first approach the system equations can be converted into two suitable sub systems. The second approach is for designing the state observer. SMO is also used to estimate the back-EMFs accurately. The equations of SMO is stated as,

$$\frac{d i_{sa}}{dt} = -\frac{R_s}{L_s} i_{sa} + \frac{\epsilon_a}{L_s} + \frac{v_{sa}}{L_s} + K_{s1} \sigma \gamma (\dot{i}_{sa}) \tag{10}$$

$$\frac{d i_{sb}}{dt} = -\frac{R_s}{L_s} i_{sb} + \frac{\epsilon_b}{L_s} + \frac{v_{sb}}{L_s} + K_{s2} \sigma \gamma (\dot{i}_{sb}) \tag{11}$$

Where, \( \dot{i}_{sa}, \dot{i}_{sb}, \dot{\epsilon}_a, \dot{\epsilon}_b \) are the estimation of \( \alpha - \beta \) axes stator currents and back-EMFs respectively. In the conventional method, a single observer gain value is selected for estimating back EMF which suits well only for particular range of speeds for which the observer gain is desined. The invariable observer gain produces multiple zero crossing for low speeds and a phase delay for large range of speeds. In the proposed method, value of the observer gain varies in accordance with the variation of speed to match the estimated back EMF with actual. When SMO with signum functions is implemented to estimate the back-EMF of BLDC motor. So chattering occurs when using signum function. In order to reduce the chattering, instead of signum functions saturation is given.

A. Rotor Position And Speed Estimation

The rotor position can be determined from the estimation of back-EMFs. The rotor position can be calculated by using the following equation.

$$\dot{\theta}_r = \tan^{-1} \left( \frac{E_{phase}}{E_{phase}} \right) \tag{12}$$

The rotor angular velocity can be estimated by the following formula

$$\omega_r = \frac{E_{\text{max(phase to phase)}}}{2K_e} \tag{13}$$

Where, \( E_{\text{max(phase to phase)}} \) is the amplitude of phase to phase back-EMFs and \( K_e \) is the back-EMF s constant.

V. SIMULATION AND RESULTS

The proposed sensor less control of Z-source inverter fed BLDC motor using sliding mode observer has been verified through the simulation diagram. The reference speed is set by 1500 rpm. The supply voltage is set by 250v. By controlling the current speed can be controlled. The theta value is estimated by integrating the speed. The flux value can be obtained through the stator voltage and current. The reference speed is compared with the calculated speed. Similarly, the reference torque is compared with the measured torque. Figure (6) shows the simulation diagram.
VI. CONCLUSION

This paper describes about the Sensor less control of Z-Source Inverter fed BLDC motor with Sliding Mode Observer. The torque ripples and losses can be minimized when using the Direct Torque control scheme. The Trapezoidal back-EMF waveform is estimated by using SMO technique. Space vector pulse width modulation is used as a modulation technique. The efficiency has been increased by reducing the total harmonic distortion. Voltage has been increased while implementing the Z-source inverter. The speed can be controlled by controlling the current. By integrating the speed the value of theta has to be estimated. The estimated speed is compared with the reference speed. Similarly, the calculated torque is compared with the reference torque. The flux value can be estimated from the stator voltage and current. Sliding mode observer is implemented to reduce the overall system error and estimates the back-EMF.

From the simulated results it is evident that the torque ripples are reduced. The main advantage of this method is it uses sensor less technique for the three phases. So it reduces the cost, size and weight.

REFERENCES

