Performance Enhancement of Sensorless Control of Z-Source Inverter Fed BLDC Motor

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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 sensorless 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 sensorless mode. Z-source inverter is used to boost up the voltage. The hardware results of Z-source inverter is shown.

Keywords: 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.

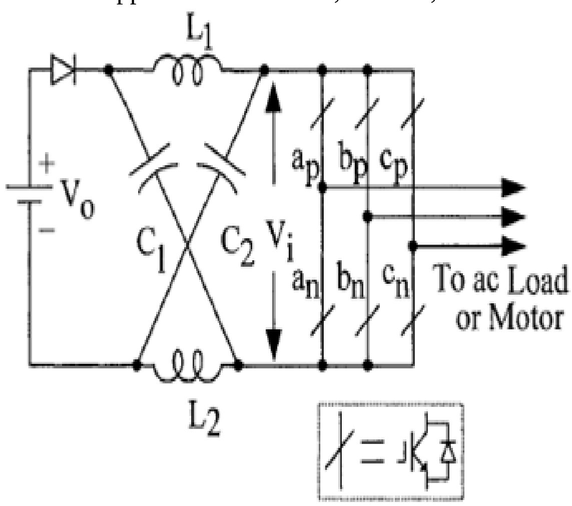

Fig. 1: Z-SOURCE INVERTER

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. Z-source inverter can produced the high output voltage even for lower input voltage.

The z-source inverter has two operating modes. There are shoot-through mode and non-shoot through mode.The block diagram of non-shoot through mode is shown in figure 2.

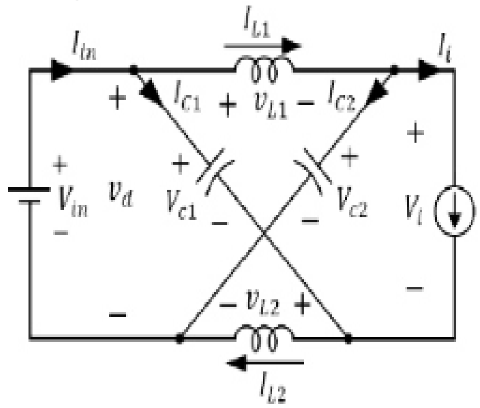

Fig. 2: NON Shoot through Mode of ZSI

The figure 3 shows shoot through mode of Z-source inverter

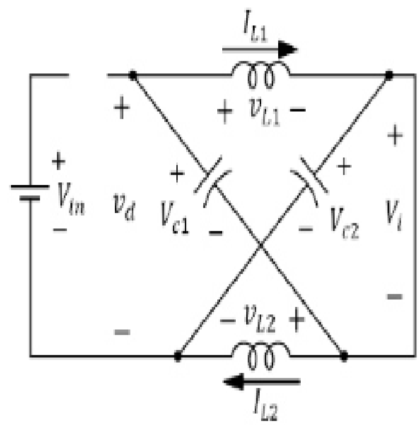

Fig. 3: Shoot Through Mode of ZSI

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. At that time the input dc source is isolated from the load and two capacitors are discharges 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. 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.

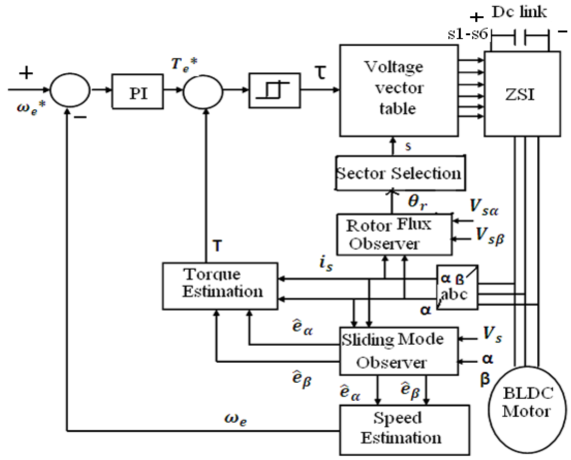

Fig. 4: Block Diagram of Torque Control of BLDC Motor with ZSI

B. *Advantages of ZSI:*

1) The load of ZSI can either be inductive (or) capacitive (or) another z-source inverter.
2) The main circuit of ZSI can be either traditional CSI (or) VSI.
3) The source of Z-source inverter can be either current source (or) voltage source.
4) The dc source of ZSI can be either battery (or) diode rectifier.
5) 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〗^0 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 sensorless 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.

- Advantages of Direct Torque Control:

1) Switching losses are reduced.
2) Dynamic response is fast
3) It reduces the complexities.

The block diagram of DTC is shown in figure 5.

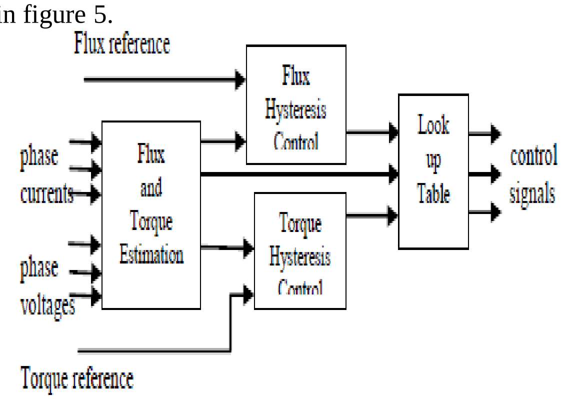

Fig. 5: Direct Torque Control

Transforming the state equation of BLDC motor in α-β stationery reference frame can be written as:

$$V_{s\alpha} = R_s\, i_{s\alpha} + L_s \frac{d}{dt} i_{s\alpha} + e_\alpha \quad (1)$$

$$V_{s\beta} = R_s\, i_{s\beta} + L_s \frac{d}{dt} i_{s\beta} + e_\beta \quad (2)$$

Where $V_{s\alpha}$, $V_{s\beta}$, $i_{s\alpha}$, $i_{s\beta}$, e_α, e_β are the stator voltage, stator current and back-EMF in the $\alpha-\beta$ stationery reference frame.
Electromagnetic Torque for DTC can be expressed as:

$$T_e = 3\frac{p}{4}\left[\frac{d\psi_{r\alpha}}{d\theta_e} i_{s\alpha} + \frac{d\psi_{r\beta}}{d\theta_e} i_{s\beta}\right] \quad (3)$$

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

$$\frac{d\psi r\alpha}{d\theta_e} = \frac{d\psi r\alpha}{dt}\frac{dt}{d\theta_e} = \frac{1}{\omega_e}\frac{d\psi r\alpha}{dt} = e_\alpha/\omega_e \quad (4)$$

$$\frac{d\psi r\beta}{d\theta_e} = \frac{d\psi r\beta}{dt}\frac{dt}{d\beta} = \frac{1}{\omega_e}\frac{d\psi r\beta}{dt} = e_\beta/\omega_e \quad (5)$$

Where $\omega_e = \frac{d\theta_e}{dt}$
Then the electromagnetic torque can be written as,

$$T_e = 3\frac{p}{4}\left[e_\alpha i_{s\alpha} + e_\beta\, i_{s\beta}\right] \quad (6)$$

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

A. Rotor Flux Observer:

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

$$\psi_{sa} = -L_s i_{sa} + \int (Vs\alpha - Rsis\alpha)\, dt \quad (7)$$

$$\psi_{sa} = -L_s i_{s\beta} + \int (Vs\beta - Rsis\beta)\, dt \quad (8)$$

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

$$\theta_r = \tan^{-1}\left(\frac{\varphi_{r\beta}}{\varphi_{r\alpha}}\right) \quad (9)$$

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,

$$\frac{di_{s\alpha}}{dt} = -\frac{R_s}{l_s}\hat{\imath}_{s\alpha} - \frac{\hat{e}_\alpha}{L_s} + \frac{V_{s\alpha}}{L_s} + K_{11}\sigma\gamma\nu(\tilde{\imath}_{s\alpha}) \quad (10)$$

$$\frac{di_{s\beta}}{dt} = -\frac{R_s}{l_s}\hat{\imath}_{s\beta} - \frac{\hat{e}_\beta}{L_s} + \frac{V_{s\beta}}{L_s} + K_{22}\sigma\gamma\nu(\tilde{\imath}_{s\beta}) \quad (11)$$

Where, $\hat{\imath}_{s\alpha}$, $\hat{\imath}_{s\beta}$, $\hat{e}_\alpha$, $\hat{e}_\beta$ 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 designed. 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.

$$\hat{\theta}_r = \tan^{-1}\left(\frac{\hat{e}_\beta}{\hat{e}_\alpha}\right) \quad (12)$$

T he rotor angular velocity can be estimated by the following formula

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

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

V. HARDWARE REPRESENTATION AND ITS RESULTS

A. Components of Hardware:

1) Transformer
2) Rectifier
3) Z-Source Inverter
4) Controller Circuit
5) BLDC Motor
6) CRO
7) Capacitor
8) Variable resistor
9) LCD display

The hardware structure of ZSI fed BLDC Motor and the specifications of the above components are discussed below.

Fig. 6: Hardware Structure of ZSI Fed BLDC Motor

B. Transformer Specifications:

– Phase - 1 Phase
– Power - 24VA
– Voltage - 24V
– Current - 2A

C. BLDC Motor Specifications:

– Phase - 3 Phase
– Power - 400 Watts
– Speed - 12000 r/min
– Voltage - 5VDC/12VDC
– •Current - 3A

D. ZSI Specifications:

– Phases - 1 phases
– Semi-conductor - 4 IGBT
2 Upper leg
2 lower leg

E. PIC 16F877A:

PIC16F873A/876A devices are available only in 28-pin packages, while PIC16F874A/877A devices are available in 40-pin and 44-pin packages. All devices in the PIC16F87XA family share common architecture with the following differences:

1) The PIC16F873A and PIC16F874A have one-half of the total on-chip memory of the PIC16F876A and PIC16F877A.
2) The 28-pin devices have three I/O ports, while the 40/44-pin devices have five.
3) The 28-pin devices have fourteen interrupts, while the 40/44-pin devices have fifteen.
4) The 28-pin devices have five A/D input channels, while the 40/44-pin devices have eight.

The Parallel Slave Port is implemented only on the 40/44-pin devices. The PIC Microcontroller is shown in the below figure.

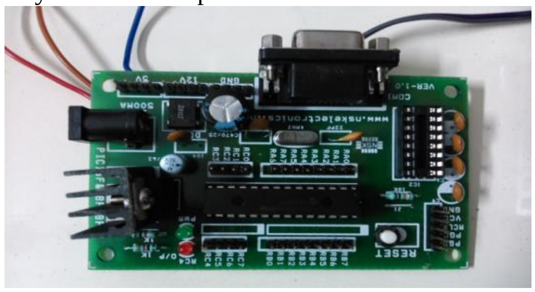

Fig. 7: Microcontroller Circuit

F. Hardware Description of ZSI Fed BLDC Motor:

The input transformer is rated at 230V/7A which is connected to the rectifier and the rectifier is used to convert the alternating current into direct current. It converts the 230v into 12V. It consists of four diodes and two capacitors. From the rectifier the current and voltage is given to the inductor and inverter. The combination of Inverter and inductor works as a Z-Source Inverter. IC 3525 is incorporated with this inverter. It will generate the pwm signals. The

Z-Source inverter generates 12v and which is given to the PIC microcontroller circuit. It is rated at 5V/3A. The pwm signals can be controlled by PIC controller. The range of PIC controller is PIC 16F877A. Voltage regulator (7805) can be used to regulate the voltage.

Z-Source inverter is connected to the output transformer which is connected in parallel and is rated at 230V/6A. The output transformer is connected to the BLDC Motor which is rated at 48V/2A and 96Watts. The speed can be displayed with the help of the LCD display. By adjusting the variable resistor the speed can be varied and the obstacle sensor is used to measure the speed. The Z-Source inverter output is connected to the CRO. The CRO generates the pwm signal waveform and back-EMF waveform. The output of the capacitor is connected to the CRO to get the voltage waveform.

G. Hardware Results:

The pulse width modulation waveform is shown in below figure 5.3.

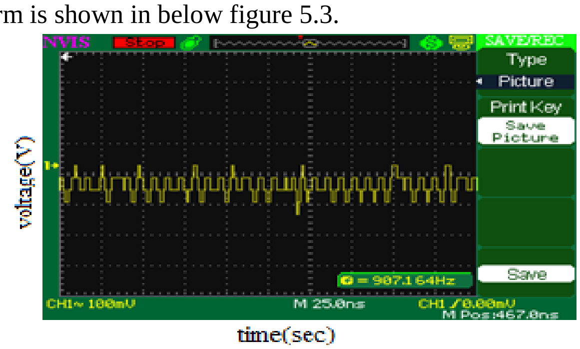

Fig. 8: PWM Waveform of Z-Source Inverter

The driver pulse waveform is shown in the below figure 5.4.

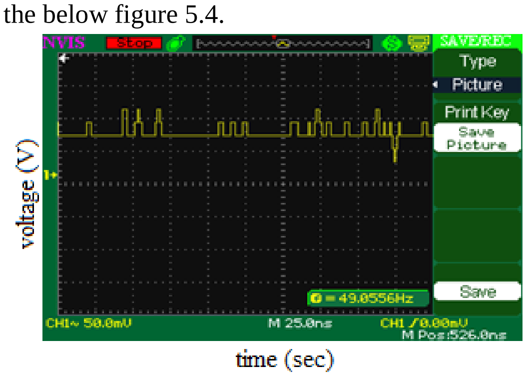

Fig. 9: Driver Pulse

VI. CONCLUSION

This paper describes about the Performance enhancement of Sensorless control of Z-Source Inverter fed BLDC motor. 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 hardware results it is evident that the torque ripples are reduced.

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