IJIREEICE
ISSN (Online) 2321-2004
ISSN (Print) 2321- 5526
International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering
NFTPCOS-18
National Conference on Future Technologies in Power Control and Communication Systems
College of Engineering Perumon, Kollam, Kerala
Vol. 1, Special Issue 2, March 2018

High Precision Sensorless Control of BLDC Motor with Z-Source Inverter

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Abstract: Brushless dc motors are getting more attention in many areas owing to its compactness, maintenance, high efficiency and low cost. Precise detection of rotor position is essential to achieve high efficiency. Mechanical sensor based methods increase size and inaccuracy. Back EMF method is one of the most popular control method for sensorless brushless dc motor. But this method is not suitable for high-speed operation, for the pulse width of zero-vector may be very short. Z-source inverter based approach to zero-crossing point detections during the shoot-through vectors for sensorless brushless dc motor is discussed here. This approach separates the zero crossing point detections from speed adjustment, and makes the shoot-through vector not influence the motor speed-adjustment directly. With this approach, the sensorless drive can operate in a wide speed range. It not only provides boost voltage for sensorless brushless dc motor drive system, but also improves the utilization rate of dc source voltage and the safety of the drive system.

Keywords: Brushless dc motor, sensorless, zero-crossing point detection, Z-source inverter

I. INTRODUCTION

Brushless DC (BLDC) motors are becoming widely used as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. These motors are basically synchronous motors with brushes replaced with electronic commutation. When using three-phase six-step commutation, current flows in only two phases at any time, leaving the third motor terminal floating [1]. For the operation of the inverter in BLDC control system, six discrete rotor position signals in one rotating cycle are required. The rotor position detecting methods can be classified into two categories: the mechanical position sensor-based methods and the sensorless methods. The typical sensors include the resolver, the encoder ,and the Hall-effect sensor, which are traditionally used in the mechanical position sensor-based methods [2]. However, these mechanical sensors need special arrangements to be mounted as well as increasing the cost, which limits the application in the high-speed motors. Hence, more and more researches are focused on the sensorless-based methods.
Various types of sensorless-based methods are present, includes the back-EMFs based method, the 3rd harmonic based method, the integration based method, the phase-locked loop (PLL) based method, and the flux linkage estimation based method. Among these, the most popular category is the back-EMF based method. The zero crossing of back EMF of the floating phase can be detected to determine the commutation sequence without Hall sensors. . Conventional methods use the concept of virtual neutral point. However, when using a chopping drive, the PWM signal is superimposed on the neutral voltage, inducing a large amount of electrical noise. This method tends to have a narrow speed range and a poor signal to noise ratio [3]. Back EMF sensing method does not require neutral voltage information. The true back EMF can be detected directly from terminal voltage by properly choosing the PWM and sensing strategy. The research about direct back EMF sensing method focuses on two aspects. One is to extend its application to the method to a wide range of speed and load torque, and to increase the utilization rate of dc source voltage. Another is to improve its precision.
Two traditional inverters normally used for AC drive applications are Voltage Source Inverter (VSI) and Current Source Inverter (CSI).These traditional inverters have relatively low efficiency, because of switching losses and considerable EMI generation. The Impedance Source Inverter overcomes these problems. For applications of AC drive system operating over a wider speed range, it is preferable to have the power converter with the buck and boost capability [4]. i.e., Impedance Source Inverter or Z-Source inverter. The paper discusses about the Z-source Inverter based approach to the zero crossing point detection of back emf for sensorless BLDC motor. Fig.1 shows the entire block diagram of Z-source inverter fed BLDC motor drive.

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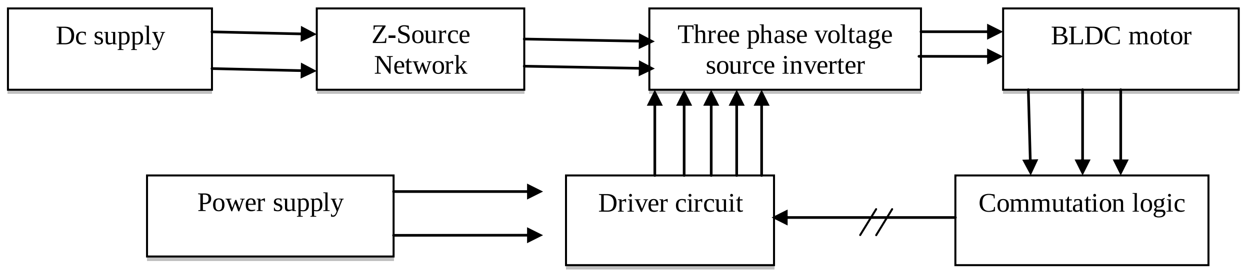

Fig.2 Block diagram of Z-source inverter fed sensorless BLDC motor

II. SENSORLESS MODEL OF BLDC MOTOR

BLDC motors are driven by a three-phase inverter with six-step commutation. Each conducting phase is called a step. The conducting interval for each phase is 120 electrical degrees. Therefore, only two phases conduct current at any time, leaving the third phase floating. The gate signals of switches are obtained from the line voltage measured across the terminals of the motor. The difference between the line voltages gives the back emf of the motor. Zero crossing point of the back emf is identified and hall signals are generated using the sequential logic. From the hall signals switching pulses for inverter are generated by commutation logic. Commutation delay is given as 30 electrical degrees. Fig.2 shows the block diagram of sensorless control of BLDC motor[5].

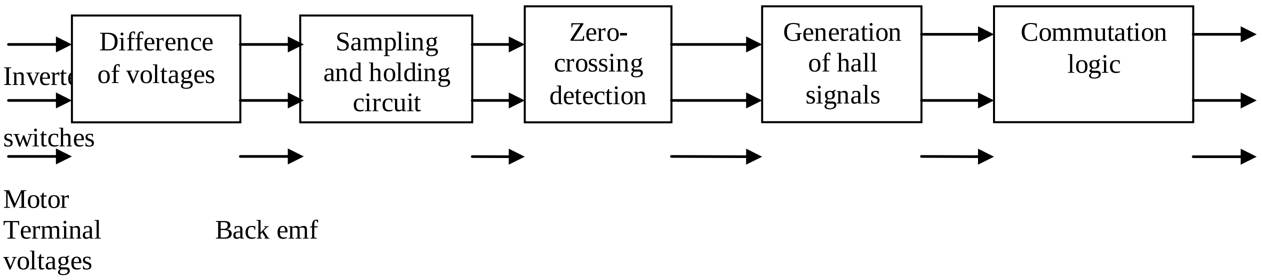

Fig.2 Block diagram of sensorless control of BLDC motor

The model of the BLDC motor used for simulation is obtained by using a built-in model of a Permanent Magnet Synchronous Machine (PMSM) in the Matlab Simulink.

III. INTRODUCTION TO Z-SOURCE INVERTER

The Impedance Source Inverter or Z-source inverter is a unique Impedance Network coupled with the inverter main circuit. This inverter has unique features compared to the traditional inverters and it overcomes the limitations of conventional voltage and current source inverters. As in Fig.3 it has a two port network that consists of split inductors L1 and L2 and capacitors C1 and C2 connected in X-shape to get the Z-source. The Z-source inverter utilize the shoot-through states to boost the dc current bus voltage by switching both the upper and lower switches of the same phase leg. By varying the shoot-through time period and boost factor the output voltage of the Z-source inverter can be varied [6]. Thus the Z-source inverter can buck/boost the input voltage accordingly to get desired output voltage. In conventional inverters the shoot-through states are prohibited in order to protect the circuit from large short circuit current. Longer the time, in which the shoot through states is employed, higher the voltage gets.

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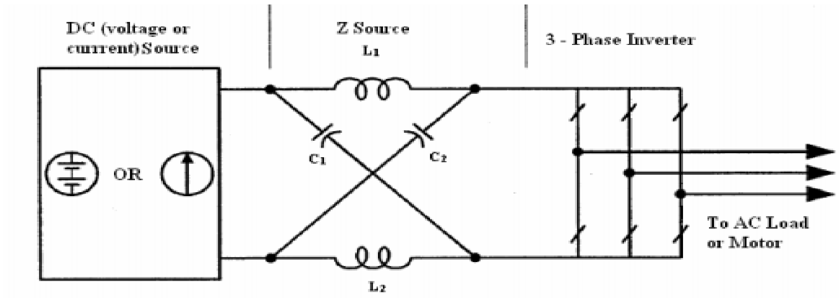
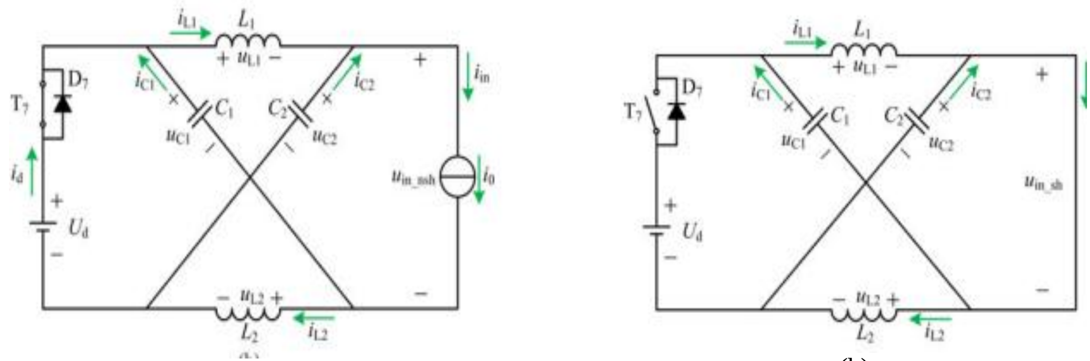


Fig.3 Z-source inverter topology

A. Z-Source Inverter Operation



(a) (b)

Fig.4 Equivalent circuits (a) shoot through state. (b) Non shoot through state

A three phase z source inverter has six active states two zero states and seven shoot through states. In non-shoot-through states, the output current of Z-source network can be represented by a constant current source by neglecting its ripple content [7]. The inverter bridge is operating in one of the six active states. In shoot through states both the upper and lower switches of the same leg is gated simultaneously. The shoot through states boosts the dc link capacitor voltage and also partially provides null states within a fixed switching cycle. Shoot through states are added immediately adjacent to the active states in such a way that equal null intervals are maintained at start and end of the switching cycles so as to achieve same optimal harmonic performance. The output voltage during shoot through period is zero [8].

Fig.8 shows the carrier signal and reference voltage signals for the generation of PWM signals of Z-source inverter. The Vp and Vn are the control signals for the shoot-through. When Vp is lower than the carrier signal, the upper switches in the three legs are switched on. When Vn is higher than the carrier signal, the lower switches in the three legs are switched on. The control signal Vp should have limit value. The maximum value is half of the input dc link voltage and the minimum value is the amplitude of the three phase reference voltage signal [9].

IV. SIMULATION ANALYSIS

Simulation of sensorless BLDC motor, Z-source inverter with shoot through and non-shoot through states, Z-source inverter fed sensorless BLDC are done using MATLAB/SIMULINK software. Fig.5 shows the simulation diagram of sensorless BLDC motor and Fig.6 shows the entire simulation diagram of the system i.e, Z-source inverter fed sensorless BLDC motor drive.

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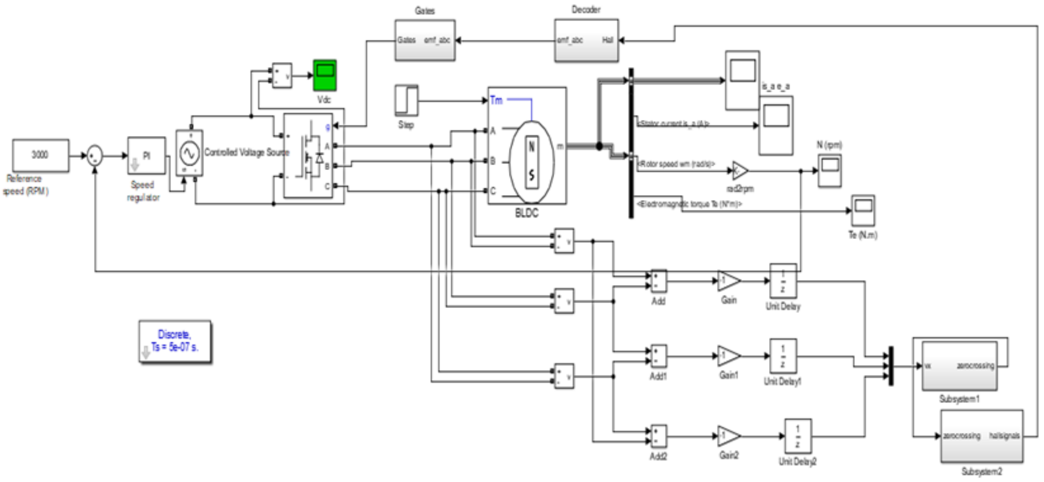

Fig.5 Sensorless control of BLDC motor

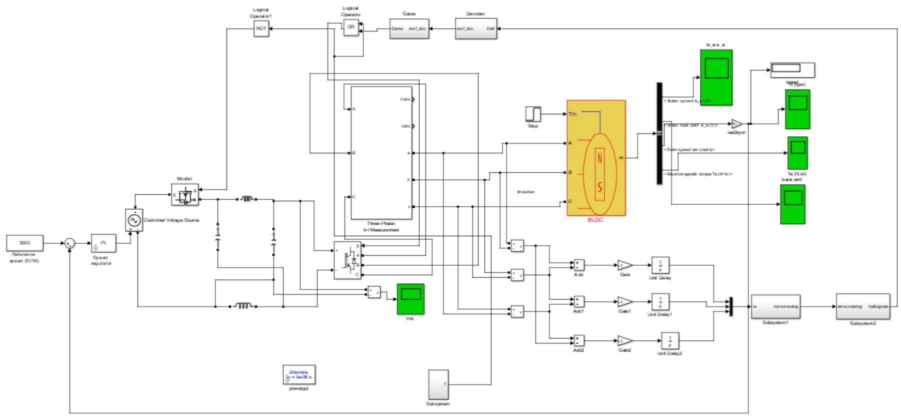

Fig.6 Z-source inverter fed sensorless BLDC motor drive

imulated waveforms are analyzed and compared with each other to get the effectiveness of the particular approach. Waveforms obtained from the simulation of sensorless BLDC motor is shown below in Fig.7 (a)(b)&(c). Speed is obtained as 2000 rpm. Trapezoidal back emf is obtained around 110V. Stator current obtained is within the limit of rated current. Simulation parameters for BLDC motor and Z-Source inverter are listed in the tables below.

TABLE I. Parameters of BLDC motor

SL.NO.	PARAMETER	VALUE
1	Rated Voltage	24V
2	Rated Speed	3000 rpm
3	Rated current	4A
4	Number of poles	4
5	Rated Torque	0.23Nm
6	Resistance per phase	3.58Ω
7	Inductance per phase	9.13mH
8	Torque Constant	0.74Nm/A
9	Moment of inertia	2.9Kgcm^2

TABLE II. Parameters of Z-Source inverter

SL.NO.	PARAMETER	VALUE
1	Rated Voltage	24V
3	Rated current	4A
5	Rated Torque	0.23Nm

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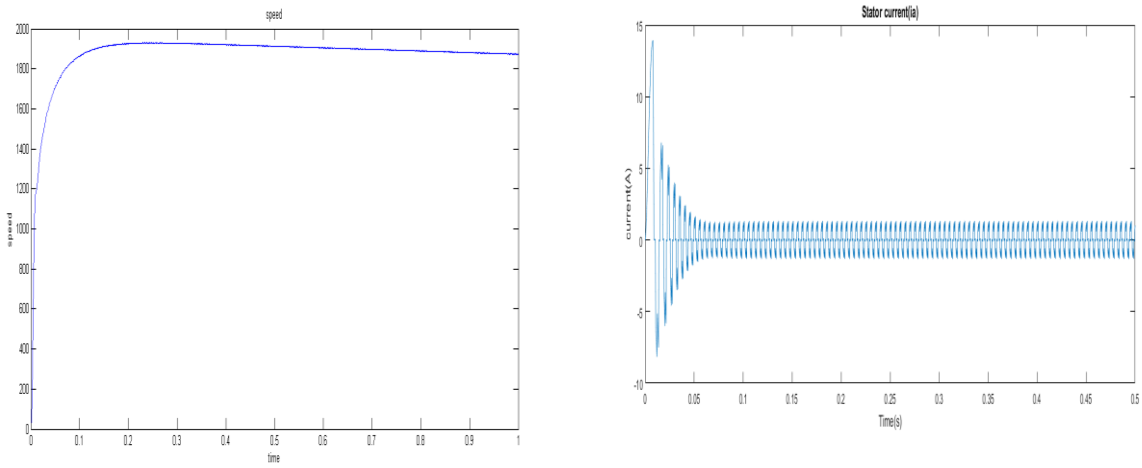
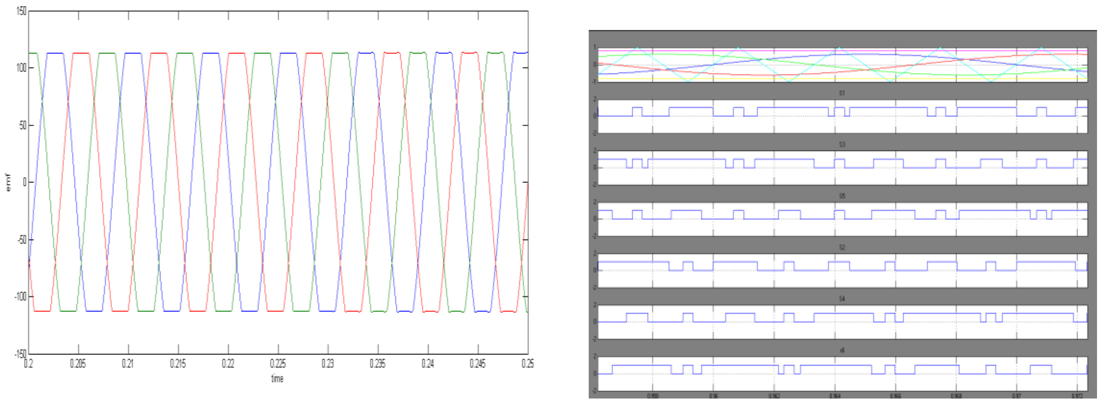


(a) (b)

Fig.7 Simulation results of sensorless BLDC motor (a) Stator current (b) Speed (c) Back emf

When shoot through pulses are given to the Z-Source inverter switches the output dc link capacitor voltage become boosted up. Fig.9 (a) shows the capacitor voltage with the non-shoot through state of the inverter and (b) shows the boosted capacitor voltage with shoot through state of the inverter. Without shoot though the voltage obtained is around 120V and boosted voltage with shoot through is about 550V. Since the voltage increase the speed of the motor is also increases, it is obtained about 2500 rpm, shown in Fig.10.



(c)

Fig.8 Shoot through pulses for Z-source inverter

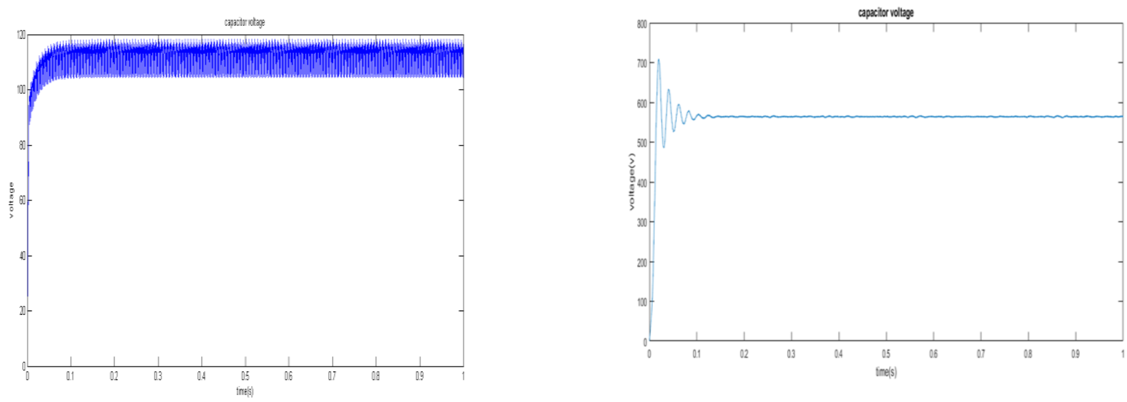


Fig. 9 output dc link capacitor voltage (a) with non shoot through (b) with shoot through

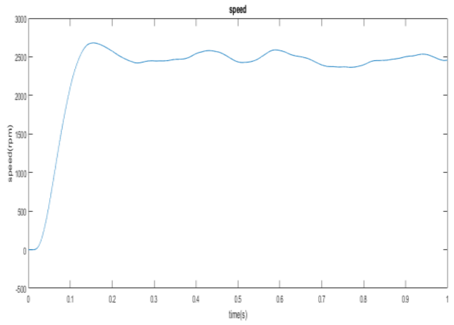


Fig.10 Speed of Z-source inverter fed sensorless BLDC motor

V. CONCLUSION

Z-source inverter based sensorless control of BLDC motor is discussed in this paper. The sensorless approach by zero crossing detection of back emf is utilized for the wide range speed control of the motor. Zero crossing points are detected during the shoot through instants of the Z-source inverter .Boost PWM provided for Z-source inverter leads the boost operation of the inverter. Sensorless method increases efficieny and reliability. Also Z-source inverter allows speed adjustment and improves stability.

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