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A SIMPLE POSITION SENSORELESS CONTROL STRATEGY OF FOUR SWITCH THREE PHASE BRUSHLESS DC MOTOR DRIVES USING SINGLE CURRENT SENSOR

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Abstract- Cost minimizing of the electrical machine drives is more attractive for low cost application. The low cost BLDC driver is achieved by the reduction of switch devices, cost down of control, and saving of hall and current sensor. In this project, a simple position sensorless control strategy four-switch three phase BLDC motor drives using single current sensor is proposed. The whole working process of the BLDC motor is divided into six modes. Phase c involves four modes, including modes 2, 3, 5 and 6. Only one switch will work in these modes. In modes 1 and 4, two switches will work simultaneously and current flow through phase a and b. The proposed sensorless scheme is based on the detection of zero crossing points(ZCPs) of three voltage function that are derived from the difference of line voltages measured at the terminals of the motor. Unlike the conventional methods, proposed control strategy has been used only one simple current controller for three phases. The effectiveness of the proposed system has been validated by simulation results.

Keywords- Brushless DC motors, four switch three phase inverter, Proportional integral derivative, Zero crossing points, and Single current sensor

I INTRODUCTION

Brushless DC motor have been widely used in a variety of applications in industrial automation and consumer applications because of their high power density, compactness, high efficiency, low maintenance and ease of control. Nowadays, many studies have been focused on how to reduce the cost of BLDC motor and its control system without performance degradation. The cost reduction of variable-speed drives such as BLDC motor drives is accomplished by two approaches. One is the topological approach and the other is the control approach. From a topology point of view, minimum number of switches and eliminating the mechanical sensors are required for the inverter circuit. In the control approach, algorithms are designed and implemented in conjunction with a reduced component inverter to produce the desired speed torque characteristics. In this paper, a single current sensor control strategy is used by the outer loop to develop the performance of speed control that leads to the same characteristics of six-switch converter for the proposed four-switch inverter. Cost saving is achieved by reducing the number of inverter switches, current sensor and the number of components in the position sensing system. Virtual Hall sensor signals are made by detection of zero crossing points of the difference between the lines voltages

measured at the terminals of the motor. In the proposed sensorless scheme, there is no need to any phase shift which is prevalent in most of sensorless algorithms.

II FOUR-SWITCH THREE PHASE BLDC MOTOR DRIVE

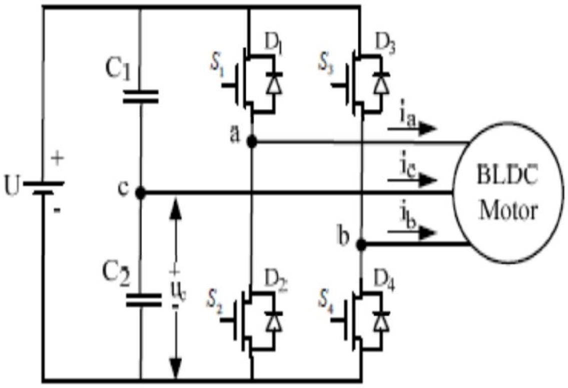


Fig 1 Four-switch three-phase inverter

Fig. 1 shows the configuration of a four-switch inverter for a three-phase BLDC motor. As shown in Fig. 1, two common capacitors are used instead of a pair of bridges, and phase *c* is out of control because it is connected to the midpoint of the series capacitors. A BLDC motor needs quasi-square current waveforms, which are synchronized with the back EMFs to generate constant output torque and have 120^0 conduction and 60^0 non conducting regions. Also, at every instant only two phases are conducting and the other phase is inactive. Compared with the conventional six-switch three-phase inverter for the BLDC motor, the whole working process of the BLDC motor in this paper is divided into six modes, as shown in Table I. Phase *c* involves four modes, including modes 2, 3, 5, and6. Only one switch should work in the four modes. These modes are divided into two sub operating modes. In modes 1and 4, phases a and b have current flowing through them, and ic should be zero. To avoid current waveform distortion, appropriate switch signals should be respectively used indifferent working modes, which imply that some new control schemes should be developed.

TABLE I

Working model of four-switch three phase BLDC motor drive

Mode	Hall values	Working phase	Current restraint	Conducting devices
Mode 1	101	+a, -b	$i_a = I^*, i_b = -I^*$	S_1, S_4
Mode 2	100	+a, -c	$i_a = I^*$	S_1
Mode 3	110	+b, -c	$i_b = I^*$	S_3
Mode 4	010	+b, -a	$i_b = I^*, i_a = -I^*$	S_2, S_3
Mode 5	011	+c, -a	$i_a = -I^*$	S_2
Mode 6	011	+c, -b	$i_b = -I^*$	S_4

Here, mode 1 is taken as an example to demonstrate the whole working process that is identical in mode 4. Mode 1 is divided into four sub operating modes, i.e. modes 11, 12, 13, and 14, as shown in Fig. 2. Switches S1 and S4 work in mode 11 with ua = U and ub = 0. Diodes D2 and D3 work in mode12 with *ua* = 0 and ub = U. Switch S1 and diode D3 work in mode 13 with ua = U and ub= U. Switch S4 and diode D2 Work in mode 14 with ua = 0 and ub = 0. According to Fig. 2, the four sub operating modes have different rules for adjusting the phase currents. In mode 11, ia and -ib rise quickly, and ic varies proportionally with the back EMF of phase c. In mode 12, ia and −ib drop quickly, and ic changes proportionally with the back EMF of phase c. Compared with modes 11 and 12, ic falls much quicker in mode 13 and rises much quicker in mode 14.In fact, when ic deviates significantly from zero, modes 13and 14 work. When ic remains at zero, modes 11 and 12 work. Because ia and ib cannot be detected, a speed loop and virtual Hall

signals are used here to decide the duty of PWM signals.

III CONTROL SYSTEM FOR FOUR-SWITCH THREE-PHASE BLDC MOTOR USING A SINGLE CURRENT SENSOR

The whole control system is shown in Fig. 3. The control system adopts the double-loop structure. The inner current loop maintains the rectangular current waveforms, limits the maximum current, and ensures the stability of the system. The outer speed loop is designed to improve the static and dynamic characteristics of the system. The system performance is decided by the outer loop. If the disturbance caused by the inner loop, it can be limited by the outer loop.

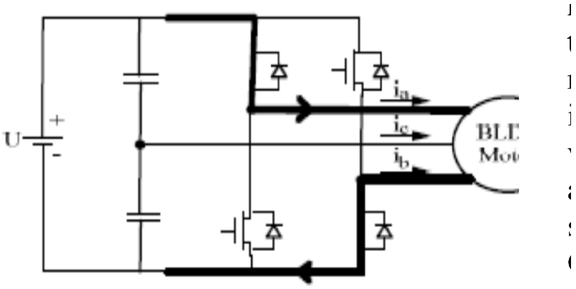
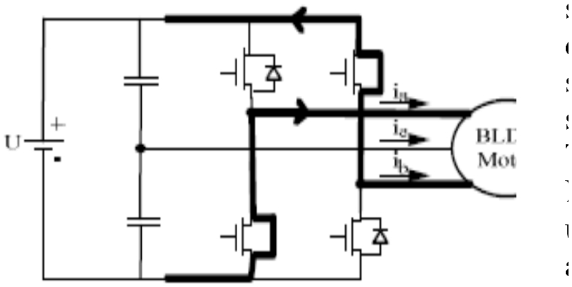
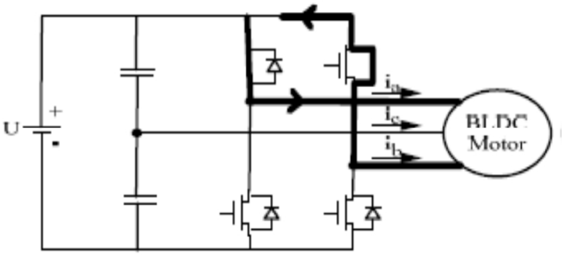


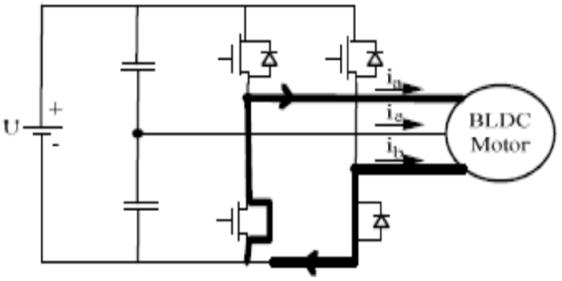
Fig 2: (a) Sub operating modes 11



(b) Sub operating mode 12



(c) Sub operating mode 13



(d) Sub operating mode 14

For BLDC motors with a trapezoidal back EMF, rectangular stator currents are required to produce a constant electric torque. The proposed voltage pulse width modulation (PWM) scheme for FSTP inverter requires six commutation modes which are (X,0), (1,0), (1,X), (X,1), (0,1) and (0,X), as shown in figure 2. The symbols in parenthesis denote the switch ON/OFF states of S_a^U,S_a^L,S_b^U, and S_b^U (phases A and B). " X" denotes the OFF state for both the high- and low-side switching devices in the same leg, "1" denotes the ON state for the high-side switching device, and "0" denotes the ON state for the low-side switching device. There are two modes need to be noted. In Mode II, if the FSTP BLDC motor drive uses the conventional voltage PWM scheme as, two stages corresponding to (1,0) and (X,0) in Mode II, respectively, are shown in Fig. 2 (a) and (b).

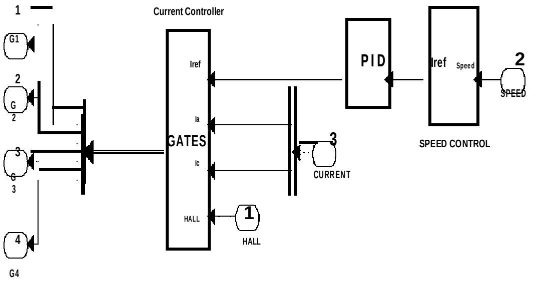


Fig 3 Controller Diagram

This conventional voltage PWM scheme provides a discharging loop between the capacitor and the low-side switch, and causes non-rectangular stator current waveforms which are harmful for constant torque, as shown. Similar situations occur in Mode V. This paper proposes a novel voltage PWM to overcome this drawback. There are three stages corresponding to (1,0),(X,0), and (X,X), respectively, in Mode II for the novel voltage PWM scheme. Experimental results show that the stator current waveforms of the FSTP inverter using this novel voltage PWM scheme are rectangular. Similar situations apply to Mode V.

IV POSITION SENSORLESS SCHEME BACK EMF ZERO CROSSING METHOD

The proposed position sensorless BLDC drive, is based on detection of back EMF zero crossing from the terminal voltages, for a six-switch three-phase BLDC motor. Considering a BLDC Motor with three stator phase windings connected in star. The BLDC motor is driven by a four-switch three-phase inverter in which the switches are triggered with respect to the rotor position. Consider the interval when phases *a* and *b* are conducing and phase *c* is open i.e. mode 4. In this interval, phase *b* winding is connected to the positive polarity of the DC supply, phase a to the negative polarity of the DC supply and phase *c* is open. Therefore ib = −ia and ic = 0 . Thus the back EMF of phase *c* may be estimated that during mode 4 the back EMF ec transients from one polarity to another zero crossing. Therefore the operation vbcca enables to detection of the zero crossing of the phase c EMF. Similarly, the difference of line-to-line voltage vabbc enables the direction of zero crossing of phase *b* back EMF when phases a and c back EMFs are equal and opposite. The difference of line-to-line voltage vcaab waveform gives the zero crossing of phase *a* back EMF, where phases c and b have equal and opposite back EMFs. Therefore the zero crossing instants of the back EMF waveforms may be estimated indirectly from measurements of only the three terminal voltages of the motor. By means of estimated back EMFs, virtual Hall sensor signals are made. This method is true even for a small rotation of the rotor.

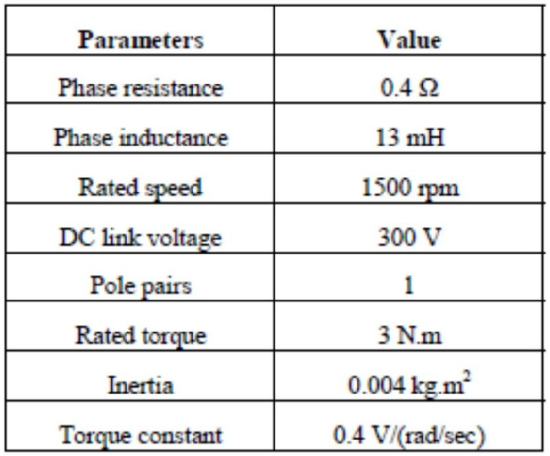
STARTING TECHNIQUE

The first step to start the sensorless drive is to get the initial rotor position. Since only in modes 1 and 4 the BLDC motor is supplied by whole DC bus, the inverter could supply enough power to drive the rotor to an expected position. Therefore, for starting, the motor is simply excites in mode 1 or 4 to force rotor to rotate in the specified direction.

V STIMULATION RESULT

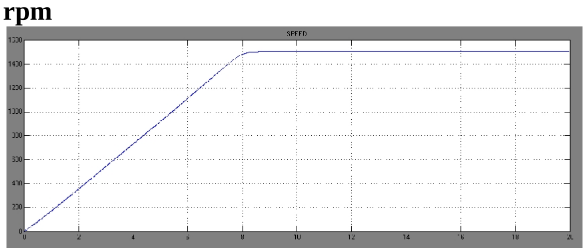
To evaluate the performance of the proposed system, simulation models have been established using MATLAB/SIMULINK. The main parameters of BLDC motor are listed in Table II. The Speed, phase currents and electromagnetic torque waveforms are depicted in Fig. 4, when the four-switch three phase BLDC motor is controlled by the single current sensor strategy and with

the position Hall sensor signals. The quasi square waveforms of phase currents using proposed method verify the good control capability of BLDC motor in comparison to conventional methods. As shown in Fig. 5, the current and torque ripples in conduction region are eliminated effectively. Also, the current and torque spikes in commutation region are very low.

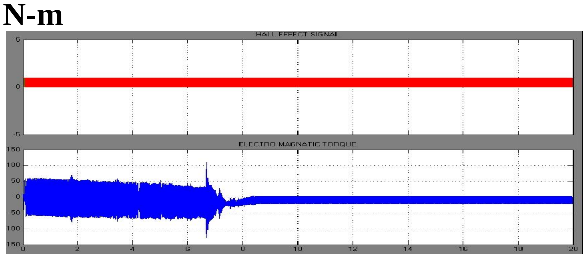


Parameters	Value
Phase resistance	0.4 Ω
Phase inductance	13 mH
Rated speed	1500 rpm
DC link voltage	300 V
Pole pairs	1
Rated torque	3 N.m
Inertia	0.004 kg.m^2
Torque constant	0.4 V/(rad/sec)

Table II
Three-phase BLDC motor stimulation parameters



t(s)
Fig 4 (a) speed



t(s)
(b) Hall effect signal and lectromagnetic torque

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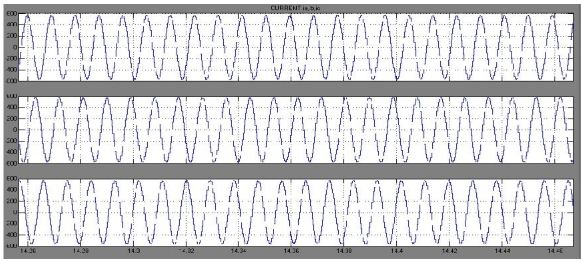
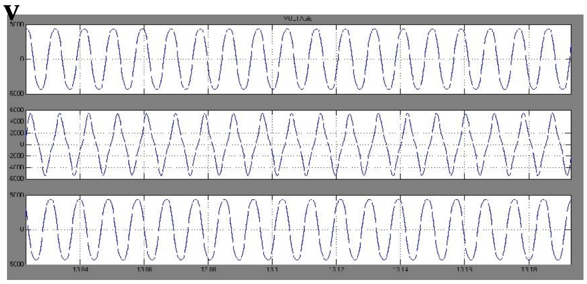


t(s)
(c) Phase currents



t (s)
(d) Phase voltages

Fig.4 (a,b,c,d) shows the position sensorless operation at rated speed 1500 rpm. Fig. 4(a, b) shows the speed and developed electromagnetic torque. It is clear that speed tracking is well and the developed torque has very low ripple. Moreover the current waveforms are the same as quasi-square waveforms with some low ripples

VI CONCLUSION

This paper introduced a new cost-effective BLDC motor drive. Cost saving is achieved by reducing the number of inverter switches, current sensors and the number of components in the position sensing system. The single current sensor control strategy is used by the outer loop to develop the performance of speed control that leads to the same characteristics of six-switch converter for the proposed four switch inverter. Virtual Hall sensor signals are made by detection of zero crossing points of the difference between the lines voltage measured at the terminals of the

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