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An Asymmetric PWM Scheme for Four-Switch Three-Phase Brushless DC Motor Drives

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Abstract

This paper proposes a position sensor less control scheme for four-switch three-phase (FSTP) brushless dc (BLDC) motor drives using a field programmable gate array (FPGA). The brushless dc motor drive became more popular for the commercial applications. Like Robotics, computer peripheral equipments, adjustable speed drives due to unique features like high power density, high efficiency, high torque, reliability, variable speed operation, low cost etc. In this paper, to drive FSTP BLDC motors a new sensor less control with six commutation modes and novel pulse width modulation scheme is developed. the modelling of four switch three-phase brushless dc motor drive using PI controller. The low cost BLDC motor driver is achieved by the reduction of switches and freewheeling diode count and conduction losses and the saving of the hall sensors. The position information is estimated from the crossing of the voltage waveforms in floating lines. The feasibility of the proposed sensor less control for FSTP BLDC motor drives is demonstrated by analysis using MATLAB and simulink.

*Index Terms—****The feasibility of the proposed sensor less control for FSTP BLDC motor drives is demonstrated by analysis and experimental results.***

I. INTRODUCTION

Permanent magnet motors with trapezoidal back EMF and sinusoidal back EMF have several advantages over other motor types. Most notably, (compared to dc motors) they are lower maintenance due to the elimination of the mechanical commutator and they have a high-power density which makes them ideal for high-torque-to weight ratio applications. The permanent magnet brushless dc (PMBLDC) motor is gaining popularity being used in computer, aerospace, military, automotive, industrial and household products because of its high torque, compactness, and high efficiency. A conventional BLDC motor drive is generally implemented via a six-switch, three-phase inverter and three Hall-effect position sensors that provide six commutation points for each electrical cycle. Cost minimization is the key factor in an especially fractional horse-power BLDC motor drive for home applications. Cost reduction of BLDC motor drive is accomplished by two approaches: the topological approach and the control approach. In topology approach, minimum number of switches and eliminating the mechanical sensors are the options while the control approach has choices in terms of complexity in control, nature of the control, implementation platform etc. In the control approach, using high performance processors, algorithms are designed and implemented in 126 conjunctions with a reduced component inverter to produce the desired torque characteristics. Therefore, effective algorithms should be designed for the desired performance. Recently, a four-switch, three-phase inverter (FSTPI) topology has been developed and used for a three-phase BLDC motor drive. Reduction in the number of power switches, dc power supplies, switching driver circuits, losses and total price are the main features of this topology. It results in the possibility of the four-switch configuration instead of the six switches. Compared with the four-switch converter for the induction motor, it is identical for the topology point

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of view. However, in the four-switch converter, the generation conducting current profiles is inherently difficult due of 120Û to its limited voltage vectors. This problem is well known as “asymmetric voltage PWM.” It means that conventional PWM schemes for the four-switch induction motor drive cannot be directly used for the BLDC motor drive. Therefore, in order to use the four-switch converter topology for the three-phase BLDC motor drive, a modified control scheme should be developed. A complete model of the PMBLDC motor drive with its performance in closed loop has been presented. The discussions have been a readable text on the operation, modeling, and control of BLDC motor for graduate students studying electric drives and control as well as practicing engineers in industries. The solutions can be obtained from a modification of the conventional voltage controlled PWM strategies, such as the space vector PWM. However, it naturally requires lots of equations for the transformation of voltage and current vectors, Įù and a–b–c frames. As a result, the current control such as block becomes much more complicated. Moreover, in order to 127 handle the complicated calculations in one sampling period, a high-speed digital processor is also necessary, which increases the manufacturing cost. Therefore, for the low cost BLDC motor applications, voltage vector PWM schemes cannot be regarded as a good solution for cost effective purpose. Modeling and simulation of electromechanical systems with BLDC drives are essential steps at the design stage of such systems. The fundamental operation of FSTP inverter fed BLDC motor drive has been analyzed by simulation. The developed the nonlinear simulation model of the BLDC motors drive system is used for proportional-integral (PI) control.

II. FSTP BRUSH LESS DC MOTOR

The brushless dc (BLDC) motor is becoming popular in various applications because of its high efficiency, high power factor, high torque, simple control, and lower maintenance. Conventionally, BLDC motors are excited by a six-switch inverter as shown in Fig. 1.

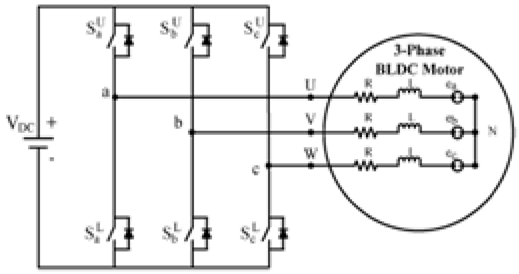

Fig.1.Conventional six-switch three-phase inverter.

However, cost-effective design is becoming one of the most important concerns for the modern motor control research. Some researchers developed new power inverters with reduced losses and costs. Among these developments, the three-phase voltage source inverters with only four switches, as shown in Fig. 2, is an attractive solution. In comparison with the usual three-phase voltage-source inverter with six switches, the main features of this converter are twofold: the first is the reduction of switches and freewheeling diode count; the second is the reduction of conduction losses.

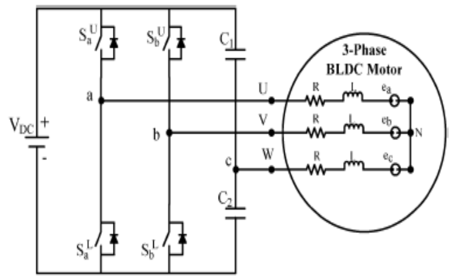

Fig.2. Configuration of four-switch three-phase inverter.

III. NOVEL PWM SCHEME FOR FSTP BLDC MOTOR DRIVES

From the motor point of view, even though the BLDC motor is supplied by the four-switch converter, ideal back-EMF of three-phase BLDC motor and the desired current profiles can be described as shown in Figure 3.

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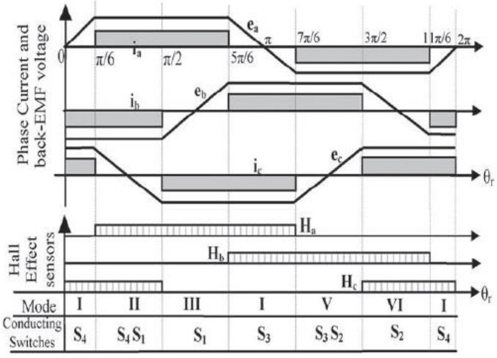

Fig.3.Back EMF, current profiles, modes, conducting switches in the four switch converter for three phase BLDC motor drives.

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically (Sebastian 1989). To rotate the BLDC motor, the stator windings should be energized in a sequence. Most of BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Rotor position is sensed by Hall Effect sensors embedded into the stator which gives the sequence of phases. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high/low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. Depending on the rotor position, the reference current generator block generates three-phase reference currents (ia*, ib*, ic*) considering the value of reference current magnitude as I*, -I* and zero. The reference current generation is shown in Figure 3 and Table 1.

Table1.Rotor position Vs reference current

Rotor Position Signal θ_r	Reference Currents (i_a*, i_b*, i_c*)		
330°-0° to 0°-30°	0	–I*	I*
30° - 90°	I*	–I*	0
90° -150°	I*	0	–I*
150° - 210°	0	I*	–I*
210° - 270°	–I*	I*	0
270° - 330°	–I*	0	I*

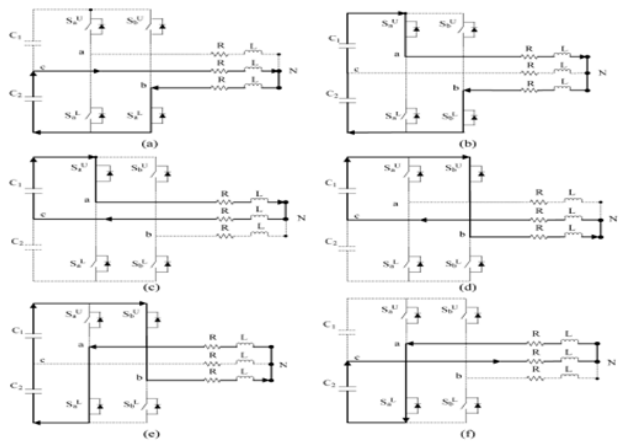

Fig. 4. Six commutating modes of voltage PWM scheme for FSTP inverter: (a) Mode I (X,0); (b) Mode II (1,0); (c) Mode III (1,X); (d) Mode IV (X,1); (e) Mode V (0,1); (f) Mode VI (0,X).

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 Fig. 4. The symbols in parenthesis denote the switch ON/OFF states of S_a^U, S_a^L , S_b^U and S_a^L (phases A and B). "1 " 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 shown in Fig. 5.

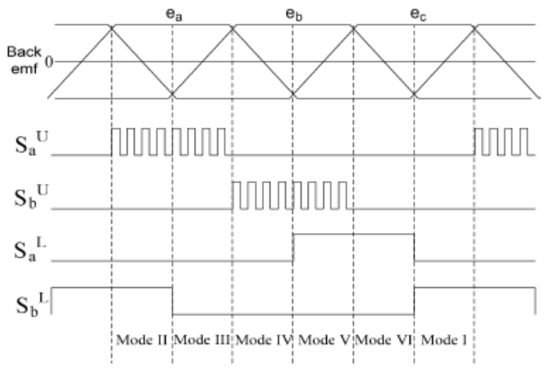

Fig. 5. Conventional voltage PWM scheme for FSTP BLDC motor.

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IV. SIMULATION RESULTS

The FSTP BLDC motor drives using the novel voltage PWM scheme have two phases to detect the back EMF, but the split capacitors cause the voltage waveform of back EMF to be triangular like. The voltages detected from phases A and B becomes two triangular like waveforms, and the voltage of the uncontrolled phase (phase C) becomes 2, as shown in Fig. 7. Furthermore, the stator current waveform of the floating phase is rectangular, as shown in Fig.6. Thus, it is impossible to detect the freewheel diode conducting current by the conventional zero-crossing method.

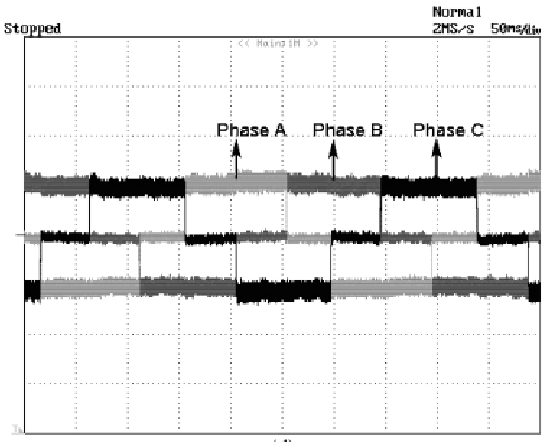

Fig. 6. The Experiment results of stator current waveforms

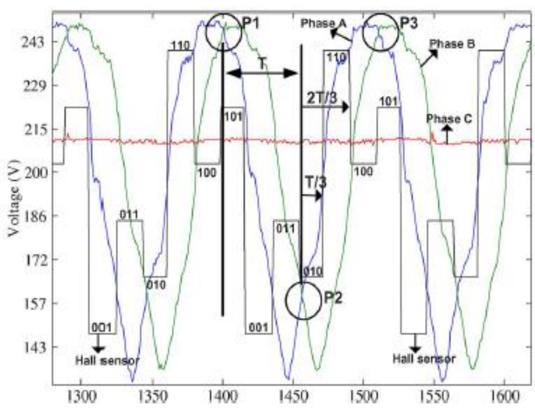

Fig. 9. Voltage waveforms for BLDC motor using FSTP inverter and the relationship between waveform crossings and Hall sensor signals.

Therefore, the conventional sensor less methods for BLDC motors using six-switch three-phase inverter could not be directly used in the FSTP BLDC motors. Fortunately, after observing a lot of experimental results, we found that there we two waveform crossings between phase A and B voltage waveforms which can be used to estimate the rotor position. The simulation result of speed response of the sensor less FSTP BLDC motor plan shown in fig.10.

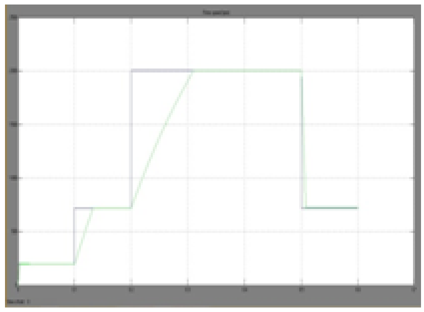

Fig. 10: Speed response of the proposed sensor less FSTP BLDC motor drive.

The simulation results of the proposed FSTP BLDC motor drive contains speed (rpm) on X-axis, and time(second) on Y-axis. The speed response of the sensor less control for FSTP BLDC motor drives is appeared in Fig.4.2. From the figure we can watch that the rotor speed is quickened to the predefined speed (720 rpm) on the grounds that the novel sensor less plan can estimate the right rotor position. At that point, we change speed command from 720 rpm to a higher speed of (2000 rpm). As shows the motor runs steadily at both high and low speeds under open loop position sensor less control.

V. CONCLUSION

The paper has proposed sensor less control plan for four-switch three-phase brushless dc motor drives utilizes an asymmetric PWM plan has six commutation modes in the FSTP inverter. The position data is assessed from the crossing of voltage waveforms in floating phases, on the grounds that the stator current waveforms of the FSTP inverter utilizing this novel voltage PWM plan are rectangular, the motor will work easily and the torque ripple will be at the same level as reported. On the other hand, the two assessed commutations may bring about commutation torque

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swell. The simulation results show that the plan works exceptionally well. With the created control plan and the most minimal expense usage, the proposed plan is suitable for commercial applications.

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