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FPGA Based a PWM Technique for Permanent Magnet AC Motor Drives

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ABSTRACT

The permanent magnet AC motor trapezoidal (BLDC motor) is not strictly DC motor, which uses a pulsed DC fed to the stator field windings to create a rotating magnetic field. Therefore, the motor needs an electronic commutation to provide the rotating field. A pair of switches must be turned on sequentially in the correct order to energize a pair of windings. If the incorrect order is applied, then the BLDC motor will not operate properly. This paper presents a smart guideline to ensure that the order to energize a pair of windings is correct. To prove the guideline, FPGA based a simple commutation state machine scheme to control BLDC motor is presented. The experiment results have shown that the guideline was correct. The commutation scheme was successfully realized using Altera's APEX20KE FPGA to control BLDC motor in both of forward/reverse rotations or forward/reverse regenerative braking properly.

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1. INTRODUCTION

Brushless DC (BLDC) motor is defined as a permanent magnet synchronous motor with a trapezoidal back electromagnetic fields (EMF) waveform shape. The BLDC motor combines the positive attributes of AC and DC systems. The term “BLDC” is used to identify the combination of AC motor, inverter and rotor position sensor to offer a linear torque characteristic as in a conventional DC motor in a drive system. BLDC drive does not require a precision rotor position sensor and only requires discrete position sensors, such as Hall Effect sensor. As a result, BLDC motors are now replacing traditional brushed DC motors due to higher reliability, efficiency, and lower noise, and their usage in new applications continues to grow [1-3].

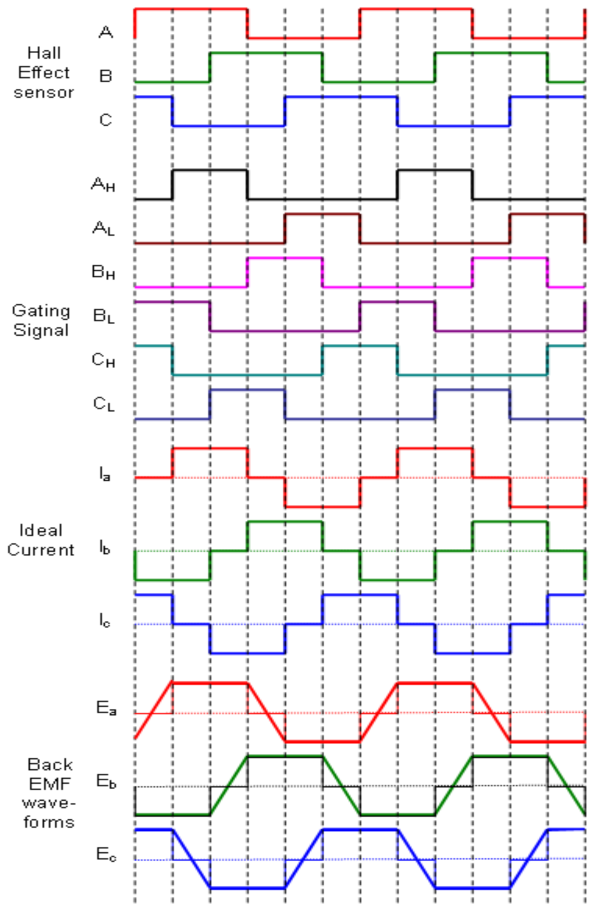
In BLDC motors, the conventional multi-segment commutators as a mechanical rectifier are replaced with an electronic circuit to do the commutation. The electronic commutation in brushless drives eliminates need for brushes in the motor, and therefore all associated maintenance. Accordingly, a BLDC motor requires less maintenance, relatively low cost and is quite robust [1, 4-5].

However, a BLDC requires relatively complex electronics for control. In this control scheme, torque production follows the principle that current should flow in only two of the three phase at a time and that there should be no torque production in the region of back EMF zero crossings. Knowledge of rotor position is critical to correctly energize the windings to sustain motion. Therefore, a pair of switches must be turned on sequentially in the correct order to energize a pair of windings. The BLDC motor will not operate properly if the incorrect switch order is applied [1, 4-5].

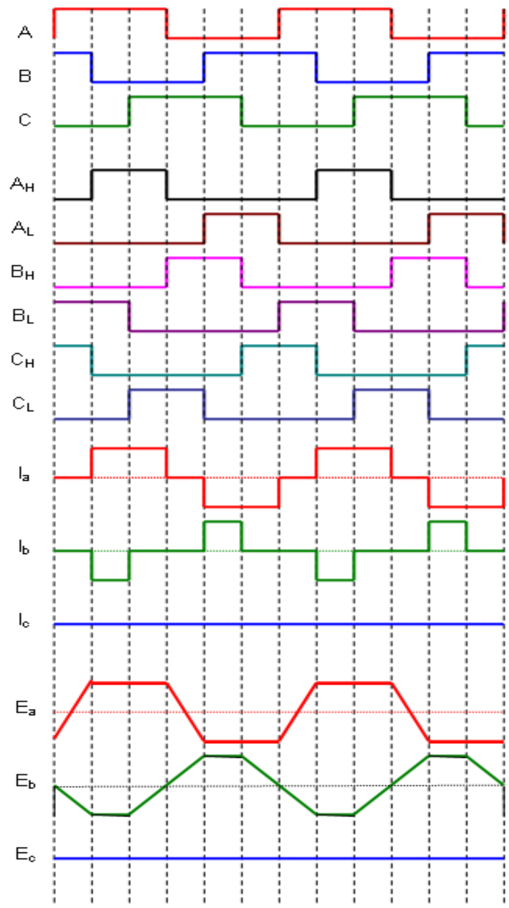
This paper presents a smart guideline to ensure that the order to energize a pair of windings is correct. The rationalization of the commutation sequence in both of forward or reverse rotations, and also in both of forward or reverse regenerative braking mode will be introduced clearly. To prove the guideline, a simple commutation state machine scheme to control BLDC motor in both of forward/reverse rotations or forward/reverse regenerative braking mode based on FPGA is conducted.

2. COMMUTATION STATE MACHINE

To ensure that the BLDC motor will operate properly, a smart guideline to realize the commutation sequence in both of forward or reverse rotations /regenerative braking mode is very important. In order to get constant output torque, current is driven through a motor winding during the flat portion of the back-EMF waveform. Thus, only two switches are turned on at a time, one in a high side and the other in a low side. Figure 1 show the both correct and incorrect commutation state machine. Sensor and drive bits by phase order in both of forward/reverse rotations or forward/reverse regenerative braking are shown in Table 1 and Table 2, respectively



a. correct commutation state



b. incorrect commutation state

Fig.1. Hall effect sensor, gating signal of inverter, phase current and back EMF

Table 1. Sensor And Drive Bits By Phase Order In Both Of Forward And Reverse Rotations

Hall effect sensor A	Hall effect sensor B	Hall effect sensor C	Forward rotation: phase	A high drive	A low drive	B high drive	B low drive	C high drive	C low drive	Reverse rotation: phase	A high drive	A low drive	B high drive	B low drive	C high drive	C low drive
0	**0**	**1**	**1**	1	0	0	0	0	1	**6**	0	1	0	0	1	0
0	**1**	**1**	**2**	1	0	0	1	0	0	**5**	0	1	1	0	0	0
0	**1**	**0**	**3**	0	0	0	1	1	0	**4**	0	0	1	0	0	1
1	**1**	**0**	**4**	0	1	0	0	1	0	**3**	1	0	0	0	0	1
1	**0**	**0**	**5**	0	1	1	0	0	0	**2**	1	0	0	1	0	0
1	**0**	**1**	**6**	0	0	1	0	0	1	**1**	0	0	0	1	1	0

Table 2. Sensor and drive bits by phase order in both of forward and reverse regenerative braking

Hall effect sensor A	Hall effect sensor B	Hall effect sensor C	Forward regenerative braking: phase	A high drive	A low drive	B high drive	B low drive	C high drive	C low drive	Reverse regenerative braking: phase	A high drive	A low drive	B high drive	B low drive	C high drive	C low drive
0	**0**	**1**	**1**	0	0	0	0	0	1	**6**	0	1	0	0	0	0
0	**1**	**1**	**2**	0	0	0	1	0	0	**5**	0	1	0	0	0	0
0	**1**	**0**	**3**	0	0	0	1	0	0	**4**	0	0	0	0	0	1
1	**1**	**0**	**4**	0	1	0	0	0	0	**3**	0	0	0	0	0	1
1	**0**	**0**	**5**	0	1	0	0	0	0	**2**	0	0	0	1	0	0
1	**0**	**1**	**6**	0	0	0	0	0	1	**1**	0	0	0	1	0	0

3. EXPERIMENT SETUP

In this paper, a simple digital three-phase Pulse Width Modulation (PWM) controller for a BLDC motor has been proposed, as shown Figure 2. In this system, the BLDC motor is treated as a digital system. Speed regulation is achieved by varying PWM duty cycle. However, the state machine commutation is heart of the system, and the PWM generator only to make varying of duty cycle.

The three-phase PWM technique is conducted to reduce the commutation current ripple. The motor drive system use hall-effect sensors which track the motor's position, for changing the PWM method to three-phase one. The experiment setup is shown as Figure 3.

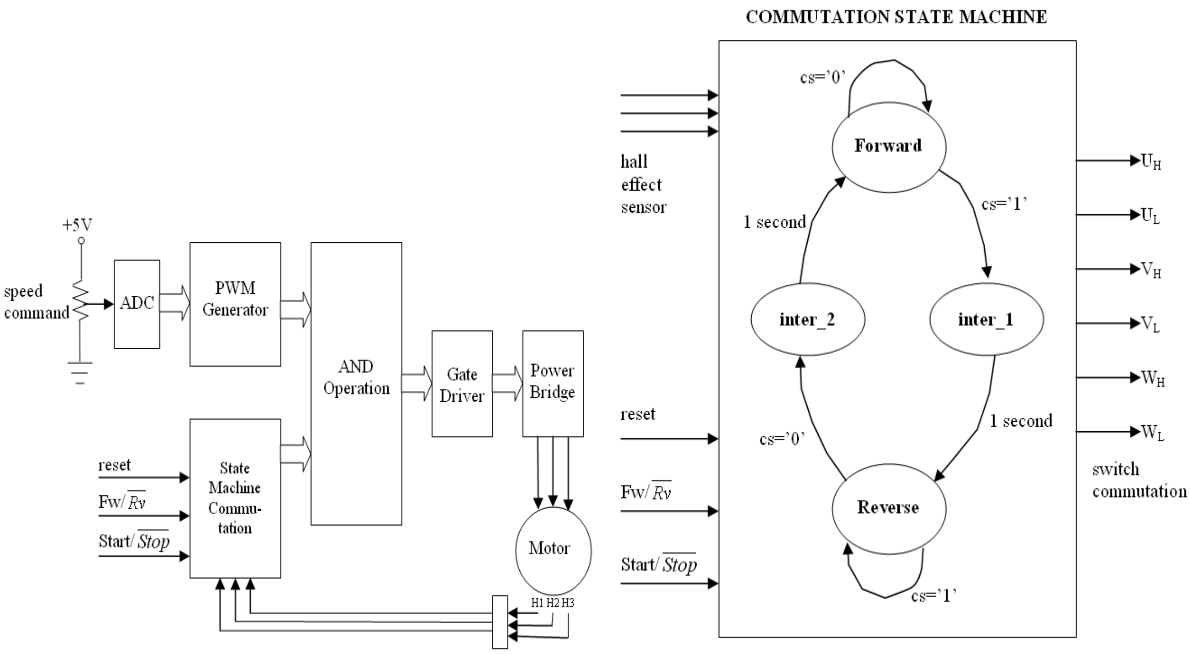


Fig. 2. Simple PWM BLDC Motor Control Based On Commutation State Machine

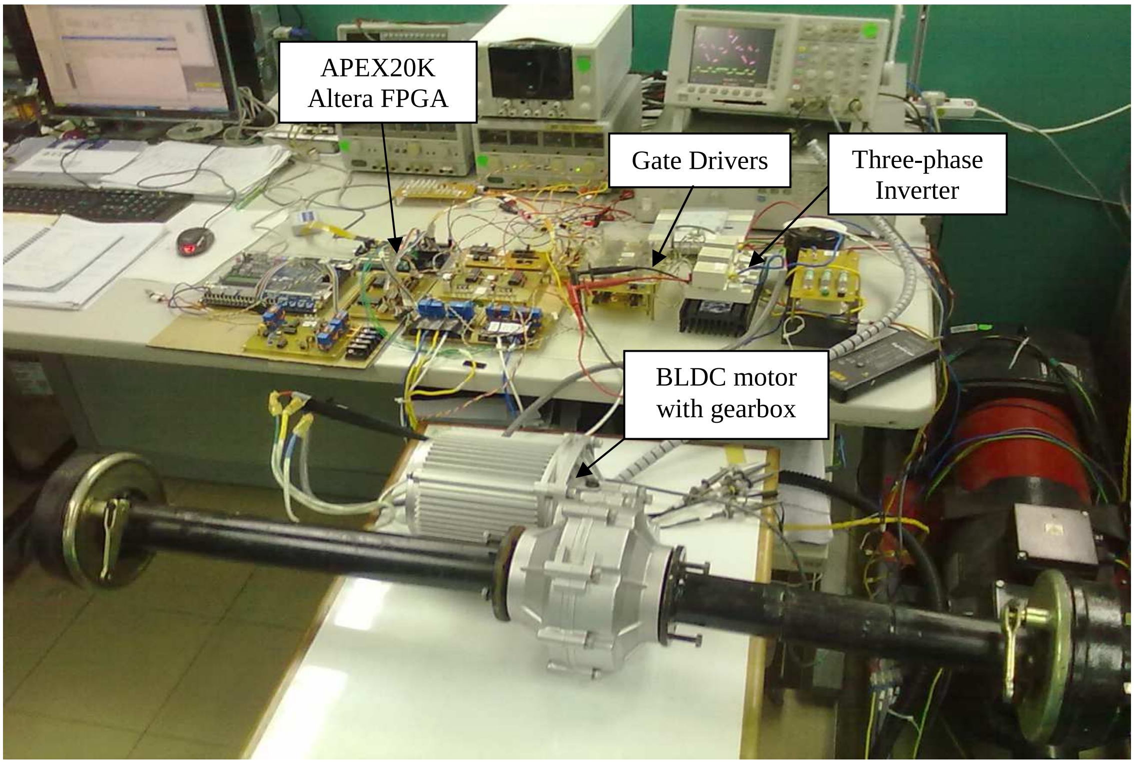
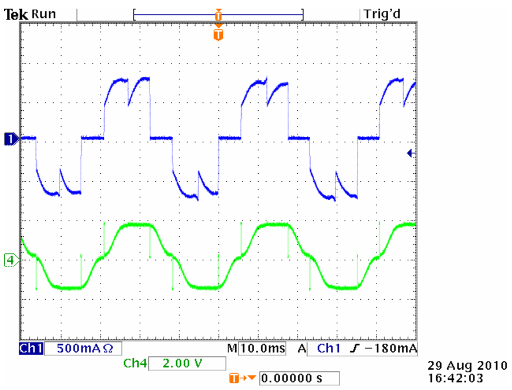


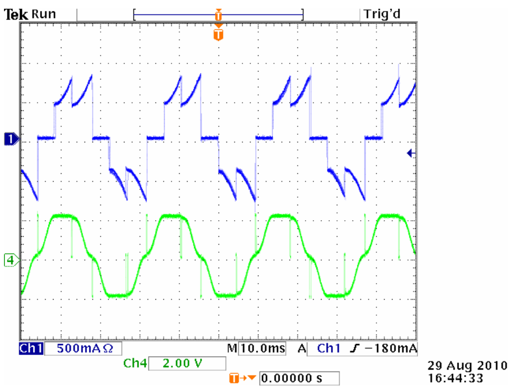
Fig. 3. Experiment setup

4. RESULTS AND DISCUSSIONS

In the research, the simple control of BLDC motor based on commutation state machine utilizing FPGA was successfully developed. The current and back-EMF results of six-step BLDC motor drive based on FPGA are shown in Figure 4. The Figure 4 (a) is six-step BLDC motor drive in forward rotation, and it is shown in Figure 4 (b) for reverse rotation. To improve the performance and to adjustable speed drive, the PWM is implemented in this system. The current and back-EMF of the proposed method is shown in Figure 5. From Figure 5, it can be seen that the PWM has successfully be implemented. Figure 5 (a), it has shown for forward rotation and Figure 5 (b) for reverse rotation. The switching frequency of inverter is at 20 kHz.

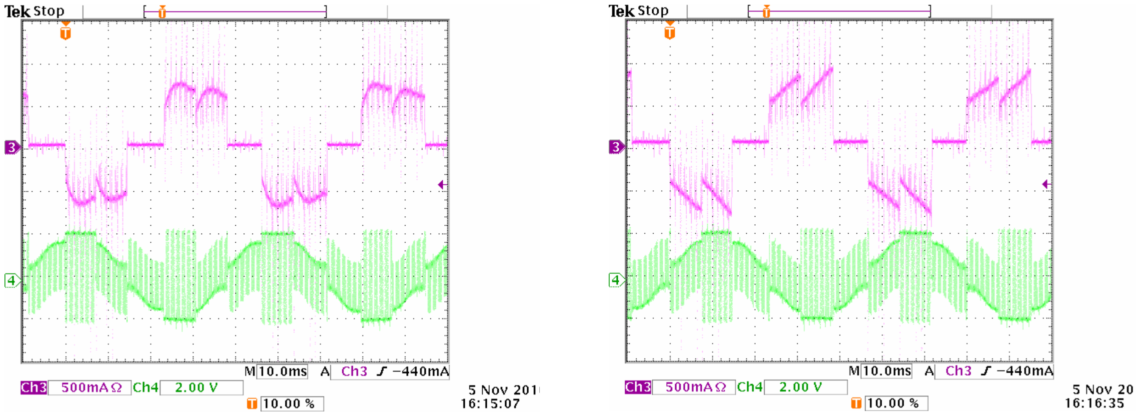


a. forward rotation



b. reverse rotation

Fig. 4. Current and Back-EMF of Six-step BLDC Motor Control Based On Commutation State Machine



a. forward rotation b. reverse rotation

Fig. 5. Current and Back-EMF of the Proposed PWM BLDC Motor Control Based On Commutation State Machine

However, the PWM method proposed still has a problem to significantly reduce the commutation current ripple because the research not yet considers the commutation period to generate PWM signal. From Figure 5, it still can be see that the current ripple is very dominant in commutation period. To overcome the problem, the basic idea is to retain the same magnitude of current slew rate with opposite sign for the incoming and outgoing phases. The idea can be achieved by controlling the duty during commutation. Obviously, the detection circuits are needed to indicate the commutation period [6-7].

5. CONCLUSION

This paper has presented a smart guideline to ensure that the order to energize a pair of windings is correct. To prove the guideline, FPGA based a simple commutation state machine scheme to control BLDC motor has been successfully type-tested. The experiment results have shown that the guideline was correct. The commutation schemes have successfully realized to control BLDC motor using Altera's APEX20KE FPGA in both of forward/reverse rotations or forward/reverse regenerative braking properly.

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