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Control of the Brushless DC Motor in Combine Mode

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Abstract

A brushless DC (BLDC) motor is considered to be a high performance motor due to its low maintenance cost, versatility, adequate torque and speed, and high reliability. Normally, a simple BLDC motor is composed of a permanent magnetic rotor and three stator coils. In each controlling step, two out of three coils are used to generate rotating magnetic field, while the floating coil induces a back electromotive force (emf) and feeds the generated current back to the controller as noise. In this work, combine mode scheme is proposed to control a BLDC motor in such a way that the excess current is accumulated via additional switching circuit for further utilization. Therefore, a BLDC motor can drive the load in concurrent with generating power. The proposed switching circuit has been designed and simulated on PSpice. The results show that up to 75% of input voltage can be charged to the storage capacitor.

Keywords: Brushless DC motor; generator; hybrid system; combine mode

1. Introduction

Producing energy, such as electricity is essential in our rapidly changing world where we use more electrical devices and consume more energy than ever. Several devices have been invented to convert natural energy to electrical energy. Without doubt, a generator plays important role as a device to convert natural mechanical power to electrical power and then stores the energy in batteries. The reverse conversion of electrical energy into mechanical energy is done by an electric motor.

In this paper, we propose a new control method that allows a motor device to simultaneously generate electrical energy and mechanical energy. A brushless direct current (BLDC) is considered here. A BLDC

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motor has permanent magnets which rotate and a fixed armature. Hence, feeding current to a moving rotor is no longer a problem. BLDC motors offer several advantages over brushed DC motors and induction motors, including more torque per weight and efficiency, reliability, reduced noise, longer lifetime (no brush and commutator erosion), and no ionizing sparks from the commutator.

BLDC machines can be controlled in 3 modes, i.e., motor, generator and hybrid. Several control methods have been proposed in motor mode. In [1], Xitai et al. adopted Y connected three-phase full-bridge drive mode as control scheme and analyzed of three closed-loop control scheme with DSP. Yasuhiro et al. [2] considered a small BLCD motor system. They proposed the design based on unidirectional current flows. In [3, 4], three-phase PWM control is used to drive motor base on DSP. A fuzzy logic control using microcontroller for sensorless BLDC motor has been proposed. In [5], two resistances are adopted to detect the zero-crossing point of back-EMF signal on the unexcited phase, instead of using the expensive Hall sensors. The system is implemented by a fuzzy logic control on a microcontroller.

In generator mode, several control techniques have been proposed in the synchronous rectifier and converter [6, 7]. In [8], the permanent magnet is replaced with assisted field coil in the rotor of a BLDC generator.

Controlling in hybrid mode is a major challenge in this field. Hybrid mode is a control technique that allows a machine to work alternatively between motor and generator. In [9], Kim *et al*. considered the control methods that minimize torque ripple and maximize power density of a brushless DC motor/generator system in electric vehicles and hybrid electric vehicles. Moreover, the design of a hybrid system of a 20-kW permanent magnet (PM) BLDC machine has been proposed in [10]. In their paper, the PM BLDC machine, coupled to the 1.9L diesel engine of the vehicle, generates the electrical power to charge the high-voltage energy storage system and to drive an induction machine connected to the rear wheels. It may also use stored energy to start the engine or to assist propulsion during vehicle acceleration. In [11], Afjei and Torkaman compared two types of new motor/generator configurations, i.e., a field assisted switched reluctance motor and BLDC motor without permanent magnet.

Note here that, in those conventional hybrid systems, a machine is alternatively switched between motor mode and generator mode. In this paper, a new control method that can store energy during the motor operation is proposed. The paper is organized as follows; the operation of BLDC motor control in combine mode is discussed in Section 2. The simulation model and simulation result are shown in Section 3 and Section 4, respectively. Finally, conclusions are remarked in Section 5.

2. BLDC motor control in combine mode

This section describes the control issues of a proposed combine mode where the electrical energy is generated and stored into batteries simultaneously during the BLDC motor operation.

Normally, a conventional three phases BLDC motor has three stator coils. However, the number of coils may be replicated to obtain a smaller torque ripple. Figure 1 shows the electrical schematic of the stator. It consists of three coils A, B and C. The rotor in a BLDC motor consists of an even number of permanent magnets. The number of magnetic poles in the rotor also affects the step size and torque ripple of the motor. More poles give smaller steps and less torque ripple. A BLDC motor with only one pair of poles is shown in Fig. 1.

When motor coils are correctly supplied, a magnetic field is created and the rotor moves. The most elementary commutation driving method used for BLDC motors is an on-off scheme: a coil is either conducting or not conducting. In 3-phase BLDC motor, only two windings are supplied at the same time and the third winding is floating.

The proposed combine mode control takes advantage of the inactive coil to generate electrical energy during motor operation.

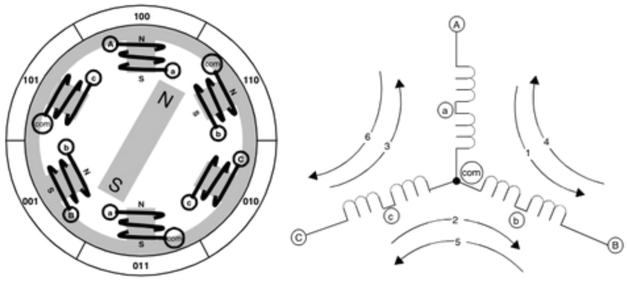

Fig. 1. Simplified BLDC motor diagrams [13]

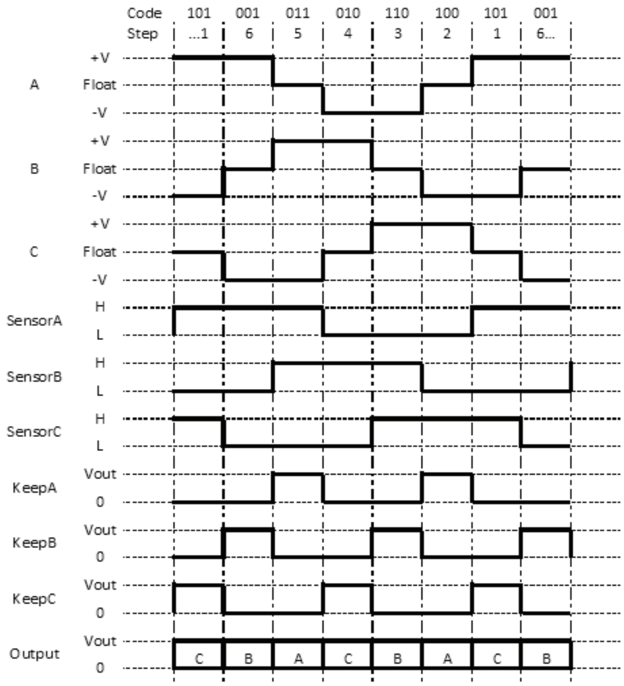

Fig. 2.Timing diagram for BLDC motor

In order to generate a rotating magnetic field pulling the rotor, the BLDC motor is driven by energizing 2 phases at a time. The static alignment shown in Fig. 2 is that which would be realized by creating an electric current flow from terminal A to B, noted as path 1 on the schematic in Fig. 1. The rotor can be made to rotate clockwise 60 degrees from the A to B alignment by changing the current path to flow from terminal C to B, noted as path 2 on the schematic. Continuously driving the motor in this way, the motor can be rotated completely 360° at the end stage 6. As seen in the timing diagram, electrical energy can be obtained at the output when a permanent magnetic field from rotor move across a floating coil. As shown in the Fig. 2, each coil can generates electrical energy twice in one turn.

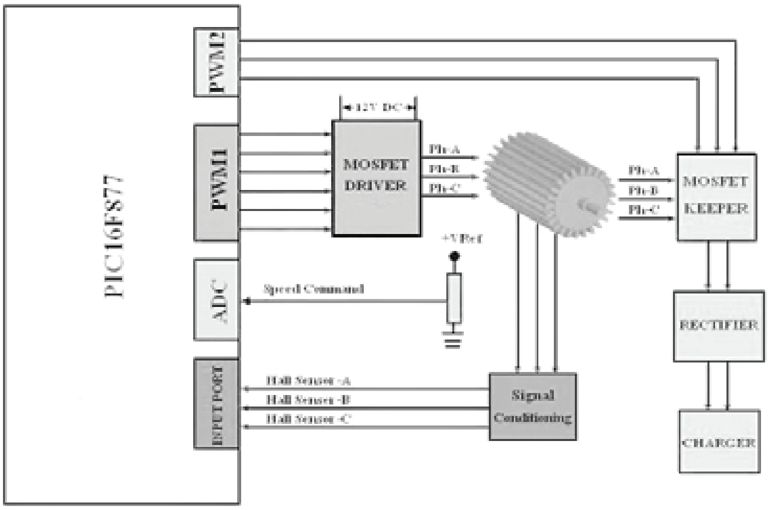

Fig. 3. System Hardware block diagram

Figure 3 illustrates block diagram of the proposed combined mode BLDC motor control system. In this system, speed command and the signal from Hall effect sensors are used as the input of the micro controller, PIC16F877. The microcontroller is used to calculate the control variable through a specific control algorithm, and converts the control variable into signal PWM signal. PWM1 is the signal to control MOSFET driver for rotating the motor, while PWM2 is used to control MOSFET keeper to collect electric energy from the floating coil. Figure 4 shows in detail of the electronic circuit of the MOSFET switches related to the block diagram in Fig. 3. During the operation, 8 MOSFETs will be used to control the two active coils to generate the rotating magnetic field (a motor mode), while the other 2 MOSFETs are used to allow the system to store the output voltage obtained from an inactive coil (generator mode).

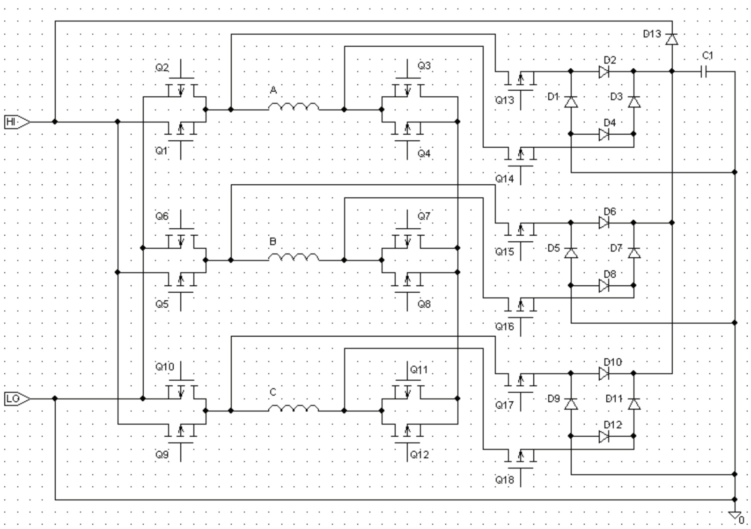

Fig. 4. Combine mode Driver circuit

To control the MOSFET switches, the motor diagram in Fig. 1 and the timing diagram in Fig. 2 are considered. Table 1 summarizes steps to control the MOSFETs according to the input signal from Hall effect sensors.

Table1. The design in 6 stage timing diagram for combine mode

Table1. Switch selection logic

Hall			Selected MOSFET switch					
ha	hb	hc	DRIVER				KEEPER	
1	0	1	Q1	Q4	Q6	Q7	Q17	Q18
0	0	1	Q1	Q4	Q10	Q11	Q15	Q16
0	1	1	Q5	Q8	Q10	Q11	Q13	Q14
0	1	0	Q5	Q8	Q2	Q3	Q17	Q18
1	1	0	Q9	Q12	Q2	Q3	Q15	Q16
1	0	0	Q9	Q12	Q6	Q7	Q13	Q14

3. System simulation

Shown in Fig. 5, the proposed control circuit has been simulated in PSpice, an analog circuit simulation software. A transformer is used as a simulation model for a stator coil in three phase BLDC motor. The simulation circuit is controlled by the presence of a 6-step timing diagram in Fig. 2.

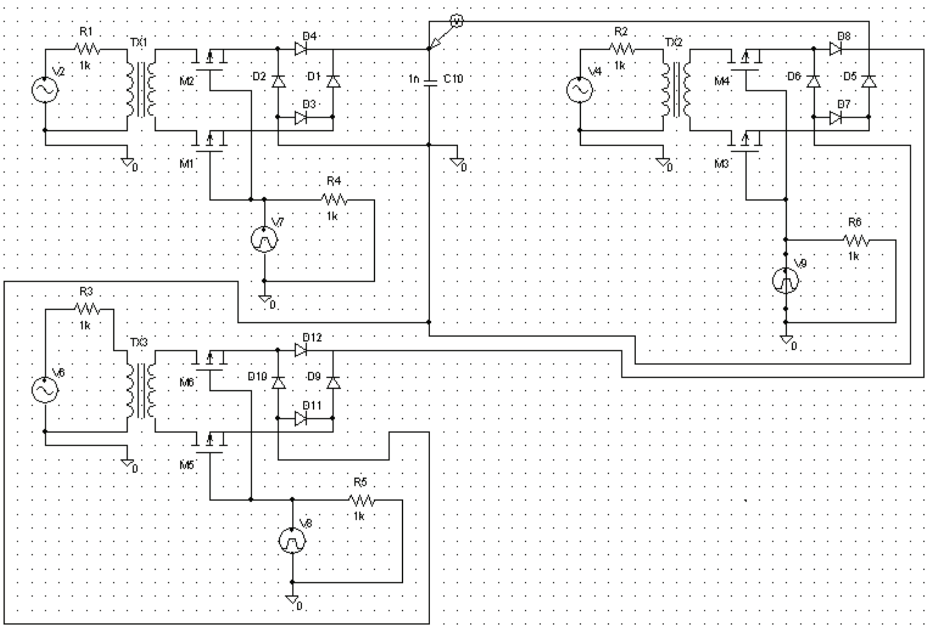

Fig. 5. PSpice simulation circuit of the proposed combine mode BLDC motor control

4. Simulation result

This section expresses some simulation results of Brushless DC motor/generator control in combine mode when the BLDC motor operates in normal control (motor mode) with 12 V dc input at 150 rpm.

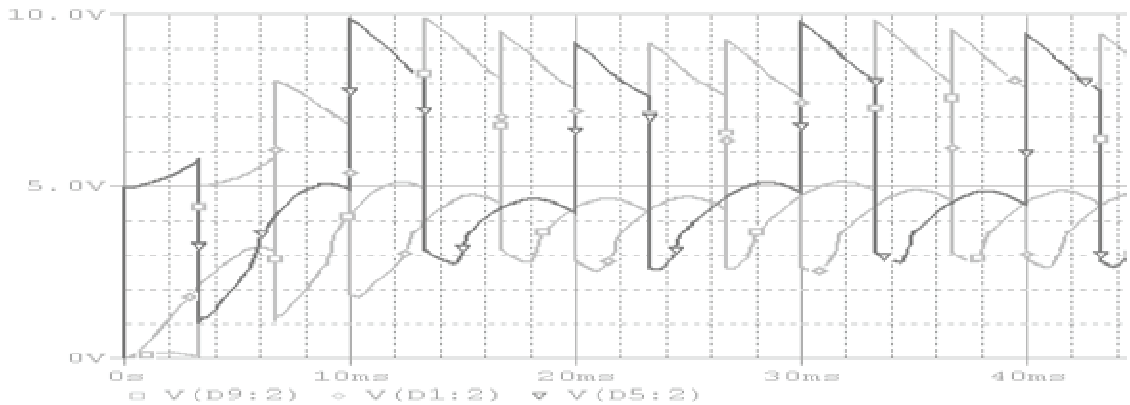

Fig. 6. Output signal from combine mode 3- phase (Simulation)

Figure 6 shows voltage output obtained from each inactive coil when the BLDC motor operates in combine mode. Figure 7 and 8 illustrate electrical voltage output obtained according to the load of 100k ohm and no load, respectively. We note here that the output voltages are varied with the value of load which is to be observed in the real experiment using charging circuit.

Fig. 7. Electrical voltage output from combine mode with Load 100k ohm

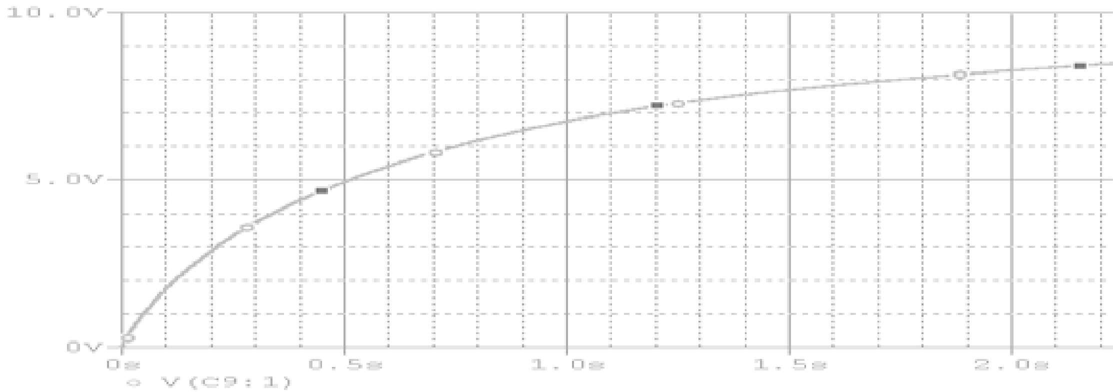

Fig. 8. Electrical voltage output from combine mode No Load

5. Conclusion

The paper proposes the BLDC motor control method which is operated in combine mode, where electrical energy can be obtained during motor operation. The system takes advantage of floating coil in a BLDC motor to generate electric energy which can be feed back to the system or store in battery for other purpose uses. The system has been simulated on PSpice. The result indicates that, using combine mode control, we can obtain the output voltages for about 75 % input voltage (9 volt from the 12 volt input) when no load. The real implementation of the proposed system is going to be further investigated.

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