INVESTIGATION OF ELECTRICAL ANGLE OF HALL SENSOR IN INNER ROTOR AND OUTER ROTOR BRUSHLESS DC MOTORS

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ABSTRACT

Today, Brushless DC Motors are frequently preferred due to their performance, efficiency and maintenance-free. Brushless DC motor is widely used in various applications. Brushless DC motor designs with inner rotor or outer rotor are made according to usage areas. Brushless DC motor needs rotor position information to control the magnetic coils in the stator. Most studies have three Hall sensors to detect rotor position. Hall sensors are placed in such a way that they give signals with an electrical angle of 60° or 120° depending on the controller selection. The switching signal that provides the brushless DC motor movement is applied to the system by a microcontroller according to the Hall sensors. Hall sensors increase low-frequency harmonics in torque, causing unbalanced operation of the inverter and motor phases. It causes acoustic noises. It fluctuates and degrades overall driver performance. In this study, the connections between the mechanical angles and electrical angles of Hall sensors on Brushless DC motors with outer rotor 20 stator slots and 18 rotor poles and inner rotor 6 stator slots and 4 rotor poles are shown in practice. Signal images were taken by placing Hall sensors in different stator grooves. The graphs obtained as a result of the tests were shared and the connection between the electrical angle and the mechanical angle was interpreted. Changing the mechanical angles of Hall sensors will provide improvements in Brushless DC motor designs.

Keywords: Brushless DC Motor, Electrical angle, Hall sensor

INTRODUCTION

Brushless Direct Current Motor (BLDC), which is widely used today, is used efficiently with the developing technology. Its usage area is quite wide from automotive to industry. BLDC has high starting torque due to its structure. It is also frequently preferred in variable speed applications. It is possible to find many theoretical and experimental studies in the literature on BLDC (Eduardo, 2010). With its advantages, BLDC can be preferred in areas where brushed DC motors are used in field studies. Without brushes, the life of the system increases, mechanical wear, temperature and noise can be minimized. A controller is required to obtain BLDC torque (Semiconductor, 2004). The control algorithm is complex compared to DC brushed motors. Rotor position must be sensed in BLDC control. The commutation process is performed according to the obtained rotor position (Semiconductor, 2004). There are many methods for rotor position information (Terzic and Jadric, 2001). Back emf detection circuits, position sensor encoder and hall sensor can be used to know the rotor position (Er et al., 2022). Hall sensors are included in BLDC control, which is referred to as sensor control in the literature (Hasanusta, 2016). Knowing the starting position is advantageous in many applications. It is advantageous to use hall sensors, especially in applications that need to be lifted under load (Er et al., 2022). For BLDC departure, it evaluates the data from three hall sensors and triggers the appropriate phase (Kolano, 2019). In this commutation method, BLDC control is provided as shown in Figure 1. V is the supply voltage. S is the mosfet with the switching element.

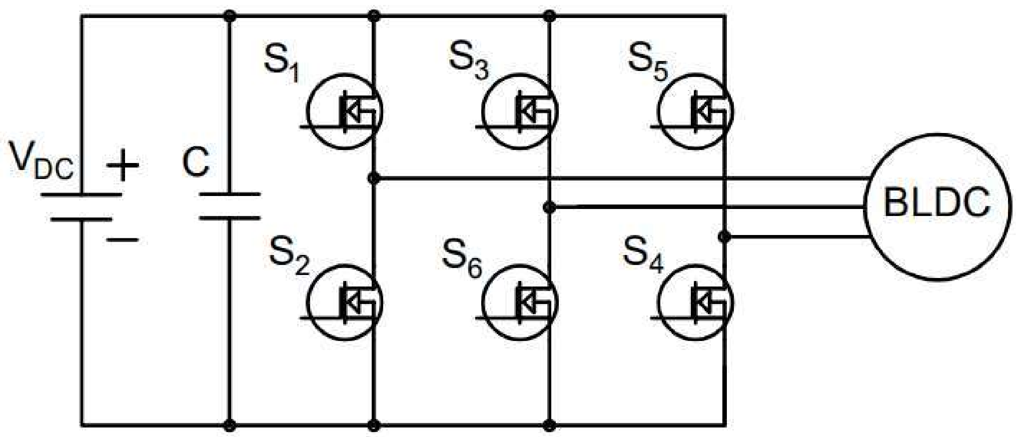

Figure 1. BLDC control structure

The process of determining the position of the motor body is detected using the hall sensor. There are 3 sensors mounted on the surface of the stator (Kolano, 2020). These sensors are mounted on the body at 60° or 120° angles. While the body is rotating, information about the engine position is obtained by giving signal outputs to the magnetic sensor according to the rotation speed and position (Yedamale, 2003). Studies have been carried out to determine the hall sensor locations in the engine in a way that will affect the operation of the engine efficiently and accurately.

MATERIALS AND METHODS

Three hall sensors mounted on the stator provide signals based on rotor position. The signal obtained from Hall sensors is used in BLDC control. As the motor rotates, the motor current is commutated every 60° electrically. The hall sensor processed by its control is transmitted to the power layer. Depending on the algorithm, voltage is applied to the motor terminals to provide torque (Aydoğdu and Bayer, 2008). V is the supply voltage. S is the mosfet with the switching element. R is motor resistance, L is motor inductance, E is motor back emf

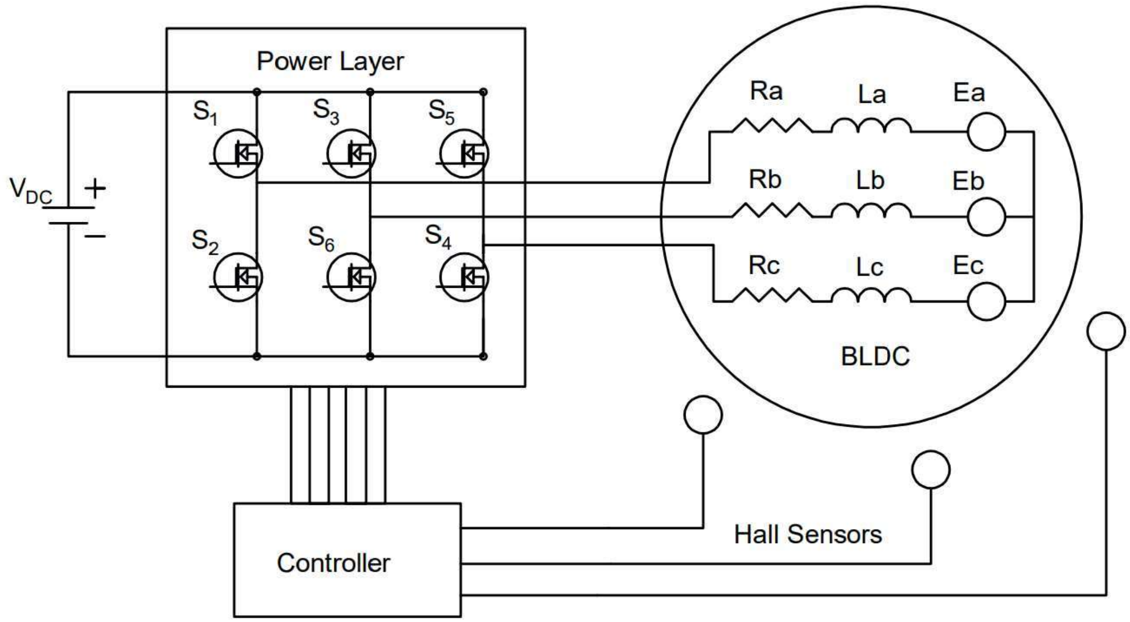

Figure 2. BLDC structure and hall sensor placement

BLDC is electronically controlled due to their structure and rotor position information is required in the control process for direct current commutation (Gao, 2013). The placement of Hall sensors and the topology of the controller are given in figure 2. Position information was obtained using Hall sensors. In the control of BLDC motors, two separate closed loops are used. The first is the internal control loop, where the motor current or torque is controlled (Hazari et al., 2014). The BLDC has a permanent magnet rotor and the rotor position must be known for electronic commutation (Leonard, 2005). The rotating magnetic field is controlled by semiconductor elements that are switched according to the rotor position. BLDC pole switching is done electronically with semiconductor switches. Table 1 shows the effect of hall sensor changes on the drive switching element inputs.

Table 1. Driver output information with Hall sensor information

Sensor Logic Locations				Driver Outputs					
HA	HB	HC	DIR	GLA	GLB	GLC	GHA	GHB	GHC
1	0	1	1	/PWM	0	1	PWM	0	0
1	0	0	1	0	/PWM	1	0	PWM	0
1	1	0	1	1	/PWM	0	0	PWM	0
0	1	0	1	1	0	/PWM	0	0	PWM
0	1	1	1	0	1	/PWM	0	0	PWM
0	0	1	1	/PWM	1	0	PWM	0	0

BLDC COMMUTATION AND HALL SENSOR SIGNALS

The relevant phases to be triggered according to the sensor positions are given in Table 2. As a result of these triggers, the motor is driven together with the trapezoidal signal. In BLDC, commutation consists of six steps. Each step corresponds to electrical intervals of 60° electrically, and the two windings are energized. The rotor position determines the order of the switching steps. Therefore, knowing the rotor position is essential for control in BLDC motors. In Table 2, HA, HB, HC represent the hall sensors PHA, PHB, and PHC indicate the relevant BLDC phase state.

Table 2. Motor phase information with Hall sensor information

Sensor Logic Locations				Motor Terminals		
HA	HB	HC	Order	PHA	PHB	PHC
1	0	1	1	H	Z	L
1	0	0	2	Z	H	L
1	1	0	3	L	H	Z
0	1	0	4	L	Z	H
0	1	1	5	Z	L	H
0	0	1	6	H	L	Z

The sensor logic positions and the energizing of the motor phases are shown by referencing the 120° electrical angle. Here, H can be expressed as the symbol that it is energized through the power layer. L is the place where the negative of the system is given over the power layer. Z means it shows high impedance. Therefore, there is instantaneous flow from the H motor phase to the L motor phase. The numbers in the fourth column in Table 2 represent the directions given in Figure 3. S are MOSFETs with switching elements.

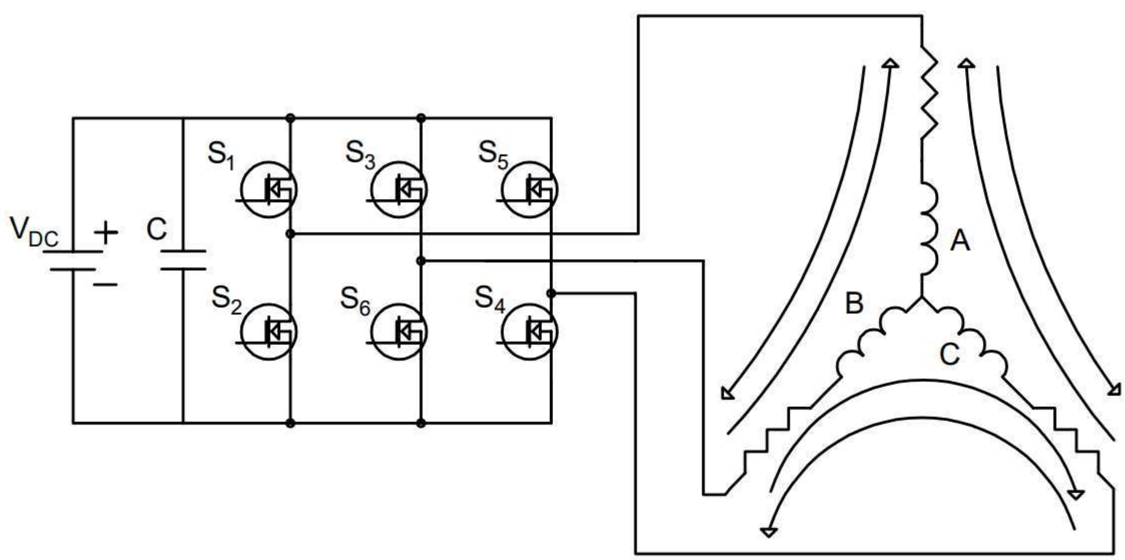

Figure 3. Energy flow in motor windings

It is transferred to the relevant channels by changing the PWM. In a motor controlled by a trapezoidal signal, only two phases are energized at the same time. The energy flow according to the triggering order of the windings using switching elements on the BLDC is shown in Figure 3. As shown in Figure 3, the phase energizing sequence changes with each electrical angle of 60° will be in six different states for one electrical cycle of the motor (NXP, 2020).

HALL SENSOR PLACEMENT AND BLDC STRUCTURE

Honeywell SS460S Hall sensors are used in the study. Although the sensor used is bipolar, it has latching feature. Latching feature ensures that the output, which is 1 when it sees the N pole, remains at 1 in case of instability. Therefore, the signal output will not be 0 until you see the S pole. In Figure 4, the output magnet pole and output relation of the SS460S sensor are given (Honeywell, 2021).

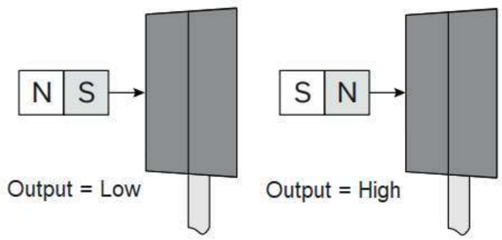

Figure 4. Hall sensor usage

Electrical angle and mechanical angle of Hall sensors vary according to BLDC structure. In the BLDC structure, the number of stators, the number of magnet pole pairs and the desired electrical angle to be used in driving directly affect the position of the hall sensors on the BLDC. Various models have been made regarding the Hall sensor location.

The electrical angle can be 120° or 60°. When we look at the MC33035 IC of ONSEMI, which is the most widely used, it seems that a choice can be made for this (Semiconductor, 2004). Looking at the DRV8312 integration of Texas Inc, it is seen that driving is carried out directly with an electrical angle of 120° (Kumari and Nawaz, 2018). Monolithicpower's MP6532 IC also drives directly with an electrical angle of 120° (MPS, 2022). MC33035, DRV8312, MP6532 hall sensor BLDC driver integrated. These ICs go into an error state when the hall sensors do not give a signal or give an unbalanced signal. Failure or fault condition in Hall sensors affects system performance (Ebadpour et al., 2021).

Equation 1 120° electrical angle Equation 2 60° electrical angle is given. Equation 1 and equation 2 result in mechanical angle. Here, the number of pole pairs directly affects the mechanical angle.

In equations, edeg Electrical Angle, erot: Electrical Rotation, 1erot=360edeg, mdeg: Mechanical Angle, mrot: Mechanical Rotation, 1mrot=360mdeg, pp: Pole Pair Number, 1 Pole Pair = 2 Poles, abbreviated as S: Slot Number.

$$120 = 360\text{mdeg} / 3 \text{ x pp mdeg} = \text{m mdeg per } 360 \text{ edeg} \quad (1)$$

$$60 = 360\text{mdeg} / 6 \text{ x pp mdeg} = \text{m mdeg per } 360 \text{ edeg} \quad (2)$$

Equation 3 is used for the angle corresponding to each groove in the BLDC stator.

$$360\text{mdeg} / \text{slot} = \text{n mdeg per slot} \quad (3)$$

Using the mechanical angle obtained in Equation 1 or Equation 2 and the mechanical angle obtained in Equation 3, the positions of the hall sensor are found by Equation 4, depending on the BLDC design. The result obtained from Equation 4 determines the slot number of the next hall sensor to be positioned after a hall sensor is positioned.

$$(m*pp) / n = \text{slot} \quad (4)$$

When the related operations are performed for the outer rotor BLDC with 20/18 stator groove/pole number, it seems that the hall sensor placement corresponds to an electrical angle of 120° by giving 12° degrees or 6 stator spacing. The BLDC rotor and stator drawing with outer rotor studied on is given in figure 5.

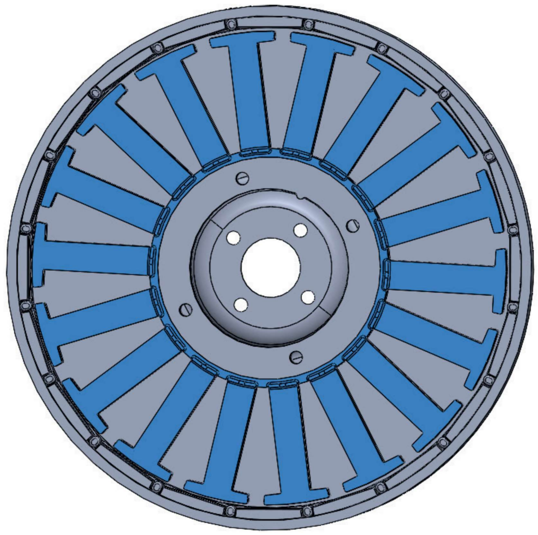

Figure 5. Outer rotor BLDC rotor stator representation

When the related operations are performed for the inner rotor BLDC with 6/4 stator groove/pole number, it seems that the hall sensor placement corresponds to an electrical angle of 120° by giving 60° degrees or 2 stator spacing. The BLDC rotor and stator drawing with inner rotor studied on is given in figure 6. Hall sensor signals are given in figure 7.

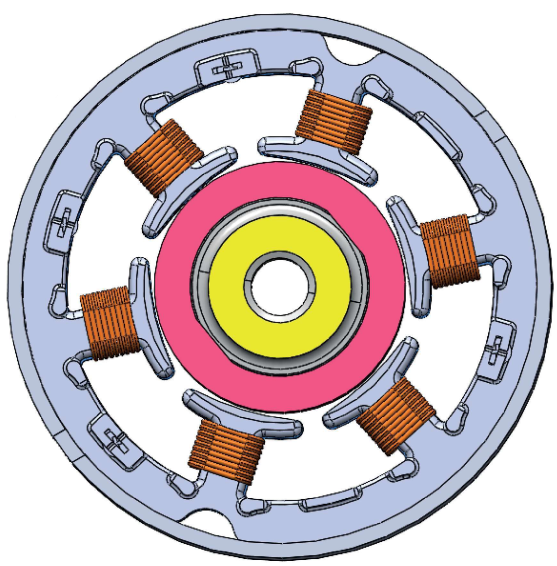

Figure 6. BLDC rotor stator display with inner rotor

Figure 7. Hall sensor graph

RESULTS

This study examines the connection between electrical angle and mechanical angle for structures controlled using hall sensor in BLDC. As a result of the experiments, the sensor outputs were given by applying the sensor placement on the BLDC. Equations and visuals are given for BLDC with different stator slot numbers and magnet pole pair numbers and sensor placement. By testing on the inner rotor BLDC and outer rotor BLDC, the operation was more effective. Information about current transitions in motor phases is given by giving examples of ICs providing control with an electrical angle of 120°. Hall sensor table suitable for 120° electrical angle regarding current transitions on BLDC terminals has been shared. Honeywell SS460S hall sensors are used in BLDC. Obtained oscilloscope images are included in the study. It has been seen that the parameters work more efficiently. This study will shed light on more detailed studies with different driver circuits and different voltage values applied to the motor.

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