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Review Paper on Brushless Direct Current Motor and their speed control with hall sensors

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Abstract: This paper gives a review of brushless direct current (BLDC) motor and there speed control method via Hall sensors. BLDC motors have been gaining attention from various industrial and household appliance manufactures because of its high efficiency, high power density, silent operation, low maintenance cost, small size and reliability. BLDC motors are controlled conventionally using Hall sensor, Shaft encoder, accelerometers, and electromagnetic variable reluctance sensors. Various applications with complex wiring and precise positioning of Hall sensors which create problem for ministration and interference free design of BLDC motor. Sensor-less technology have various advantages like low cost of hardware along with disadvantages like complicated electronics , algorithm. This paper explains the advantages, drawbacks and applications of Hall sensors speed control techniques. Hall sensors are commonly used while back-EMF (voltage induced due to movement of permanent magnet) sensing techniques are used for sensor-less speed control.

Keyword: BLDC motor, Hall sensor, back-EMF, speed and position control.

1. INTRODUCTION

BLDC Motor is a rotating electric motor consisting of stator armature winding and rotor permanent magnets. With rapid development in power electronics, semi-conductor and manufacturing technology for high performance magnetic materials, the BLDC motors have been used for energy saving applications such as air-conditioners, refrigerators, Air-pumps, kitchen appliances and electric vehicles [1]. BLDC Motors have three phase windings that are wound in star or delta fashion and need a three phase inverter bridge for electric commutation. Because BLDC motors does not use brushes for commutation so they have longer operating life and noiseless operations. It has permanent magnet so high ratio between torque and motor size, so suitable for applications where space and weight are critical e.g. in satellite applications. BLDC motor has linear relationship between current vs. torque and voltage vs. rpm.

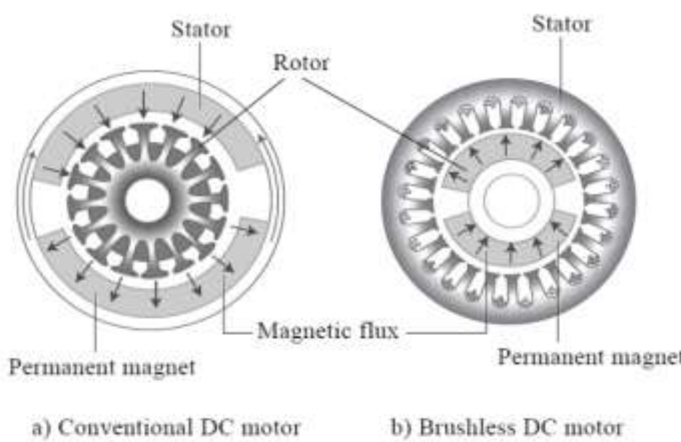


Figure 1. Schematics of BLDC & Convential DC Motor

Low rotor inertia improves acceleration and deacceleration times in short operating cycles e.g. in electric vehicles in crowded areas [2]. In BLDC motor the permanent magnets rotate and armature remains static as shown in figure 1.
BLDC motors don't require an electric connection(made with brushes in DC motor) between stationary and rotating part. Based on permanent magnets mounting [3] and the back-EMF shape [4] BLDC motors can be divided into two categories.

1. Surface mount permanent magnet (SMPM) motor : permanent magnets are surface mounted on the rotor
2. Inside permanent magnet (IPM) motor : permanent magnets are installed inside the rotor

BLDC motor requires rotor position information for proper commutation of current in its stator winding. Back-EMF sensing includes Terminal Voltage Sensing, Third Harmonic Voltage Sensing, Terminal Current Sensing, Back-EMF Integration, Pulse Width Modulation (PWM) techniques. Where reliability of system is important, it is not desirable to use the position sensor because a sensor failure may cause instability in control system.

In BLDC motors the phase windings are distributed in sinusoidal fashion or in trapezoidal fashion. The back-EMF shape can either be sinusoidal or trapezoidal back-EMF and powered by a set of currents. In trapezoidal commutation where only two phases will be conducting at any given point of time while in sinusoidal commutation all the three phases will be conducting at any given point of time. Permanent Magnet Synchronous Motors (PMSM) are interchangeably called as BLDC motors which have the windings distributed in sinusoidal fashion. PMSM motors are smooth as compared to BLDC in which torque will have more ripples but high peak torque. Trapezoidal commutation is the simplest way to control the BLDC motor and easy to implement.

2. POSITIONAND SPEED CONTROL OF BLDC MOTORS USING SENSORS

BLDC motor drive needs a rotor position sensor e.g. Hall-effect sensor, Variable Reluctance sensor and accelerometers [5] to perform phase commutation and current control. Angular motion sensors based on magnetic field sensing principles standout because of their inherent advantages and sensing benefits. Low cost Hall-effect sensors [6] are mostly used shown in figure 2.To rotate BLDC motor the stator windings should be energized in a sequence and rotor position is sensed using three Hall-effect sensors embedded into the stator placed 120 degree on a PCB and fixed to enclosure cap on non-driving end. Whenever North Pole of a magnetic rotor Hall sensor passes near it produce HIGH Level ('1') of output signal. The Hall sensor pattern for a single pole pair BLDC motor during its 360 degree of rotation is shown in figure 3. The relationship between electrical revolution and mechanical revolution depends on pole-pair. Because, As the number of Pole-Pair increases with the motor, more electrical revolutions occur and Hall sensor pattern changes will be faster so commutation change will also be faster.

Electrical Angle = Pole-Pair*Mechanical Angle
No. of Electrical revolutions = Pole-Pair*No. of Mechanical revolutions

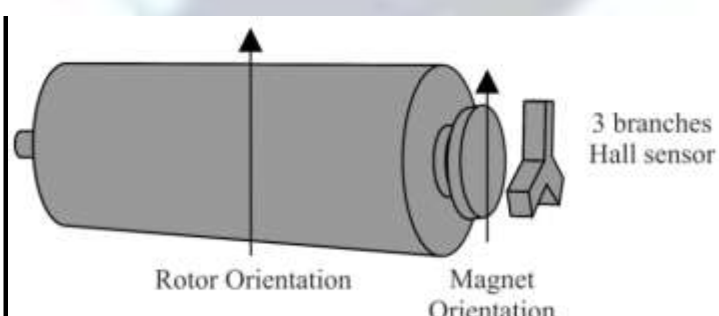


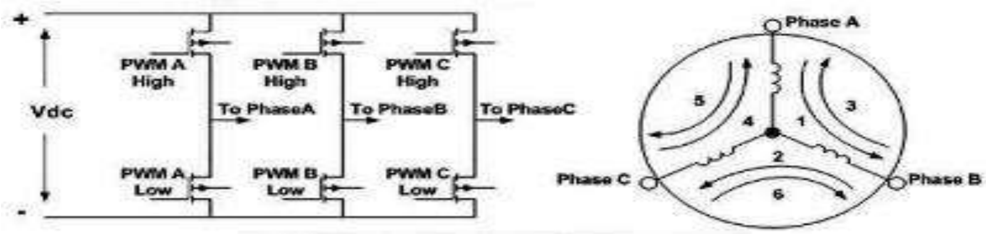
Figure 2 : Three branches vertical Hall device mounted as angular position

3. COMMUTATION LOGIC WITH HALLSENSOR INPUTS

Exciting the appropriate phase coil based on Hall sensor inputs is known as commutation logic. Whenever a new Hall signal change is detected, new drive switching pattern is applied. The commutation logic specifies the coils that need to be energized for every 60 degree of electrical revolution based on Hall inputs. Figure 4 is showing the commutation logic and Drive Pattern for clock-wise Direction, for anti-clock-wise Hall sensor inputs are interchanged.

4. SPEED CONTOL

The speed of BLDC motor is directly proportional to applied voltage. The PWM logic specifies the time intervals,



Hall3 (H3)	Hall2 (H2)	Hall1 (H1)	PWM C High	PWM C Low	PWM B High	PWM B Low	PWM A High	PWM A Low
1	0	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	1	0	1	0	0	1	0	0
0	1	0	0	1	1	0	0	0
0	1	1	0	0	1	0	0	1
0	0	1	0	0	0	1	1	0

Figure 4: Commutation Logic with Hall Sensor Input and Drive pattern for CW direction of BLDC motor

During which the switches should be ON and OFF to average the dc bus voltage applied thereby controlling the speed showing in figure 5.

a. Open Loop Speed Control: In open loop speed control, the duty cycle is directly calculated from the set reference speed and there is no actual speed feedback for control purpose.

b. Closed Loop Speed Control: In closed loop speed control, the set speed and the actual speed are compared and the error is fed to the PI controller, which finally outputs the required duty cycle in order to achieve the required speed operation of the motor.

Proportional-Integral Controller (PI Controller): The regulation of speed is done with the PI controller. The error difference between the actual speed and reference speed is calculated at every PWM cycle and is given as an input to the PI controller. The proportional and integral gains of the controller are configurable.

The duty cycle output from the PI controller is given in continuous time domain as:

$$\text{Duty Cycle: } Kp*error + Ki \int error\, dt$$

Where,
Kp: Proportional Gain

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Ki: Integral Gain
error: Difference in Reference speed with Actual speed

In discrete time domain the same PI controller also represented using discrete equations.

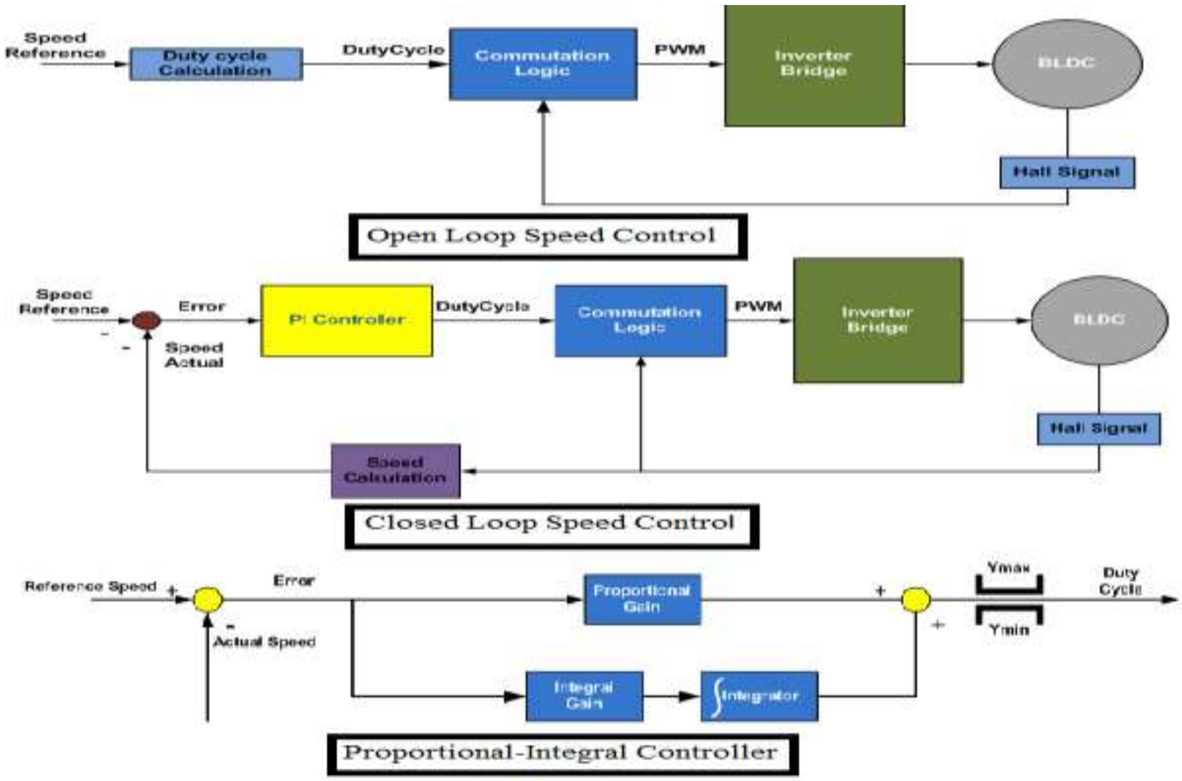

Figure 5 : Speed Contol of BLDC Motor

5. RESULT AND CONCLUSION

More than 90% of the BLDC motors have three phase windings are each part is separated by 120 degree. For feedback of the rotor position they have hall sensors also arranged at an offset of 120 degree or 60 degree that provides six different switching functions per revolution as shown in figure 6

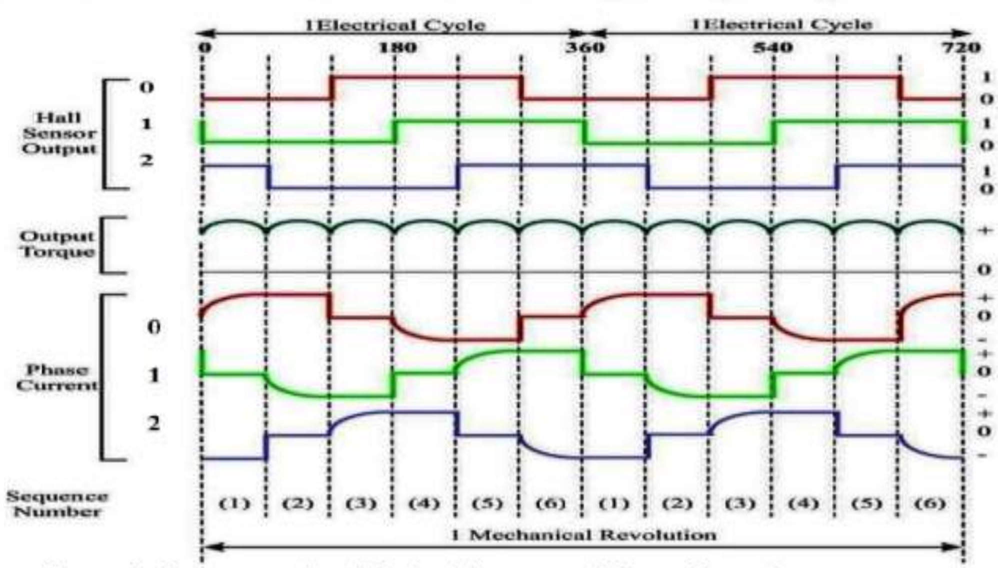

Figure 6: Hall sensor signal, Output Torque and Phase Current

We can use either star or delta winding for BLDC motor but the majority of BLDC motors are implemented with star connections as the star connection delivers a higher torque up to approx. 3000 rpm (speed and torque behavior as inversely proportional to the delta connection by a factor of 1.73) in the delta connection circulating current can also occur in the magnetic circuit and winding due to the Third Harmonic, causing undesirable losses and heating and reducing the efficiency. If a failure occurs (failure of a MOSFET) only one winding is accessed while rotating in the delta connection (in the star connection two windings still are in operations) which quickly leads to overheating and risk of damage to the motor. Drawbacks of BLDC motor control using Hall sensor are increased cost and size, Hall sensors are temperature sensitive so operation range is limited. Depending on an increasing/decreasing load or supply voltage or PWM, the motor rotates proportionally more quickly /slowly. Because of the low feedback signals of the hall sensors in block commutation, speeds lower than approximately 300 rpm are not possible. And the max speed range of approx. 40:1 is also limited. The torque ripple of 15% results in rather unstable running performance and greater noise development at lower speeds.

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Pardeep Narwal was born in Rohtak, Haryana, India in 1988. He completed his Senior Secondary from G.S.S.S; Rohtak in 2006.He received B.Tech degree in Electronics and Communication Engineering from CDLM Government Engineering College, Sirsa in 2011 and is currently a final year M.Tech student of Electronics and Communication Engineering at MERI College of Engineering and Management, Bhadurgarh (Sampla), Haryana, India.