Brushless DC Motor

Report for project done in summer 2015 under guidance of
Prof. Ramprasad Potluri
Dept. of Electrical Engineering
IIT kanpur

by
Akshay Khandelwal
(13074)
Amit Gupta
(13092)
Mayur Gubrele
(13401)

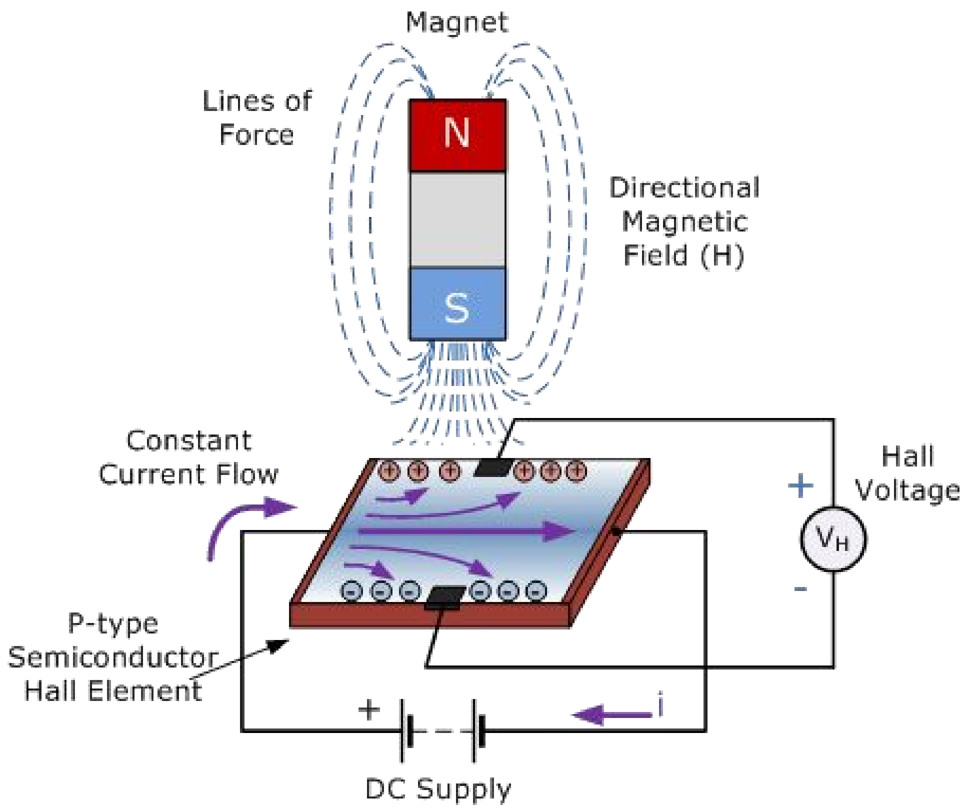
Introduction

Recently, the DC motors have been gradually replaced by the BLDC motors since the industrial applications require more powerful actuators in small sizes. Elimination of brushes and commutators also solves the problem associated with contacts and gives improved reliability and enhances life. The BLDC motor has the low inertia, large power to volume ratio,and low noise as compared with the permanent magnet DC servo motor having the same output rating. Therefore, high-performance BLDC motor drives are widely used for variable speed drive systems of the industrial applications. In case of the control of robot arms and tracking applications with lower stiffness, we cannot design the speed controller gain to be very large from the viewpoint of the system stability. The PI controller is usually employed in a BLDC motor control, which is simple in realization. But it is difficult to obtain the sufficiently high-performance applications. Thus,
the feedforward compensator using disturbance torque observer was proposed. This method can improve the servo stiffness without increasing the speed controller gain.

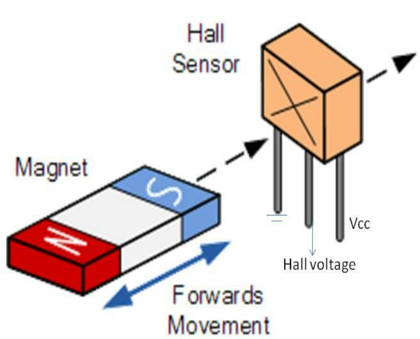
This document provides a detailed overview of BLDC motors, structure, electromagnetic principles, and mode of operation. This document also examines control principles using Hall sensors for three-phase BLDC motors.
It also shows that the torque-current linear relationship can be safely assumed to be valid for a BLDC motor.

Hall effect sensors

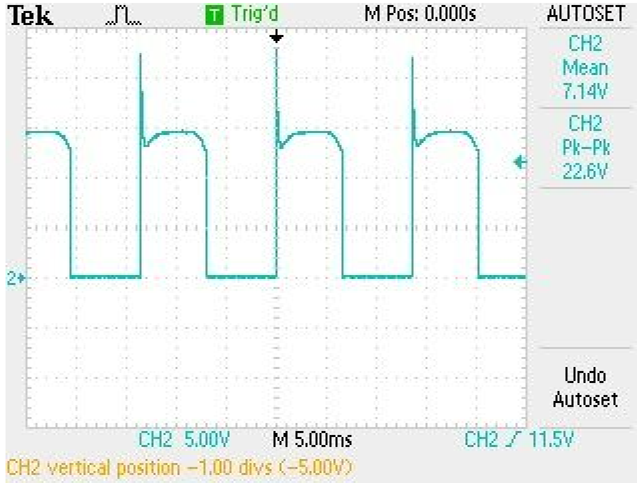
A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications. In its simplest form, the sensor operates as an analog transducer, directly returning a voltage.With a known magnetic field, its distance from the Hall plate can be determined. Using groups of sensors, the relative position of the magnet can be deduced.



As evident from the figure above a hall sensor has 3 pins (some may have 4) that are for common ground (assume zero), supply voltage (Vcc) and Hall voltage.
When hall sensor is not in effect of any magnetic field its voltage remains at ≈Vcc/2. As soon as magnetic field is applied the electrons inside hall sensor rearrange and Hall voltage increases or drops accordingly.



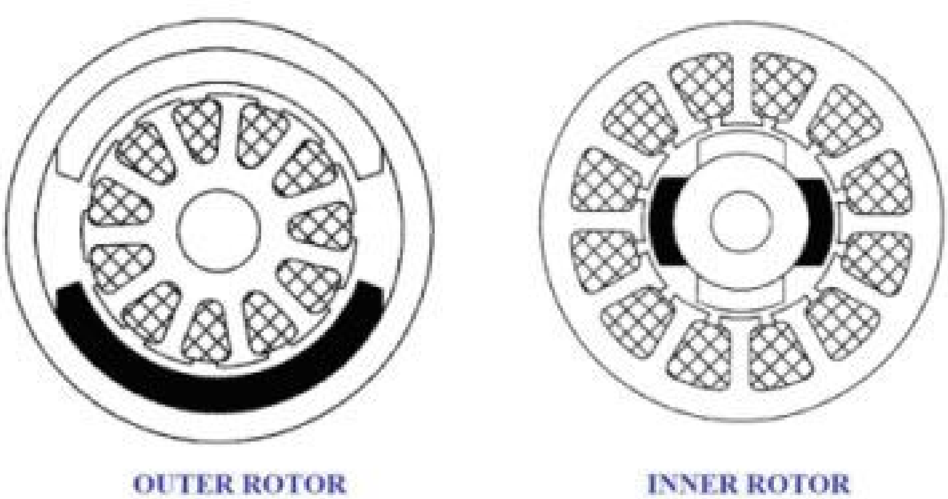
The adjoining graph was obtained by performing experiments on a hall sensor of SMPS fan of a CPU.



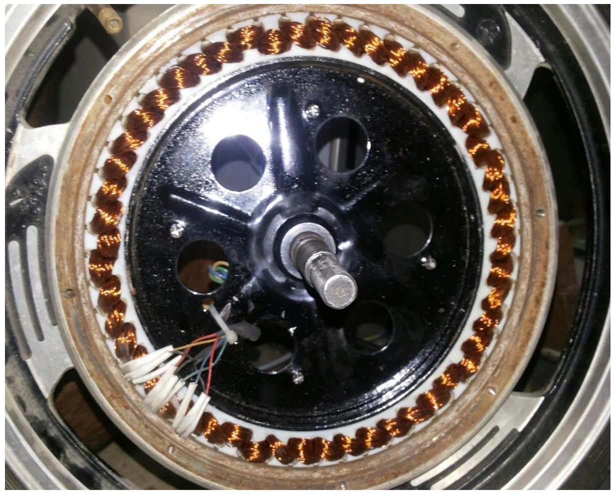
The graph should ideally be a square waveform but due to certain errors momentary peaks are observed.

Construction of BLDC motor

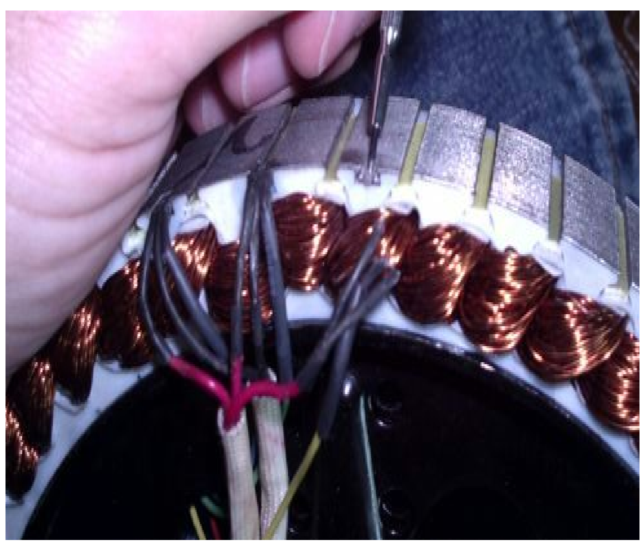
Any BLDC motor has two primary parts; the rotor, the rotating part, and the stator, the stationary part. Other important parts of the motor are the stator windings and the rotor magnets.There are two basic BLDC motor designs: inner rotor and outer rotor design.



The motor available in the lab is as shown in the picture. Motor has stator on the inside while rotor part is outside.



The stator part has 51 windings(17 windings for 3 DC phases) while there are 46 poles(23 pairs of north south) on the stator part. Three groups of wires(3 in each group) that can be easily seen in the picture are those of Hall effect sensors (or simply hall sensors), these three hall sensors are located at a difference of one and a half windings (therefore at 360°/51*1.5 =10.5° from each other)to correctly determine the position of rotor.



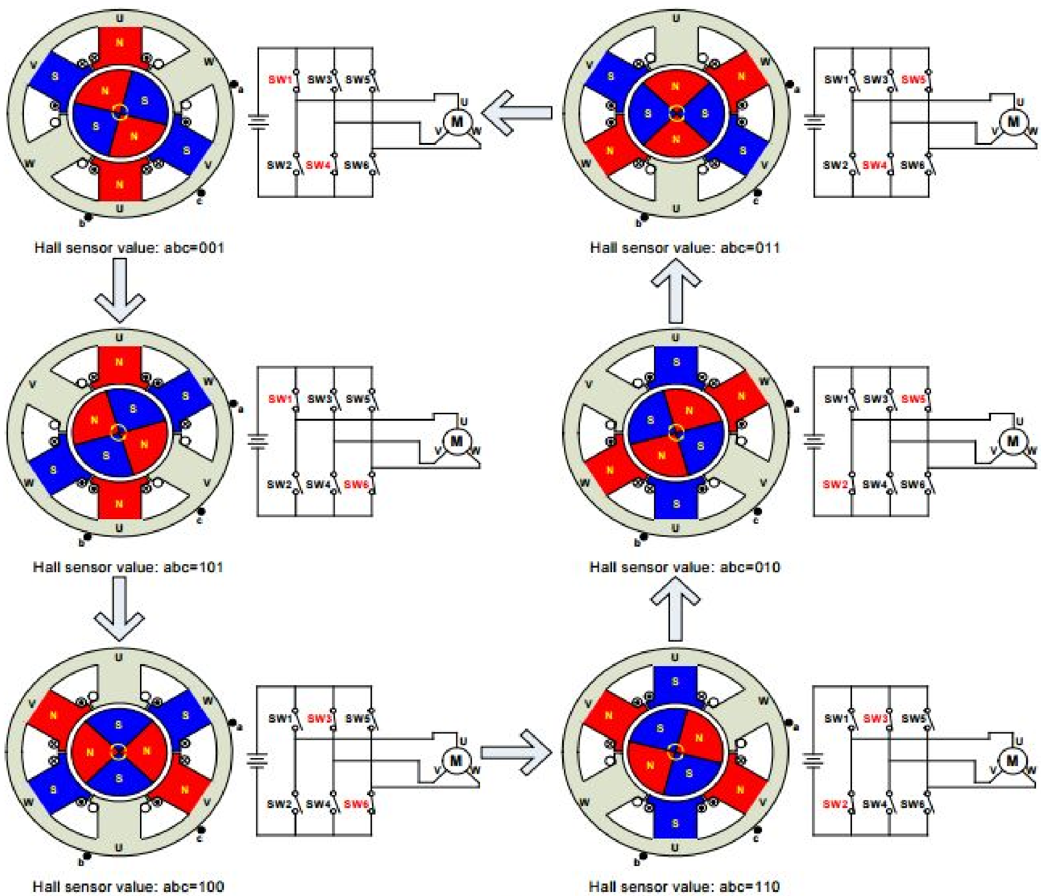
The advantages of having so many poles and windings are

- smooth running of motor
- More torque can be generated
- better position control

Working of BLDC motor

A BLDC motor accomplishes commutation electronically using rotor position feedback to determine when to switch the current. Feedback usually entails an attached Hall sensor or a rotary encoder(hall sensor in our case). The stator windings work in conjunction with permanent magnets on the rotor to generate a nearly uniform flux density in the air gap. This permits the stator coils to be driven by a constant DC voltage (hence the name brushless DC), which simply switches from one stator coil to the next to generate an AC voltage waveform with a trapezoidal shape.

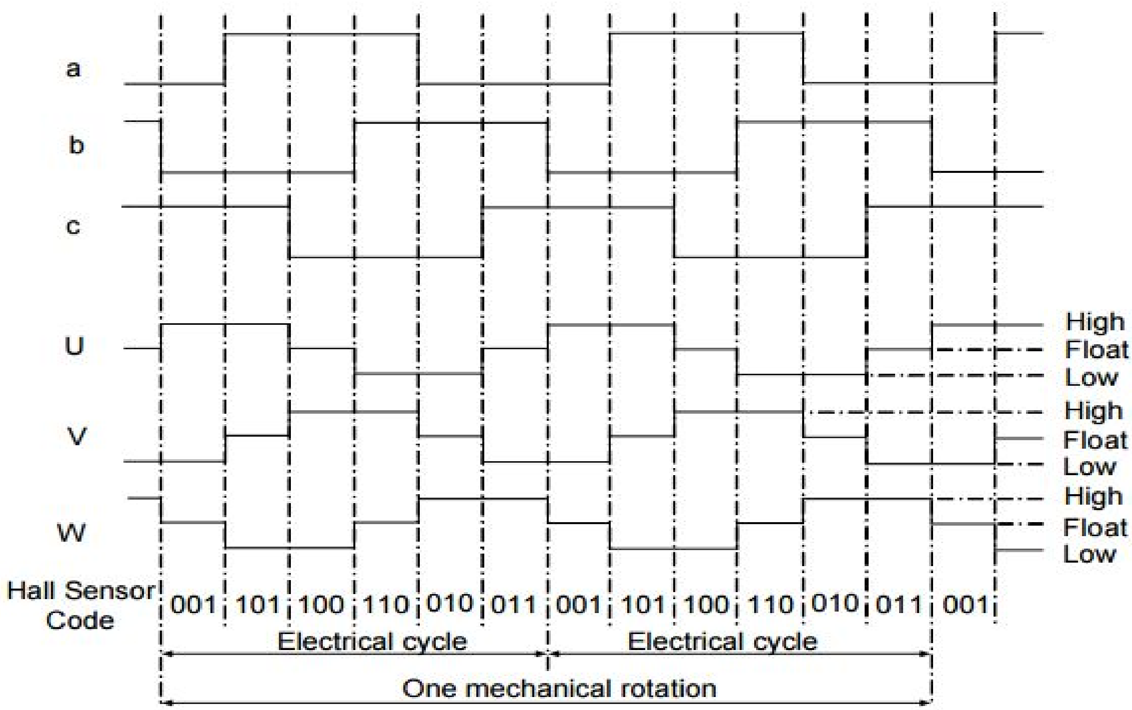
Three-Phase BLDC Motor



Three-Phase BLDC Motor Commutation Sequence

A three-phase BLDC motor requires three Hall sensors to detect the rotor's position. Based on the physical position of the Hall sensors, there are two types of output: a 60° phase shift and a 120° phase shift. Combining these three Hall sensor signals can determine the exact commutation sequence. Figure above shows the commutation sequence of a three-phase BLDC motor driver circuit for counterclockwise rotation. Three Hall sensors—"a," "b," and "c"—are mounted on the stator at 120° intervals, while the three phase windings are in a star formation. For every 60° rotation, one of the Hall sensors changes its state; it takes six steps to complete a full electrical cycle. In synchronous mode, the phase current switching updates every 60°. For each step, there is one motor terminal driven high, another motor terminal driven low, with the third one left floating. Individual drive controls for the high and low drivers permit high drive, low drive, and floating drive at each motor terminal. However, one signal cycle may not correspond to a complete mechanical revolution. The number of signal cycles to complete a mechanical rotation is determined by the number of rotor pole pairs. Every rotor pole pair requires one signal cycle in one mechanical rotation. So, the number of signal cycles is equal to the rotor pole pairs.

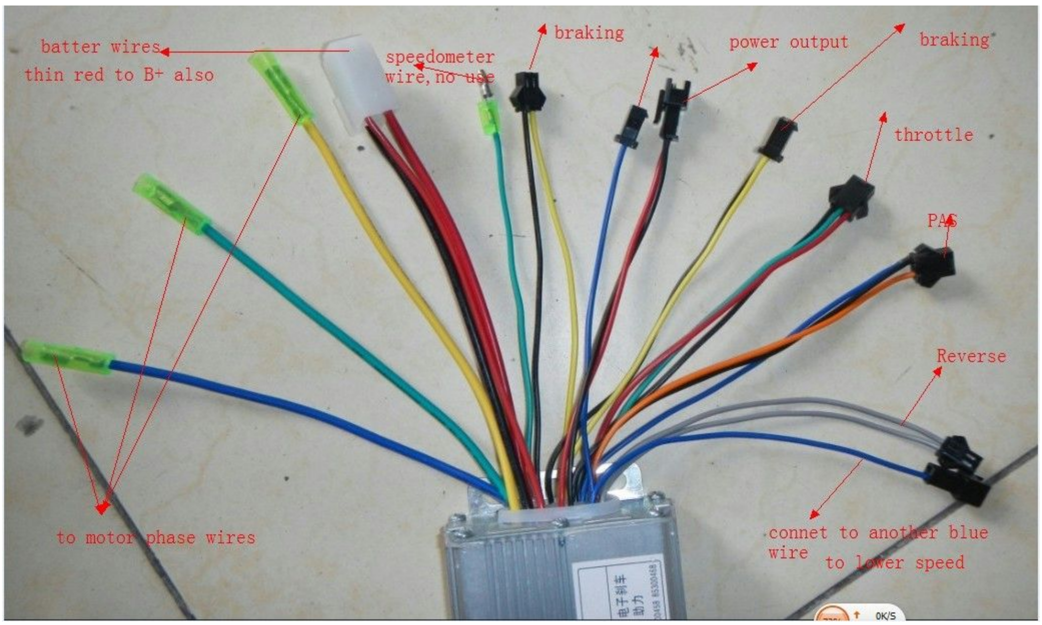
Figure shown below shows the timing diagrams where the phase windings—U, V, and W—are either energized or floated based on the Hall sensor signals a, b, and c. This is an example of Hall sensor signal having a 120° phase shift with respect to each other, where the motor rotates counter-clockwise. Producing a Hall signal with a 60° phase shift or rotating the motor clockwise requires a different timing sequence. To vary the rotation speed, use pulse width modulation signals on the switches at a much higher frequency than the motor rotation frequency. Generally, the PWM frequency should be at least 10 times higher than the maximum motor rotation frequency. Another advantage of PWM is that if the DC bus voltage is much higher than the motor-rated voltage, so limiting the duty cycle of PWM to meet the motor rated voltage controls the motor



Output voltage of hall sensor of BLDC motor

Controller

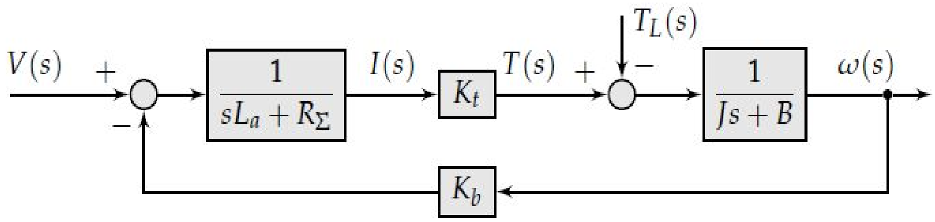
BLDC motor does not have mechanical commutators so we need electronic controller for this purpose.
The signals from hall sensors are manipulated in the controller which then determines how much current has to flow and in which coils.
The controller takes 48V DC supply as input and gives output to the motor.



Torque Current relationship in BLDC motor

We have already mentioned that BLDC motor is most energy efficient motor(has efficiency close to 90%). Most of the losses that occur in this motor are due to friction in axle,non ideal bearings and irregular working atmosphere of the motor.
Here we wish to derive a relationship between torque and current and for this purpose we assume ideal conditions for the motor(i.e. absolutely no mechanical loss). So the only loss left is electrical loss in the copper windings that are too small to be considered, hence all the power input in the motor is delivered to the shaft (output).
since,
Back emf (E) = $K*\omega$
Therefore, Energy input = $E*I = K*\omega*I$
And output power = $\Gamma*\omega$
hence equating the input and output power we directly get the linear relationship of torque and current.
i.e. $\Gamma = K * I$

Therefore, the following block diagram can be used for a BLDC motor.



Plan of Action to control BLDC motor

- To do experiments 5 and 6 of EE380.
- To run BLDC motor at 48V supply
- To implement closed loop control of BLDC motor using L298
- To implement disturbance observer based speed control of BLDC motor using L298

We did experiments of EE380 and tried to run the BLDC motor from 48V 10A supply. However the later part was not achieved.

Problems faced

- **Throttle** : when we connected the BLDC motor to 48V supply, unfortunately the motor didn't run and one of the reasons could be the absence of throttle (as a motor of a bike doesn't rotate without throttle input).
- **Dynamometer** : The torque current relationship is difficult to verify as measurement of torque needs dynamometer which is itself very difficult to set up and handle.
- **connections** : Since this motor is taken out from an electric bike, there are no manuals available for setting up the connections.

References

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- EE380 lab manual IIT kanpur.