Bideirectional Operation of BLDC Motor using MATLAB/Simulink

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***Abstract*: In this paper simulation of bi directional operation of BLDC motor is carried out using MATLAB. The recent development in power electronic devices and advanced trends in micro controllers and DSPs gives the rise in application of BLDC motor . The BLDC motor is having the superior advantages over all other motors in terms of maintenance and dynamic performance. Bi directional operation of BLDC motor is used in EV to obtain regenerative braking. Implementation of regenerative braking using BLDC motor in electrical vehicles improves the life and efficiency of EV battery as well as it also increases the running period of the vehicle [1]. To obtain regenerative breaking using bi directional operation of BLDC motor is a cost effective solution as regeneration is obtained by only changing the switching pattern of inverter.**

***Key words*- brushless DC motor (BLDC), Electrical vehicles (EV)**

Abbreviations and Acronym

BLDC: Brushless Direct current

EMF: Electromotive force

PWM: Pulse width modulation

EV: Electrical vehicles

I. INTRODUCTION TO BLDC MOTOR

BLDC motor is becoming more popular and is widely used in wide range of applications from small, low power applications like fan and disk drives to the large industrial automation and aerospace applications because of its advantages such as better speed vs. torque characteristics, high efficiency, low noise, long operating life and high power density.

BLDC motors are powered by a conventional 3Ø inverter which is controlled based on the rotor position information so it requires rotor position information for electronic commutation. [2]. Position sensors such as Hall sensor, position resolver and absolute position sensors are used to detect rotor position. Generally hall sensors are used to detect position of rotor.

A. STATOR

Stator of a BLDC motor consists of stacked steel laminations, winding are placed in the slots that are axially cut along the inner periphery which is similar to the stator of an induction motor. However, windings are distributed in different manner.[3]. Each of these winding is distributed over stator periphery to form an even numbers of pole.

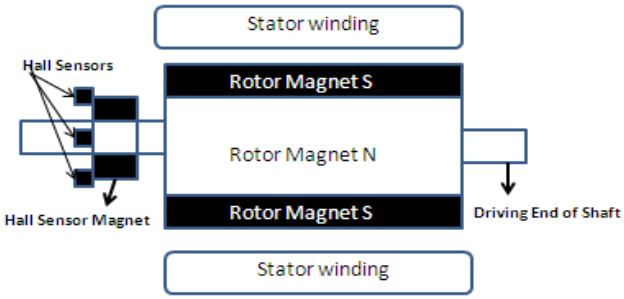

Figure 1 Transverse section of BLDC motor

B. ROTOR

Rotor is made up of permanent magnet. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Rare earth and ferrite are used in rotor. Cross section of various rotor magnets are shown in figure 2.

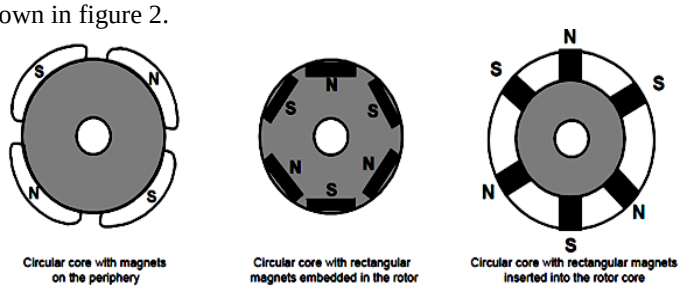

Figure 2 various rotor magnet cross sections [4]

There are mainly two types of Brushless DC motors, depending upon the shape of back EMF of stator winding
Trapezoidal BLDC motor
Sinusoidal BLDC motor
In the entire project the total simulation is carried out on Trapezoidal BLDC motor.

C. WORKING PRINCIPLE:

The operation of BLDC motor is based on fundamental principle of magnetism, similar poles repel, while opposite poles attract. Consider the configuration in figure 4. When the current is passing through two coils, it generates a magnetic field with a polarity that produces torque on the central magnet in a certain direction. When current is passed in the direction shown in figure 3, the central magnet rotates clockwise [2].

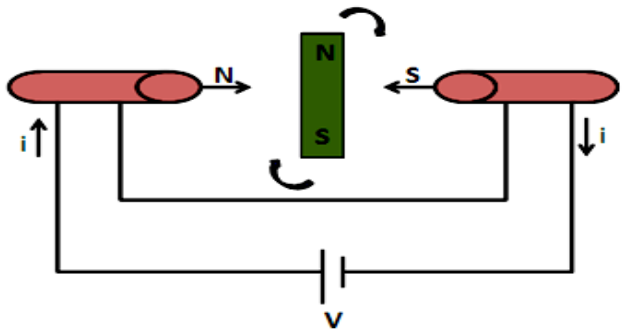

Figure 3

When rotor reaches to a certain position, direction of the current has to be changed so that the torque continues further in the same direction. However instead of two coils 3Ø BLDC motors consist of six coils which are 60° apart as indicated in Figure 4, below.

Two coils are energized at a time to develop torque in order to obtain desired rotor position. Torque on the rotor can be obtained using the Lorentz force formula:

$$T = r * i * L * \beta * sin\theta$$

Where,

T= Electromagnetic torque in N.m.

r = moment arm of the rotor

i = current passing through stator coils

L = length of coil

β = magnetic field of the rotor

θ = angle between the current direction and the magnetic field of the rotor

The 3Ø BLDC motor operates in 120° mode so only two phases are energized at a time and third phase is in idle condition. The energizing sequence of the phases is depending on the position of the rotor. The rotor position is detected by the Hall sensors mounted on the non rotating part of the shaft. The typical inverter to control the each phase is shown in figure 5. Maximum torque is reached when the field lines are perpendicular [2].

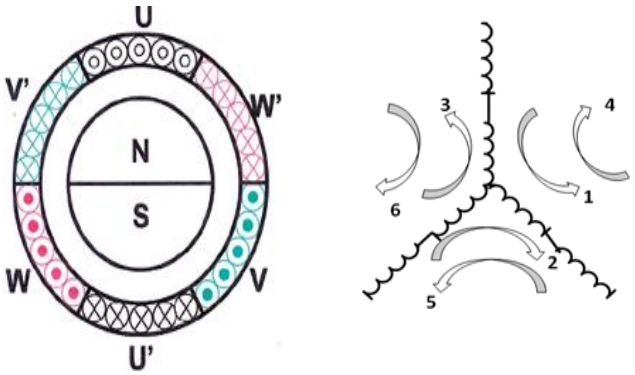

Figure 4 Cross section of winding with its energized coils [2] & excitation

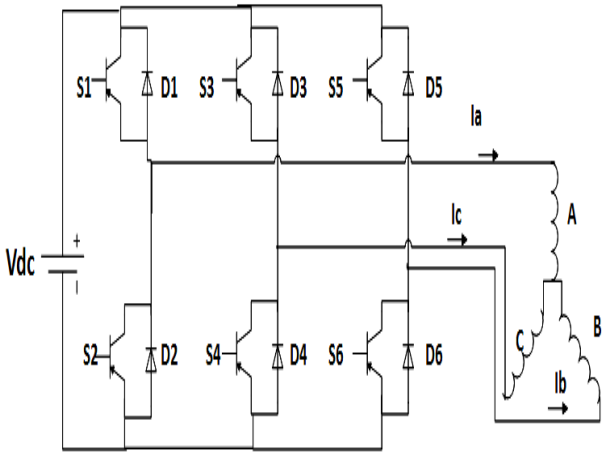

Figure 5 Typical BLDC motor drive scheme

Depending upon the hall sensor output pattern, the appropriate windings are energized through switches S1-S6 of inverter [5]. The direction of the phase currents is also shown in each phase of the winding in figure 6. The operation is divided into six parts so called six step commutations.

There is 60° offset between Hall sensor outputs. At any instant only two windings are energized so BLDC motor operates in120° mode [6]-[7]. The current in the stator winding is rectangular in nature and excitation of phase windings and direction of currents are as shown in figure 6.

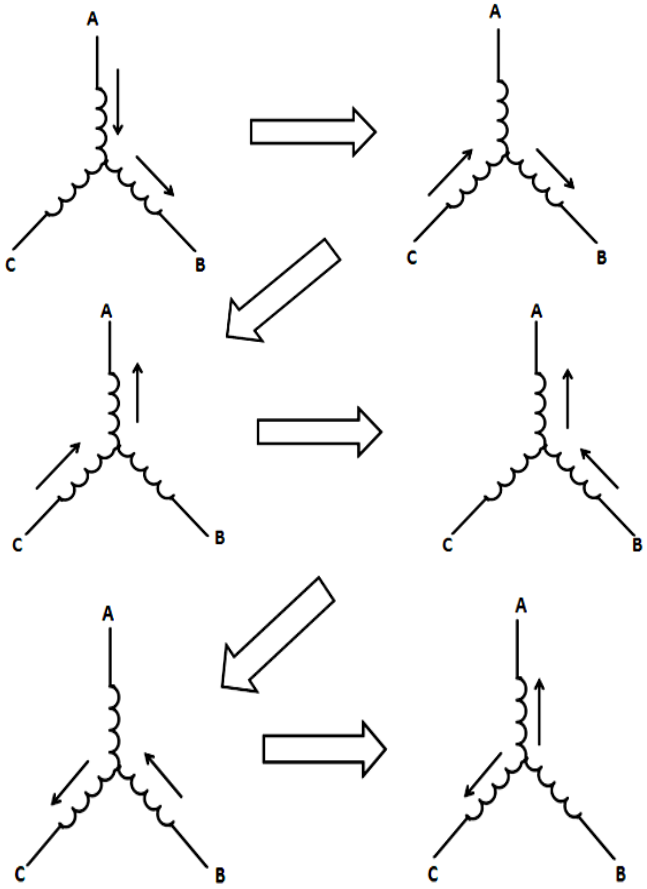

Figure 6 Current entering and leaving the stator windings

II. BIDIRECTIONAL OPERATION OF BLDC MOTOR

BLDC motor can operate in both the direction by changing the switching pattern of inverter. This bi directional operation is used in EV to achieve regenerative braking. When motor operates in clock wise direction operation is considered as motoring. By changing switching pattern of the inverter motor can be operated in anti clock wise direction and regeneration is achieved.

Table 1 shown below is for clock wise operation of BLDC motor. In this operation motor speed is positive and load draws current from motor.

Table 1 Switching sequence for Clock-wise operation

Mode	Hall Sensor Output			Inverter Switches					
	H3	H2	H1	S6	S4	S2	S5	S3	S1
1	1	0	1	0	1	0	0	0	1
2	1	0	0	0	1	0	1	0	0
3	1	1	0	0	0	1	1	0	0
4	0	1	0	0	0	1	0	1	0
5	0	1	1	1	0	0	0	1	0
6	0	0	1	1	0	0	0	0	1

Table 2 shown below is for anti clock wise operation of BLDC motor. In this operation motor speed is negative and load feeds current to the motor so regenerative braking can be obtained.

Table 2 Switching sequence for anti clock-wise operation

Mode	Hall Sensor Output			Inverter Switches					
	H3	H2	H1	S6	S4	S2	S5	S3	S1
1	1	0	1	0	0	1	0	1	0
2	1	0	0	1	0	0	0	1	0
3	1	1	0	1	0	0	0	0	1
4	0	1	0	0	1	0	0	0	1
5	0	1	1	0	1	0	1	0	0
6	0	0	1	0	0	1	1	0	0

III. MATLAB SIMULATION

Simulation has been carried out for bidirectional operation of BLDC motor by changing the switching pattern of motor. Table 3 shows parameters of BLDC motor for which simulation is carried out.

Table 3 BLDC motor parameters

PARAMETER of BLDC Motor			
Phase Resistance	5 Ohms	Pole pair	4
Phase Inductance	5 mH	Rated Torque	0.32 N*m
Rated Current	15 amp	Rated Speed	5000 r.p.m.

A. MATLAB MODEL

Figure 7 shows MATLAB model. One external signal is given to change direction of rotation. When motor receives an external signal to change direction of rotation, 6 m.sec delay is provided to avoid shoot through fault in inverter.

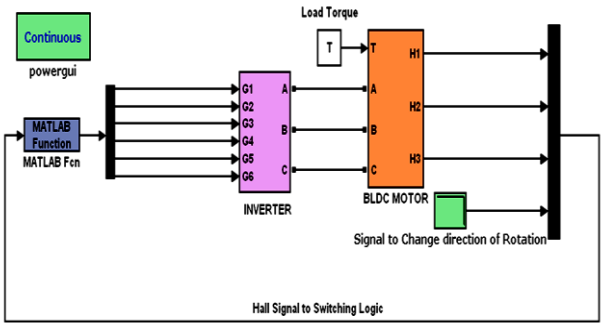

Figure 7 MATLAB Simulink Model

Simulation result

Figure 8 shows the hall sensor signals. Hall sensors are placed 120º apart on non rotating part of shaft. Transition takes place at every 60º. Each hall sensor conducts for 180 º depending on the polarity of the magnet.

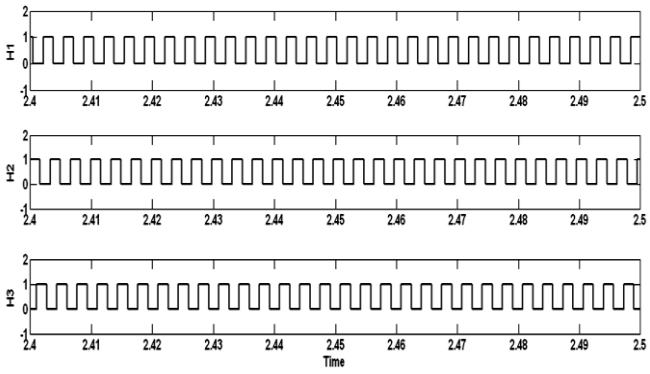

Figure 8 Hall sensor signal

Figure 9 shows inverter switching patterns. Inverter switches are fired as per the logic table 1 and 2.

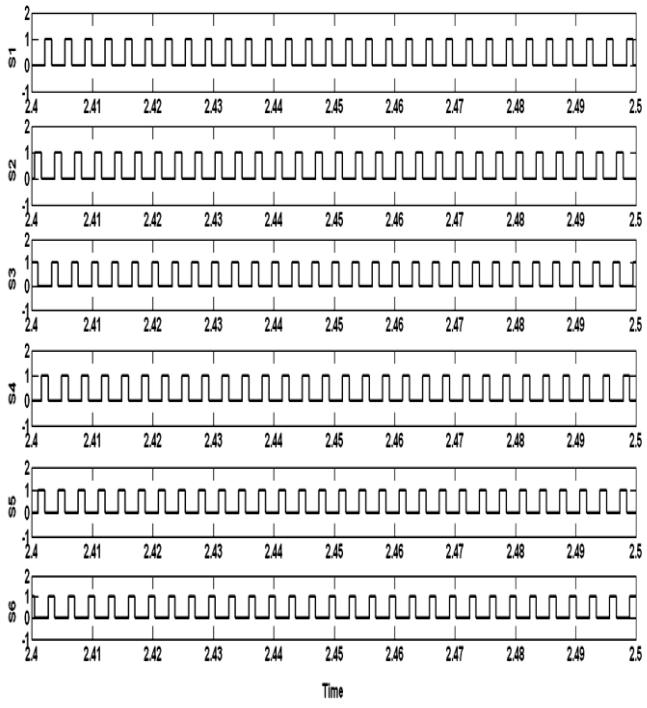

Figure 9 Inverter Switching signal

At any instant only two phases of motor conduct hence inverter operates in 120º mode.

One external signal is used to change direction of rotation. When external signal is received for clock wise rotation, inverter switches are fired as per table 1. When external signal is for clock wise rotation, inverter switches are fired as per table 2.

Figure 10 shows back EMF waveforms. The back EMF signal of each phase is trapezoidal in nature as it is the function of rotor position and speed. Motor operates in clock wise direction till 2.5 sec. 6 m.sec delay is provided to change direction of rotation to avoid shot through fault in switching of inverter. At 2.506 switching sequence are as per table 2. Due motor inertia, motor cannot change its direction suddenly. Motor speed will gradually reduce so current drawn by motor is fluctuated.

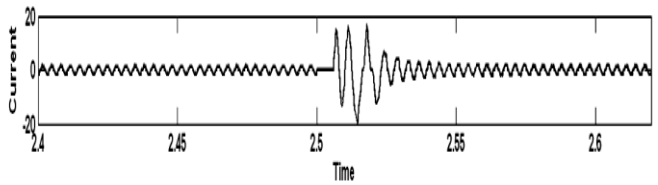

Figure 10 Stator Phase Current

Figure 11 shows expanded waveform of stator phase current.

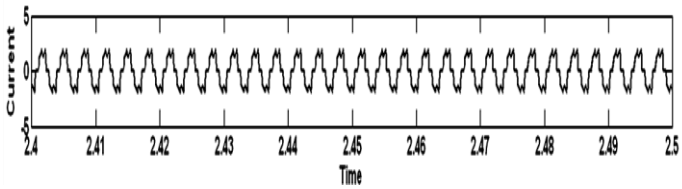

Figure 11 Expanded waveform of stator phase current

Figure 12 shows Back EMF waveform. Back EMF is trapezoidal in nature. It is function of speed and rotor position. Up to 2.5 sec motor operates in clockwise direction. There is delay of 6 m.sec and after 2.506 sec motor operates in anti clock wise direction.

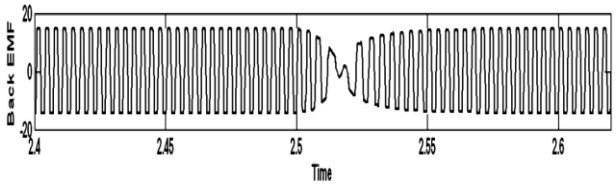

Figure 12 Back ENF

Figure 13 shows expanded waveform of Back EMF.

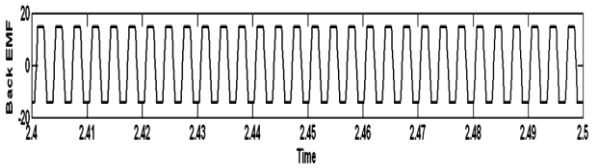

Figure 13 Expanded waveform of Back EMF

Figure 14 shows torque and speed waveform. As motor operates in clock wise direction up to 2.5 sec motor speed is positive. Motor cannot suddenly change direction of rotation due to inertia so gradually motor speed reduce then motor operates in anti clock wise direction and motor speed is negative.

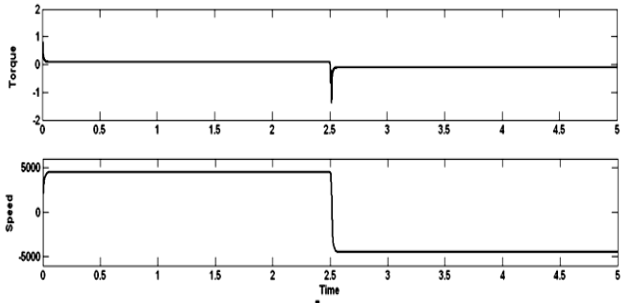

Figure 14 Load Torque and Speed

CONCLUSION

In this paper simulation of bi directional operation of BLDC motor is carried out using MATLAB. One external signal is used to change direction of rotation. Switching sequence of inverter is changed as per the direction of rotation. Bi directional operation is used in EV to achieve regenerative braking. Regenerative braking using BLDC motor is cost effective as there is no use of multiple winding or ultra capacitors.

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