Chapter 1
Demonstration and Simulation of Brushless Direct Current Motor

Prakriti Mohanty, Debani Prasad Mishra, Anshuman Behera, and Swati Swarupa Das

Abstract In this paper, the Brushless Direct Current Motor (BLDC) is simulated with the help of the software MATLAB using some basic theories and its practical features and its performance is analyzed. This helps simulate the corresponding model for the BLDC with ease. The output of BLDC motor performance which was obtained in MATLAB can be analyzed for different input parameters, critically in the MATLAB. The precision and practicality of the model can be known by analyzing the output results obtained from simulation with actual BLDC model. The construction of the BLDC Motor is briefly discussed.

Keywords BLDC · MATLAB · PMBLDC · Modeling · Simulation · Construction

1 Introduction

Direct Current motors conventionally contain brushes and commutators which makes their maintenance very difficult and expensive. So brushless Direct current motors have been started being preferred to use. It consists of permanent magnet. It is used in households as well as automobiles. Also, it has its applications in aerospace. It has its applications in military because of the high torque that it produces. It also has very high ratio of output to input also known as efficiency. It is because of these characteristics that the brushless Direct Current motor has found a lot of applications. The information regarding the position of the rotor is required for corresponding values of variation of current or commutations so that the values can be controlled electronically [1, 2].

It has a variety of applications as mentioned above. Apart from those, the brushless Direct Current motor can be implemented in offices, hard drives, robots used for automation, also for automation of offices. It is also used in various drive applications. The main advantages of the motor are its high efficiency, no complex controls, high

P. Mohanty · D. P. Mishra (✉) · A. Behera · S. Swarupa Das
Department of Electrical Engineering, International Institute of Information Technology, Bhubaneswar, India
e-mail: debani@iiit-bh.ac.in

S. Mahapatra et al. (eds.), *Advances in Energy Technology*, Advances in Sustainability Science and Technology, https://doi.org/10.1007/978-981-15-8700-9_1

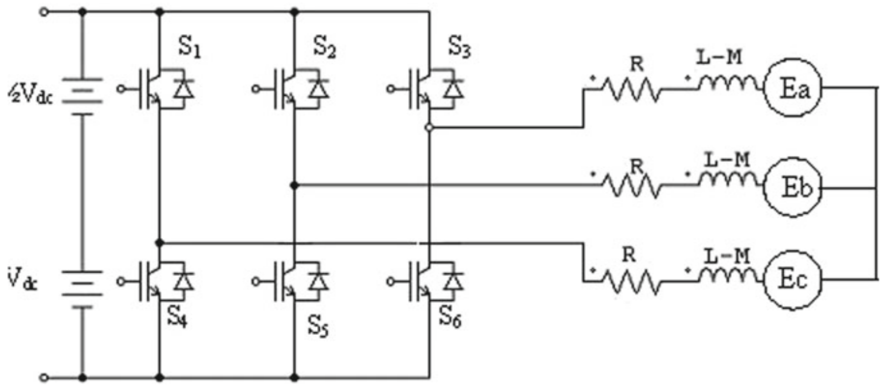

Fig. 1 BLDC motor connected to a converter circuit

ratio of speed to torque. Also, it is portable and compact. The maintenance of brushes is not required anymore. The mechanical and physical wear and tear of the brushes causes a lot of problems which are avoided by using BLDC motor. A diagram showing a typical BLDC motor connected to a converter circuit is given below (Fig. 1).

It can be achieved by changing rotor and stator position. An inverter is required which shall help in the alternating the functions of the used brushes and the commutator. Another essential component utilized is a position sensor which is helpful in detecting the position of the rotor. The software Simulink of MATLAB has been used for the modeling of the motor and for the simulation part as well MATLAB consists of many commands and can be used to solve and simulate different types of problems ranging from power electronics to control systems to power systems or DC machines. It provides quick simulation and also has an interface which is user-friendly so it is preferred to be used for simulation purposes. It also makes it possible to get connected to third-party software such as PSIM or Proteus. We can use the MATLAB and Simulink software to solve a wide variety of problems in an easy and efficient manner [3, 4].

2 Principle and Construction

The Brushless DC motors are categorized based on the shape of the wave of their emf that is induced in it, which are of two types, i.e., trapezoidal and sinusoidal. The permanent magnet synchronous motor comes under sinusoidal type and trapezoidal type s included in PM Brushless dc (BLDC) machine. Synchronous motors are those types of motors in which the stator and the rotor both generate their respective magnetic fields at the same or equal frequency.

Since the BLDC motors do not contain brushes, they do not experience the wear and tear of brushes and also the slip that is found in normal induction motors is

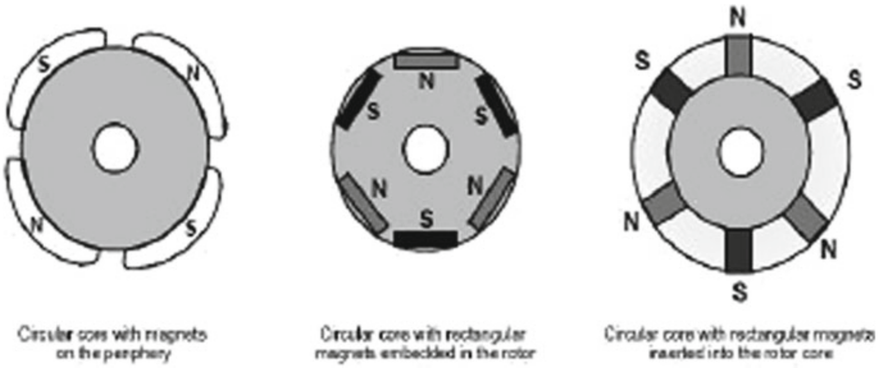

Fig. 2 Construction of a rotor

absent. The BLDC motors are available in various different variants namely one, two, or phases and the number of rotor windings depends on its type. The major components of motor are stator and rotor [5, 6].

2.1 Rotor

The rotor consists of permanent magnets consisting of varying pole pairs, two to eight in number, with South and North in alternating fashion. The material chosen to make the rotor depends on the density of the magnetic field required for rotor. Generally, ferrites or rare earth metals are used. It is because they are cheap, but they have low density of flux corresponding to a given volume. On the contrary alloys have flux density enabling the rotor to get more compressed for the similar values of torque [7].

They also have increased size and weight ratio and they also have the capability to generate a larger amount of torque as compared to their ferrite counterparts possessing similar size. A few constructions have been shown as follows (Fig. 2).

2.2 Stator

The BLDC motor and induction motor has similar constructional features. Brushless Direct motors generally have three stator windings which are generally interconnected in the form of a star. Windings placed are stacked steel in axially cut internal slots placed in the periphery co-axially. The BLDC motor and induction motor has similar constructional features.

Each slot consists of a single or more coil that are connected to one another to form a winding. The rotor is surrounded by windings to form the poles which are

Table 1 Phase sequence of the rotating position of rotor

Hall effect signals			Decoded signals		
H1	H2	H3	h1	h2	h3
0	0	0	0	0	0
0	0	1	0	−1	+1
0	1	0	−1	+1	0
0	1	1	−1	0	+1
1	0	0	+1	−1	0
1	0	1	0	+1	−1
1	1	0	+1	0	−1
1	1	1	0	0	0

even in number. Sinusoidal and trapezoidal are the two variants of stator windings found. It is based on the connection of coils to generate reverse Electromotive Force in the stator winding [8].

2.3 Sensing Position of the Rotor

In a brushed Direct Current motor, the commutation is physical whereas, in brushless, it is electronical. When the windings of the stator are filled with energy, sequentially, the motor shaft rotates. The exact position of the shaft (Rotor) can be sensed through the sensors contained in the stator using Hall effect. It also provides the order of energization of the phase. Mostly BLDC motors contain three sensors which give high signal for North Pole and low signal for South Pole when they pass by the sensors. The combination of phase sequence is determined by the Sensor order [9] (Table 1).

3 Mathematical Modeling

A differential equation of the first order can be used to describe the phase of activity of a motor of Alternating Current type [10, 11]. A voltage equation for any of the phases can be generalized as follows.

$$Vx = Rix + \sum_{k=1}^{n} \frac{\mathrm{d}\Psi kx(\theta, ix)}{\mathrm{d}t}$$

where Vx is voltage of phase, R is Resistance, ix is current of the phase, θ is the position of the rotor, ψ is the linkage of flux, n is the phase number.

The three phase equations are:

$$Va = R(ia) + L\frac{\mathrm{d}(ia)}{\mathrm{d}t} \tag{1}$$

$$Vb = R(ib) + L\frac{\mathrm{d}ib}{\mathrm{d}t} \tag{2}$$

$$Vc = R(ic) + L\frac{\mathrm{d}ic}{\mathrm{d}t} \tag{3}$$

where,

L is the self-induction (H).

R is the resistance of armature (Ω).

Va, Vb, Vc are the voltages at end terminal in per phase (V).

ia**,** ib**,** ic are the input currents of the motor (three-phase) (A).

The reverse voltages can be represented in terms of mechanical speed of the rotor, ωm, and the electrical angle of the rotor, θr as follows:

$$ea = Kw(\theta e)w \tag{4}$$

$$eb = Kw(\theta e - 2\pi/3) \tag{5}$$

$$ec = Kw(\theta e + 2\pi/3) \tag{6}$$

The rotor angle θr determines the coefficients ke_a, ke_b, and ke_c. This model assumes an ideal waveform in the form of a trapezoid.

The equation for mechanical torque is:

$$J\,.\,\frac{\mathrm{d}\omega m}{\mathrm{d}t} = T\mathrm{em} - B.\omega m - T\mathrm{load}$$
$$\frac{\mathrm{d}\theta r}{\mathrm{d}t} = (P/2).\omega m$$

where B refers to coefficient, Tload refers to torque of the given load, and P refers to the number of poles. The mechanical time constant and moment of inertia J help in calculation of coefficient B given as:

$$B = J/\tau\mathrm{mech}$$

4 BLDC in Simulation Environment

Figure 3 shows the simulation diagram of BLDC motor with PID controller and Hall Effect sensor. Figure 4 shows the circuit which has been used to implement commutation logic. Figure 5 shows the electromagnetic torque of the BLDC motor under no-load condition and closed-loop system. Figure 6 shows the Hall Effect Signal for the BLDC motor under no-load condition and closed-loop system. It is obtained from the sensors which sense the rotor speed of the motor. Figure 7 shows the Stator Current of the Brushless DC motor under no-load condition and in closed-loop system. Figure 8 shows the Output-Rotor Speed of the Brushless DC motor

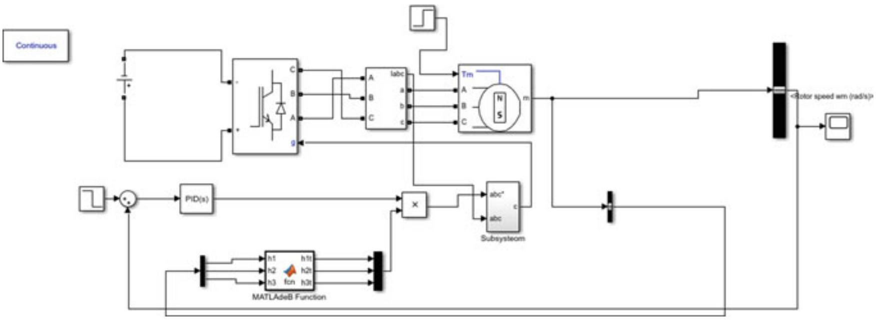

Fig. 3 Simulation diagram of BLDC motor with PID controller

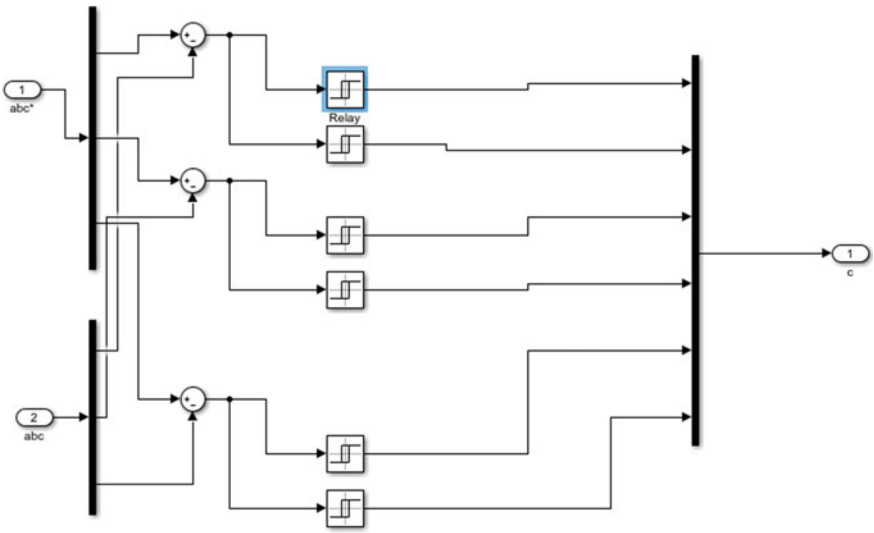

Fig. 4 Subsystem

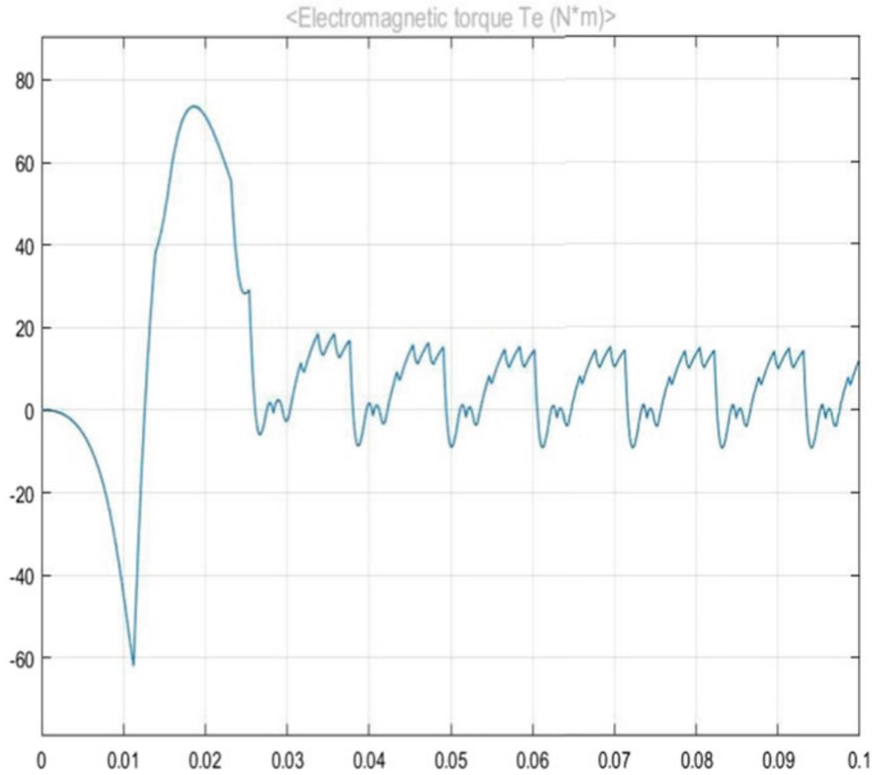

Fig. 5 Electromagnetic torque

under no load condition and in closed loop system. This speed is sensed by the Hall Effect sensor and thus determines conduction of winding commutation of each phase.

5 Conclusion

The working and construction of the Brushless Direct Current motor were studied successfully. The motor model was simulated using MATLAB in which different characteristics like rotor speed, electromagnetic torque, Hall Effect signal, stator current of the motor were analyzed. The speed and load torque were varied and various results were obtained. The result of the simulation helps in building real-time model and helps in saving manpower and reduces cost.

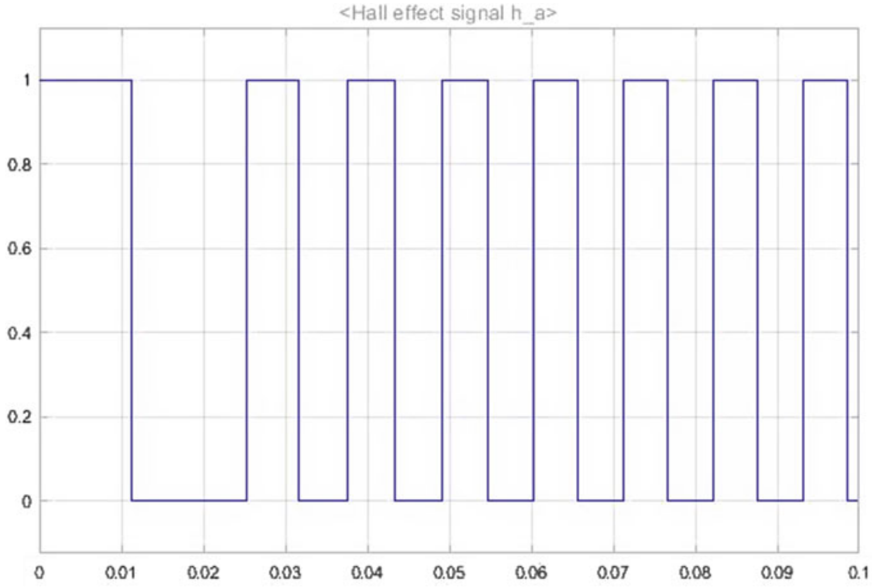

Fig. 6 Hall effect signal for one-phase

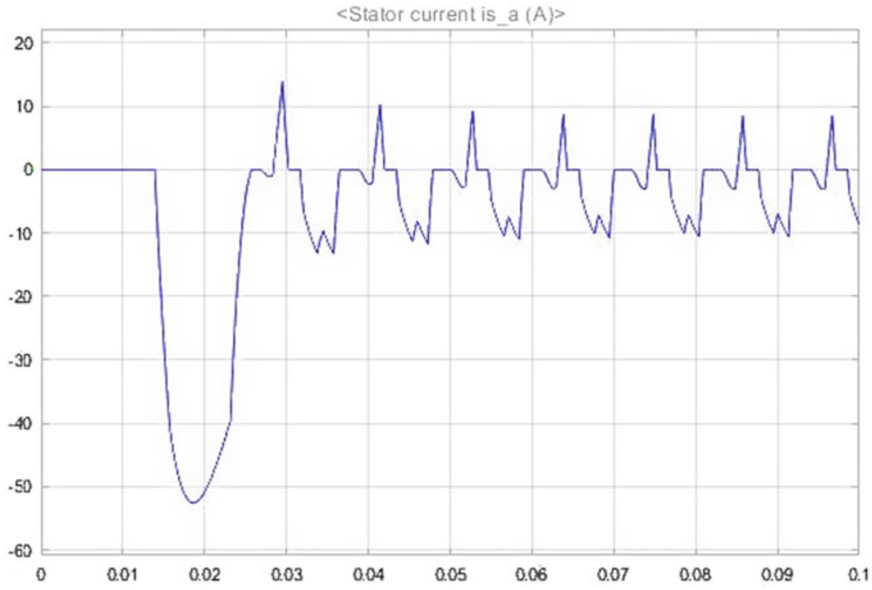

Fig. 7 Stator current

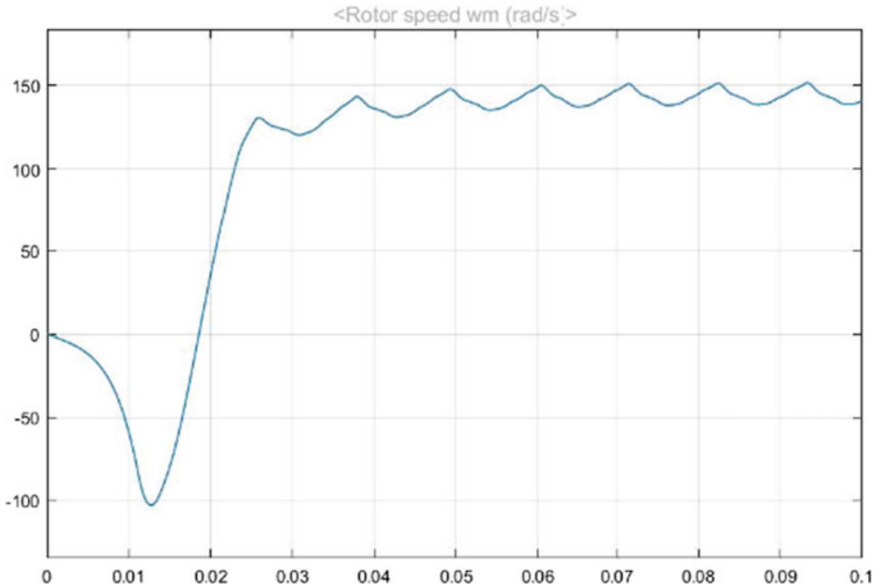

Fig. 8 Output-rotor speed

References

1. Kim JH, Jung IS, Ha GS (2015) Design and manufacturing of ultra small actuator. IEEE 3rd international conference on mechatronics, pp 23–26
2. Mishra DP, Sarangi JP (2019) Identification and analysis of different parameters for eddy current braking system along with its applications. IJRTER, 5(11):23–29
3. Mishra RN, Mohanty KB, Ray P, Mishra DP (2016) A reduced MF-based self-tuned robust neuro-fuzzy control of a decoupling linearized IM drive. ICNGIS-2016, 1st–3rd Sep 2016, Rajiv Gandhi Institute of Technology, pp 1–6
4. Alanson Sample P, Meyer DA, Smith JR (2016) Analysis, experimental results, and brushless DC motor speed control based on PID controller with 2-DOF and anti-windup techniques, vol 58, no. 2
5. Etacheri V, Marom R, Elazari R, Salitra G, Aurbach D (2018) Research on speed control system of brushless DC motor based on neural network: a review. Science 4(9):3243–3262
6. Kainan C, Zhengming Z (2013) Modelling and simulation methods for brushless DC motor drives IEEE. J Emerg Sel Topics Power Electron 1(2):114–121
7. Puqi N, Miller JM, Onar OC, White CP (2013) Brusless DC motor controlled by using IOT. In: Proceedings of IEEE ECCE, pp 3629–3634
8. Lukic S, Pantic Z (2013) Brushless DC motor speed control using proportional integral and fuzzy controller. IEEE Electrific Mag 1(1):57–64
9. Budhia M, Boys JT, Covic GA, Chang-Yu H (2013) Rapid control prototyping approach to fuzzy speed control of brushless DC Motor. IEEE Trans Ind Electron 60(1):318–328
10. Yiming Z, Zhengming Z, Kainan C (2014) Speed performance evaluation of BLDC motor based on dynamic wavelet neural network and PSO algorithm. IEEE Trans Power Electron 29(3):1058–1063
11. Mishra DP, Ray P (2018) Fault detection, location and classification of a transmission line. Neural Comput Appl 30(5):1377–1424