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SIMULATION & CONTROL of BRUSHLESS DIRECT CURRENT MOTOR WITHOUT CONSIDERING EFFECTS of HALL SENSORS

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Abstract: The Brushless Direct Current motor has its distinct properties and lossless operation. These qualities of Brushless Direct Current motors allow them to be used in a wide range of applications and make them a preferable alternative for many other types of motors. This literature has concentrated on the simulation and controlling of the Brushless Direct Current motor excluding the effects of hall sensors, which will provide a fundamental understanding of the Brushless Direct Current motor's operation and control approach.

Keywords: Include at least 4 keywords or phrases. Brushless Direct Current motor, commutation logic, inverter circuit, controlling, simulation, microcontroller, IR sensors.

I.INTRODUCTION

Brushless dc motors are used in anything from everyday items to more complicated machinery like washing machines, electronics, drones, cranes, and electric vehicles. Brushless dc motors transform electrical energy into rotational motion. Brushless dc motors, often known as Brushless Direct Currents, have several benefits over their brushed equivalents. Although Brushless Direct Current motors are more efficient and need less maintenance, they have essentially superseded brushed motors in many applications in the past few decades. Brushed and brushless dc motors work on the same principle, in which rotational motion is created by the attraction and repulsion of magnetic poles of permanent and electromagnets. However, the manner these motors are controlled is vastly different. A sophisticated controller is required for Brushless Direct Currents to convert dc power into three-phase voltages, whereas a brushed motor may be readily controlled by dc voltage. We can produce an electromagnet with the poles in brushless dc motors by feeding current through the stator coil windings. These electromagnetically produced poles on the stator interact with the poles of the permanent magnet of the rotor, causing the rotor to spin. There are motors with various magnet layouts in which the stator has a variable number of windings and the rotor does have several pole pairs. To maintain the rotor spinning in a Brushless Direct Current motor, we need to flip the poles of the electromagnet of the stator winding, which is done by altering the polarity of the current in the stator coil windings. Such switching of phases is referred to as commutation [1]. In contrast to brushed dc motors, Brushless Direct Currents use electronically driven commutation rather than mechanical commutation. Our approach is distinct in a way that controlling the Brushless Direct Current motor is applicable irrespective of its internal stator-rotor arrangement or number of poles, without even considering the effects of hall sensors.

II.SIMULATION

Position Here, the entire task is simulated with the help of the MATLAB/Simulink tool. The arrangement shows in the below figures, made via blocks of the Simulink tool's library. Fig – 1 shows the Open Loop control circuit of the Brushless Direct Current motor. It shows three blocks namely,

1. Commutation Logic Block
2. Three-phase Inverter Block
3. Brushless Direct Current Motor Block

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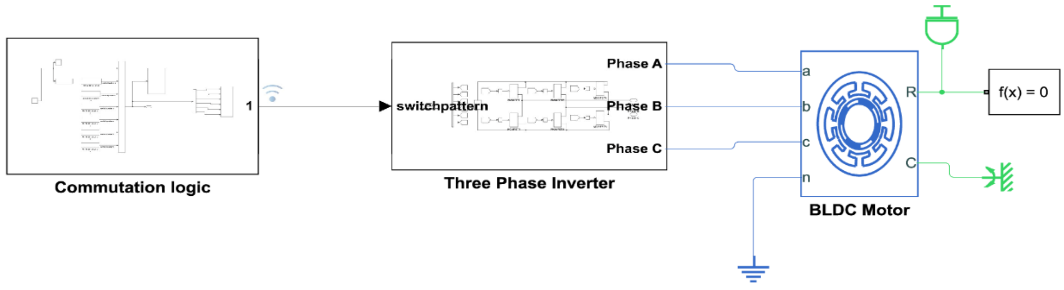

Fig. 1. MATLAB Circuit of Open Loop Control of Brushless Direct Current motor

A. Commutation Logic block

A commutation means altering the polarity of the phases of the motor. Here, the arrangement of Simulink components is such that the commutation logic will give commands to the inverter circuit about which group of switches should be ON at a particular instance. It can be done by selecting the pre-defined switching patterns. As there is a total of six switches available in the 3-phase inverter, six different combinations can be made according to consecutive commutation steps [4].

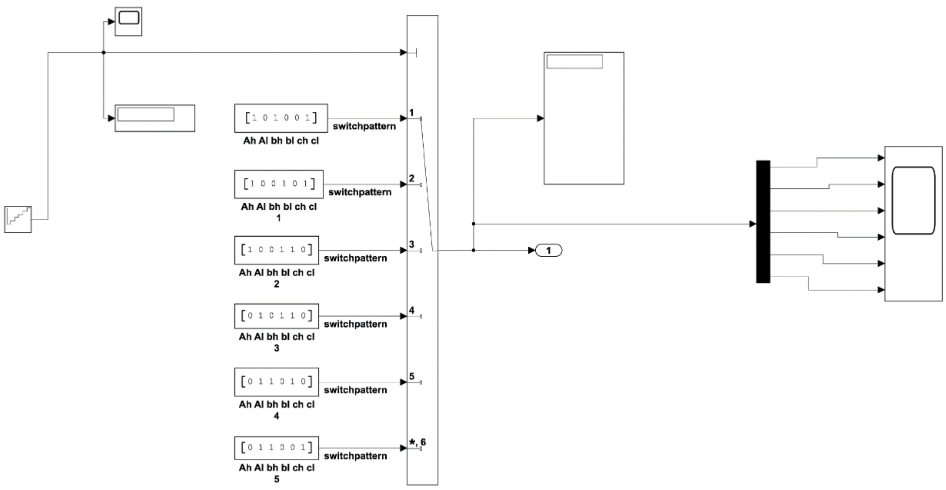

Fig. 2. Commutation Logic arrangement

B. Three-phase Inverter block

A commutation means altering the polarity of the phases of the motor. Here, the arrangement of Simulink components is such that the commutation logic will give commands to the inverter circuit about which group of switches should be ON at a particular instance. It can be done by selecting the pre-defined switching patterns. As there is a total of six switches available in the 3-phase inverter, six different combinations can be made according to consecutive commutation steps [4].

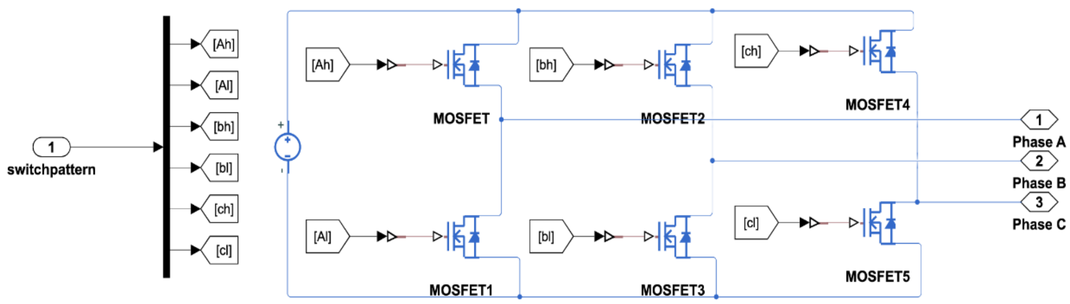

Fig. 3. Three-Phase Inverter MATLAB Circuit

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C. Brushless Direct Current Motor block:

The Brushless Direct Current motor block has six terminals, out of which 4 are electrical terminals and the remaining 2 are mechanical ones. The First 3 electrical terminals receive the 3-phase currents generated by the inverter circuit and 4th terminal is of electrical reference. So, the 3 phase currents received by the phase terminals will energize the stator winding according to the commutation logic and the motor will rotate [7].

III. HARDWARE AND SETUP

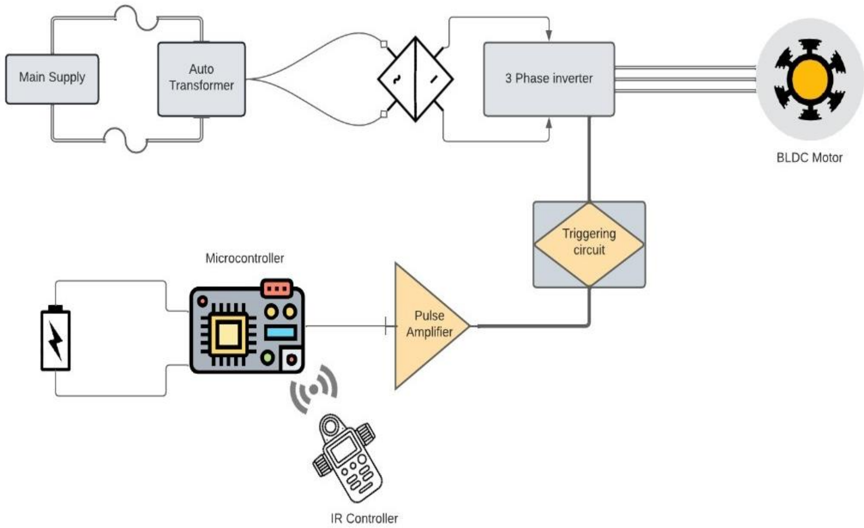

Fig. 4. Block diagram

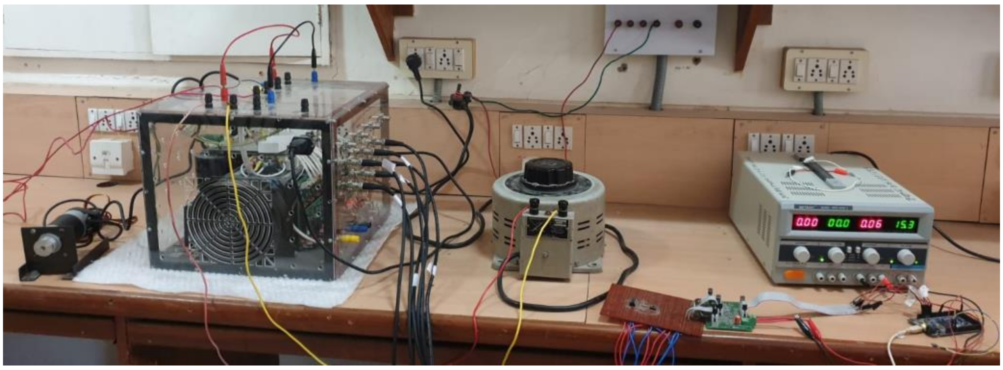

Fig. 5. Lab Setup

Autotransformer. An autotransformer is a single winding transformer that works on the principle of faraday's law of electromagnetic induction. Mostly used in low voltage range for industrial, commercial, and laboratory purposes. Here, the autotransformer will be fed via the main supply and it will be used to actuate the voltage as per the Brushless Direct Current's ratings.

Rectifier. The output of the autotransformer will be AC in nature so that the rectifier is used to convert the AC power to unidirectional or pulsating DC power. Because the major regulating component of the motor is a three-phase inverter, the DC power must be provided as the inverter circuit's input, which necessitates the need for a rectifier circuit.

Inverter. A three-phase inverter is used to convert the DC output of the rectifier to AC power. For this conversion of DC to AC, the inverter consists of six sets of MOSFET switches. These six switches are arranged such that the inverter circuit will have three legs, each made up of two switches in a series connection. These three legs behave as three phases and give three different signals which are out of phase with each other. Generally, the three legs of the inverter will be delayed with an angle of 120 degrees. These three-phase currents obtained as the output of the inverter will be fed to the stator winding of the Brushless Direct Current motor.

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Pulse Amplifier. As the microcontroller can only generate the signals at 5 volts, here the amplifier circuit is used to amplify the pulses to 15 volts by auxiliary supply.

Triggering circuit. This circuit will receive the amplified pulse signals and by feeding it to the IGBTs, we can trigger the IGBT switches.

Microcontroller. In this case, a microcontroller is utilized to create six separate PWM pulses to regulate the speed and direction of a Brushless Direct Current motor. The microcontroller will create the control signals that will be supplied to the three-phase inverter. Six separate PWM signals are responsible for the 360-degree rotation of the Brushless Direct Current motor, and users may actuate the speed of the motor by adjusting the frequency and duty cycle of the PWM signals. This entire task may well be completed with the assistance of a microcontroller.

IR Sensor. IR(Infrared) sensor is extensively used in wireless remote-control systems. Now, the end-user can give the commands to the microcontroller directly via IR remote to change the speed of Brushless Direct Current.

Brushless Direct Current Motor. By triggering the IGBTs of the inverter via amplified pulse signals, the inverter will transmit the power to the Brushless Direct Current motor and the motor will operate according to the applied switching strategy.

IV.CONTROL STRATEGY

Controlling the operation of the Brushless Direct Current motor is a significant task to understand while working with the Brushless Direct Current motor. There are mainly two methods used for controlling namely

1. Sensor control
2. Sensor less control.

In the sensor control method, hall sensors are used to detect the current rotor's position of the motor [5]. While, in sensor less technique output of hall sensors is not taken into consideration, instead which back emf is measured to obtain the information about it. The main goal of these methods is to sense the rotor's position because, to start the Brushless Direct Current motor, the basic requirement is to get an idea of the rotor's position. This fact concludes that one cannot operate the Brushless Direct Current by applying any of the above methods without knowing the position of the rotor. But, here, in our control technique there is no need for the rotor's position and thus can be widely used in the control operation of Brushless Direct Currents.

D. Figures and Tables

Consider the inverter's load, which is made up of inductors coupled in a star pattern as illustrated in the diagram. In the star connection, there are a total of six switches to commutate the inductors. Six-step commutation will be used to alter the polarity of the load windings due to the six switches included in the inverter. So, using the commutation logic, the user can able to get six possible combinations of switches. These combinations will produce various switching patterns, resulting in the energization of inductors in different combinations as shown in Fig. 6.

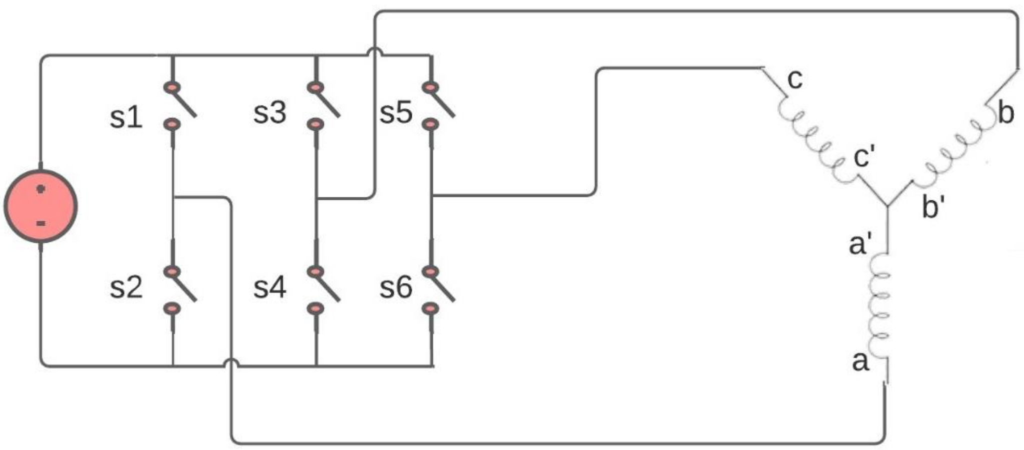

Fig. 6. 3-phase Inverter connected with star connected load

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Table I. Six steps commutation strategy to control Brushless Direct Current Motor

Steps of Commutation	Switching Combination
1	S1, S3, S6
2	S1, S4, S6
3	S1, S4, S5
4	S2, S4, S5
5	S2, S3, S5
6	S2, S3, S6

Table I shows the switching pattern in which of the six switches will remain ON in a particular segment of commutation. As shown in the circuit diagram S1, S2, S3, S4, S5, and S6 are the six switches provided. Let's Consider that the switches are in ON state as 1 and which are in OFF state as 0. By using such a binary fashion, a matrix can be formed, which represents the conduction state of all switches in all segments of 60 degrees.

$$\begin{matrix} A_h & A_l & B_h & B_l & C_h & C_l \end{matrix}$$
$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 \end{bmatrix} \begin{matrix} = 60^0 \\ = 120^0 \\ = 180^0 \\ = 240^0 \\ = 300^0 \\ = 360^0 \end{matrix}$$

For the first step of commutation, as shown in the matrix, switches S1 & S3 will conduct and energizes a-a' and b-b' phases by making them the North pole, and S6 will energize c-c' in the reverse direction and make it south pole electromagnetically. Because of such energization, the rotor will feel attraction and repulsion according to the poles adjacent to the active phases, and the rotor will rotate from 0 to 60 degrees, 60 to 120 degrees, and so on, as shown in the matrix.

E. Gate pulses and its waveform

The characteristics of the gate pulses which fed to six switches are the essence of this approach to controlling the Brushless Direct Current. The sequence in which, the switches will get the pulse signals is such a way that the Brushless Direct Current motor can be controlled even without knowing the position of the rotor.

Table. II. Properties of Gate signals

Gate Pulse	Time Period (sec)	Pulse Width	Delay
G_1	T	50%	(T/6)*0
G_2	T	50%	(T/6)*3
G_3	T	50%	(T/6)*4
G_4	T	50%	(T/6)*1
G_5	T	50%	(T/6)*2
G_6	T	50%	(T/6)*5

Table II reveals the characteristics of those six pulse signals, which will drive the commutation logic. The gate terminals of switches will get the signals, whose frequency will be f Hz with the pulse width of 50% giving the delay of d = 1/f s. For instance, if the frequency of the signal is 50 Hz, then the period will be 0.02s. This renders the repetition of the signal for each gate pulse after every 0.02s.

The sequence in which these gates will get the pulses can be defined by assigning different "delays". Because of the six-step commutation technique, the signal can be divided into six-segment and the according to which different time delays are applied as shown in the table. Using this, the six different gate pulses are simulated and shown in the Fig. 7.

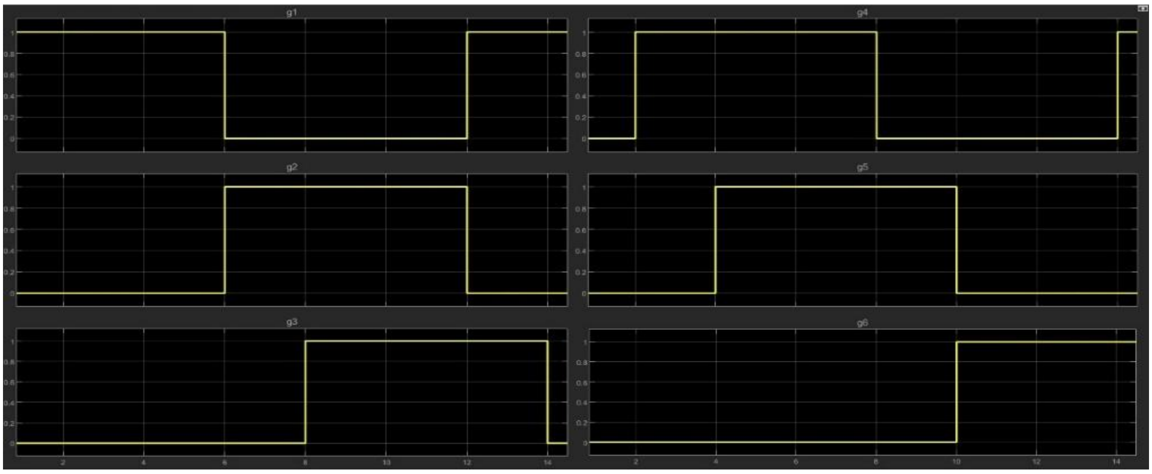

Fig. 7. Waveform of Six Gate Pulses

V. CONCLUSION

Our technique to control the Brushless Direct Current motor easily integrates to any Brushless Direct Current regardless of its internal construction. Moreover, it is an open-loop control system which makes it simpler and cost-efficient by using fewer electronic components. The necessity of tracking the location of the rotor is eliminated with this approach.

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