Development of BLDC Motor Controller using Sensor-based Method

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***Abstract*— In this paper, the development of Speed Controller of Brushless DC motor using Hall Effect position sensor has been illustrated. Implementation of a system that can control the motor's speed in four different modes: motoring, coasting, braking, and regenerative braking as well as the development of algorithms and control strategies that enable smooth transitions between the four modes of operation. The primary focus of using the Hall Effect position sensor is to determine the rotor position of the BLDC motor and generate Pulse width modulation (PWM) signal using the rotor position. The sensor-based control method results in improving performance and efficiency as it provides more precise control over the motor's speed, position, and torque and reduces motor noise and vibrations by providing smoother operation and reducing the likelihood of torque ripple.**

***Keywords*— BLDC, Hall effect sensor, PWM, Sensor-based control, Motor noise, Smooth Operation, Torque ripple.**

I. Introduction

A Brushless DC (BLDC) motor is an electric motor that operates using a direct current (DC) power supply and is characterized by the absence of brushes. It uses switch-commutation logic to trigger specific switches at a time. BLDC motors are remarkably efficient, reliable, and durable compared to other traditional brushed motors. The BLDC motor offers both substantial torque and is suitable for applications requiring adjustable speeds. These motors deliver precise speed control over a wide range of operating speeds. This is possible due to the electronic controller's ability to alter the frequency and amplitude of the current supplied to the motor windings, enabling precise manipulation of the motor's rotation speed. Due to the absence of brushes motor's temperature doesn't go high and there is no mechanical wear [1].

The aggregation of these advantages renders BLDC motors a more appropriate choice for industrial applications. BLDC motors needs to detect the rotor position data in order to ensure proper commutation. There are two different types of ways: Sensor-based and Sensor-less control methods. The sensor-based control approach for BLDC motors entails utilizing sensors like Hall Effect sensors or encoders to detect the rotor's position and manage the motor's commutation. On the other hand, sensor-less control is a method of governing BLDC motors that eliminates the need for traditional sensors such as encoders or Hall Effect sensors. This approach employs the measurement of the back EMF (Electromotive Force) produced by the motor to ascertain its position and velocity [2], [3].

In this paper, BLDC Motor of 330 W, 8-poles with Hall Effect sensors installed in the stators, 3-phase inverter and Arduino UNO as a microcontroller. Sensor-based control method approach has been considered as it is generally considered to be better than sensor-less control because it provides greater accuracy and stability in controlling the motor. The Hall Effect position sensor assists in precisely determining the location of the rotor, enabling the controller to effectively regulate the current passing through the motor windings. This results in smoother and more precise motor operation, particularly at low speeds and during transient conditions. The state in which the motor is not being actively powered, and is instead being allowed to rotate freely due to the momentum of its rotor is called *Coasting*, it is an important concept in electric vehicles that can help improve efficiency, extend range, and enhance safety. The paper includes speed, brake and regenerative brake control. A potentiometer is used as speed and brake regulator. Variation of potentiometer value will led to change in frequency of PWM signal, which will vary the speed of the motor, apply the brake, coast the motor or apply regenerative brake depending upon mapped range of potentiometer. By using regenerative braking and other strategies to optimize coasting, EV manufacturers and drivers can make the most of this important technique [4], [5]. This paper is structured as follows: Section II presents the Circuit Diagram, Section III discusses the Switching Sequence and Pulse Width Modulation, Section IV provides a representation of selectedexperimental results, and Section V concludes the paper.

II. Circuit Diagram

A 3-phase BLDC motor of wire $Phase_A$, $Phase_B$ and $Phase_C$ requires two phases ON operation to control the inverter, the 3 phases of inverter consist of three IRFP460N high side and three IRFP460N low side MOSFETs. Basic circuit is given in Figure 2. Total six gates of 3-phase inverter connected to digital pins (D8 to D13) of the Arduino UNO for Pulse Width Modulation.

The output of Hall Effect sensors is given to digital pins (D4 to D6) of the Arduino UNO, Pull-up of 10KΩ has been given to each Hall Effect Sensor, it ensures that the signal line remains at a high logic level when the sensor is not actively driving it. When the sensor is activated and drives the signal line low, the pull- up resistor provides a path for current to flow, allowing the microcontroller to detect the change in signal level.

A Potentiometer of 1 MΩ is connected to Analog pin (A0) of Arduino UNO microcontroller. The Arduino has 10 bit ADC, the actual numbers in range of 10 bit ADC are 0 to1023. Figure 1 shows the flowchart of conditions for the Potentiometer. The mapping of Potentiometer is as follow:-

- 0-450: Braking
- 451-513: Coasting
- 514-574: Regenerative Braking
- 575-1023: Motoring

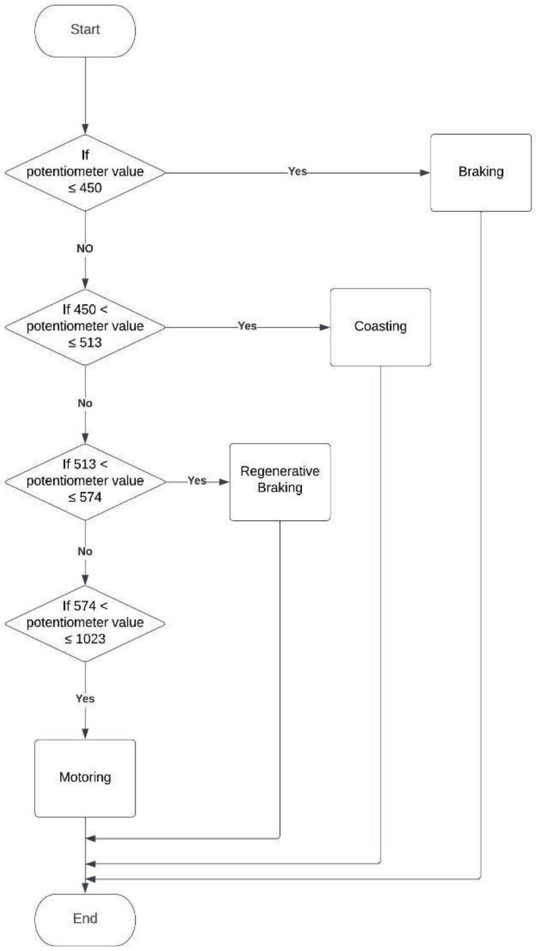

Figure 1. Flowchart of Potentiometer Conditions

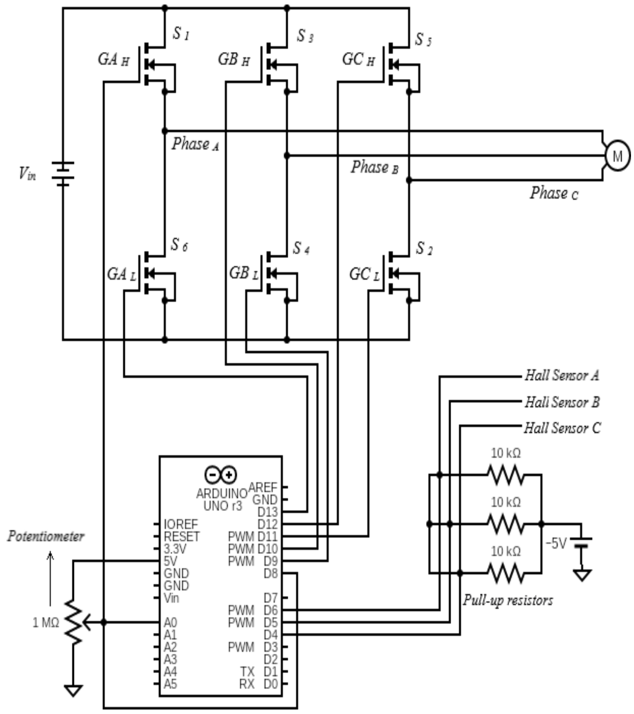

Figure 2. 3 Phase BLDC Motor Controller

III. Switches Sequence And Pulse Width Modulation

To start a BLDC motor, rotors position is required that will be gathered by Hall Effect Sensor. The PWM signal will be generated accordingly to run the motor. The frequency of the PWM signal is determined by the Potentiometer, where the analog value of mSpeed corresponding to the Potentiometer value adjusts the frequency. Increasing the frequency leads to higher motor speed.

Table I shows the switches sequence for motoring condition. It is important to regulate the order in which all the switches are activated to ensure that the electrical current flows accurately to the appropriate phase winding. Theprocess of controlling these switches in six distinct timing sequences is known as trapezoidal control or six-step control [6], [7]. By providing no PWM signal to the inverter that will directly cut-off the input power supply of the motor that will lead motor to run in coasting mode.

A. Switching Sequence and Pulse Width Modulation for Motoring Condition

For motoring one higher MOSFET and one lower MOSFET has to be at a logically high state. The switching sequence will vary depending upon Hall Sensors value. To make the rotor of a BLDC (brushless DC) motor spin, a specific sequence of energizing the three-phase windings is used to create a magnetic field that rotates and drives the rotor [8]. Current Ia, Ib and Ic will be flowing from Inverter to the Phases of the motor as shown in Figure 3. The phase difference between two phases is 120 degrees as shown in Figure 3.

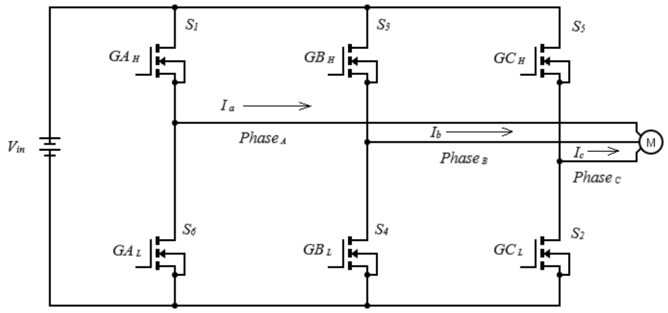

Figure 3. Flow of Current from Inverter to Motor

TABLE I. SWITCHING SEQUENCE FOR MOTORING CONDITIONS

Hall Input			**Phase$_A$**		**Phase$_B$**		**Phase$_C$**	
A	B	C	S_1	S_2	S_3	S_4	S_5	S_6
1	1	0	mSpeed	Low	Low	High	Low	Low
1	0	0	Low	High	mSpeed	Low	Low	Low
1	0	1	Low	Low	mSpeed	Low	Low	High
0	0	1	Low	Low	Low	Low	mSpeed	High
0	1	1	Low	Low	Low	High	mSpeed	Low
0	1	0	mSpeed	High	Low	Low	Low	Low

B. Switches Sequence and Pulse Width Modulation for braking Condition

One way to achieve braking of BLDC motor is by simultaneously activating all low-side MOSFETs, which creates a path for the current to flow through the MOSFETs. This results in the back EMF being effectively shorted, leading to a rapid reduction in motor speed and gradual dissipation of current.

The frequency of the PWM signal is determined by the Potentiometer, where the analog value of bSpeed corresponding to the Potentiometer value adjusts the frequency. Increasing the frequency results in a greater braking force for the motor, leading to a faster reduction in motor speed.

TABLE II. SWITCHING SEQUENCE FOR BRAKING CONDITIONS

Hall Input			**Phase$_A$**		**Phase$_B$**		**Phase$_C$**	
A	B	C	S_1	S_2	S_3	S_4	S_5	S_6
1	1	0	Low	Low	Low	High	Low	bSpeed
1	0	0	Low	High	Low	bSpeed	Low	Low
1	0	1	Low	Low	Low	bSpeed	Low	High
0	0	1	Low	bSpeed	Low	Low	Low	High
0	1	1	Low	bSpeed	Low	High	Low	Low
0	1	0	Low	High	Low	Low	Low	bSpeed

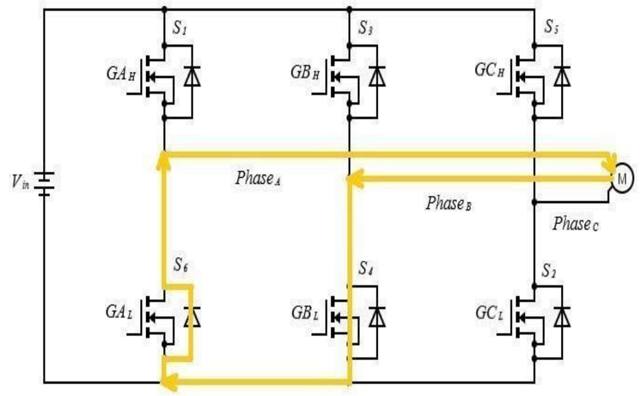

Figure 4. Flow of Current from Motor to Inverter

C. Switching Sequence for Regenerative Braking Condition

During the process of deceleration, regenerative braking occurs when the current in the motor-battery circuit is reversed, utilizing the motor's ability to function as a generator. This enables the redirection of the current flow back into the supplying BAT (Battery). One of the common effective methods for regenerative braking is *Independent Switching* [9]. During regenerative braking using *Independent Switching*, all electronic switching devices are deactivated. Specifically, the bottom switching devices are activated for a 120-degree portion of the cycle, which aligns with the flat top section of the phase electromotive force (EMF) [10], [11].

When engaged in regenerative braking, the flow of current in the winding is reversed, returning it back into the battery. In this operating mode, all switches are deactivated, allowing the current to pass through the freewheeling diodes and flow back to the battery.

The degree of braking is managed by adjusting the PWM duty cycle, which alternates the current flow between regeneration and coasting. The highest level of regeneration happens when all the low-side switches are deactivated. As a result, the duty cycle is modified from high to low. By disconnecting the inverter circuit from the control source that governs the switching sequence of the inverters, regenerative braking can be maximized [12].

Figure 5 illustrates the current flow whenthe winding pairs of phases A and B receive electrical energy. In this specific instance, the current pathway involves passing through the freewheeling diode of the high-side switch, S_1, continuing through the battery, and concluding by flowing through the low-side switch, S_4, associated with the low- phase.

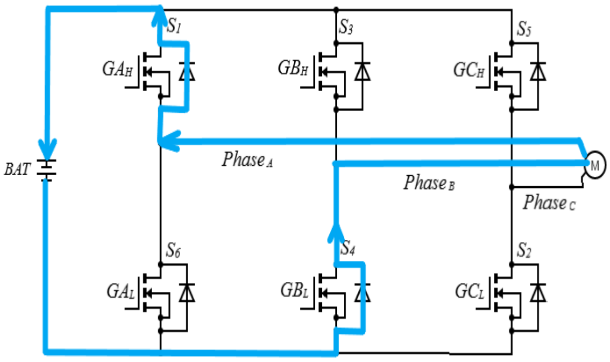

Figure 5. Flow of Current for Regenerative

IV. Experimental Results

Figure 6 displays the hardware utilized in all experiments, featuring a 3-phase, 330 W, 8-pole BLDC motor. Table III contains the important details of the motor's specifications and Table IV contains important details of IRFP460N MOSFET, which is used for designing 3-phase Inverter. A set of experiments for motoring and braking cases was conducted to confirm the efficiency of the Sensor-based control method.

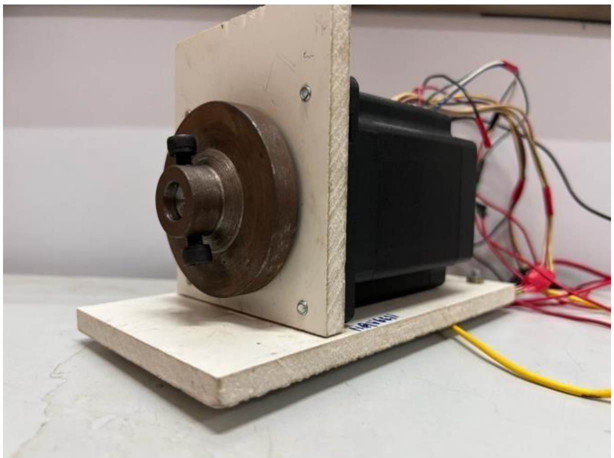

Figure 6. BLDC Motor

TABLE III. MOTOR SPECIFICATIONS

Motor Data	**Value**
Rated Voltage (VDC)	48
Rated Speed (rpm)	3000
Rated Torque (N.m)	1.4
Peak Current (A)	33
Peak Torque (N.m)	4.2
Back E.M.F (Vrms/KRPM)	9.4
Rotor Inertia (g.cm2)	1600

TABLE 1V. IRFP460N MOSFET SPECIFICATIONS

MOSFET Data	**Value**
Gate Threshold Voltage (V)	3 to 5
Rated Drain Source Voltage (V)	500
Rated Drain Current (A)	20
Power Dissipation (W)	280

The Arduino UNO microcontroller and laptop establish serial communication at a baud rate of 9600 bits per second to collect the reference commands and Hall Effect position sensor values. The Potentiometer Mapped value is varied manually to vary the speed of the BLDC motor. Speed of the motor is measured by using Hall sensor installed in stator and verified by Digital Tachometer. A load of 750 grams shows in Figure 7. It is connected to the shaft of the motor for providing inertia to the motor. The frequency of the PWM signal is measured using oscilloscope. The stopping time is calculated by microcontroller using Hall Effect position sensor. Figure 8 shows the hardware setup of the entire circuit.

Figure 7. Load

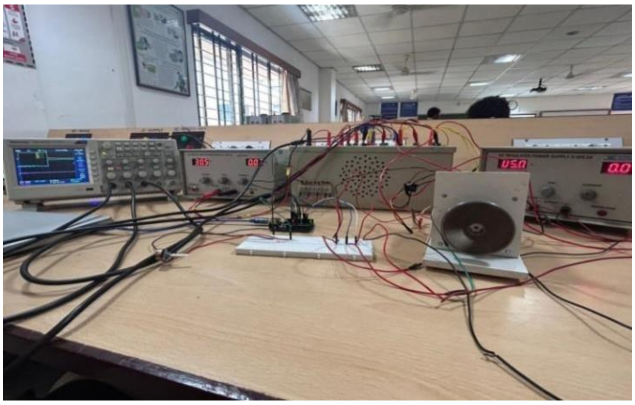

Figure 8. Hardware Setup

At first experiment, value of potentiometer is kept at 700 from mapped range such that it will work in motoring condition. The supply voltage to the inverter is 30 Volts. Keeping supply voltage constant Potentiometer value is increased so the frequency of the Pulse Width Modulation given to the gate also increases due to which the speed of the motor also increases as shown in the Table V. Figure 9 shows PWM signal of gates GA_H , GC_L, and GB_H.

A phase difference of 120 electrical degrees between each phase is shown in Figure 10. A directly proportional relation between speed of the motor and frequency of the PWM signal is shown in Figure 11.

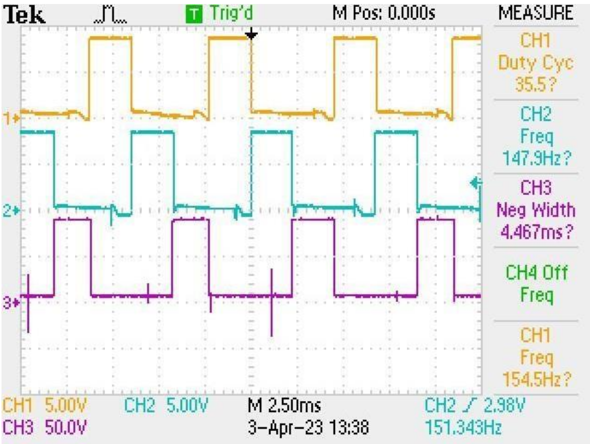

Figure 9. Variation in PWM Signals

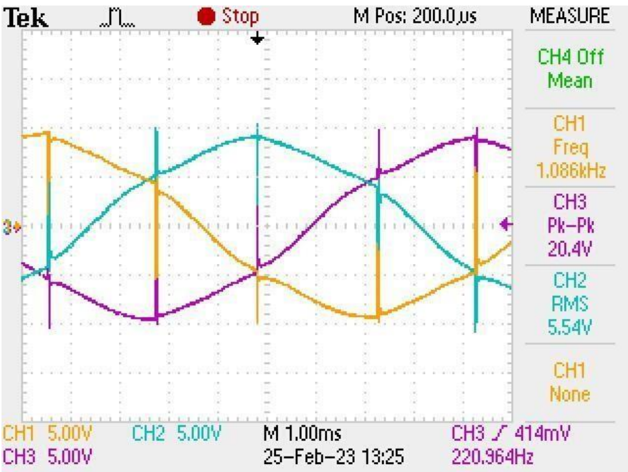

Figure 10. Phase difference in 3 Phases

TABLE V. SPEED CORRESPONDING TO POTENTIOMETER VALUES

S. No.	Potentiometer Mapped Values	Frequency (Hz)	Speed (rpm)
1	700	41	607
2	800	74	1105
3	900	108	1608
4	1000	147	2191
5	1023	149	2225

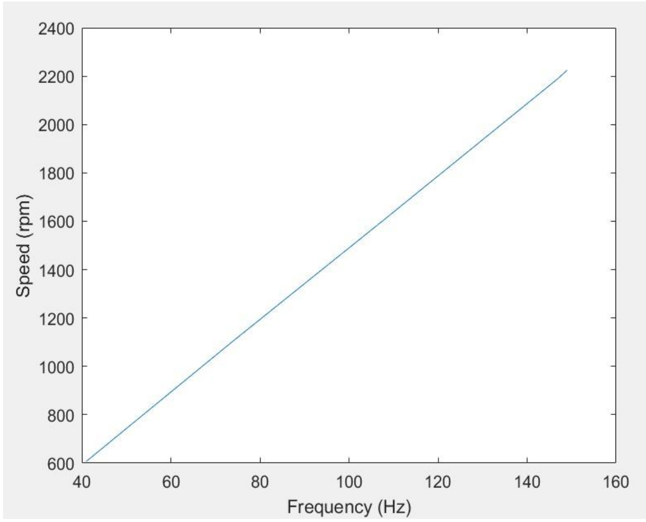

Figure 11. Speed corresponding to different values of Frequency.

At second experiment, the supply voltage to the inverter is 30 Volts. Keeping supply voltage constant and keeping the motor speed at 2225 rpm the experiment results has been taken. The Potentiometer value has been manually shifted from motoring condition to braking condition. For testing in each case of braking the motor speed is kept at 2225 rpmand supply voltage 30 Volts. As Potentiometer value is decreased the frequency also decreases and the stopping time of the motor increases. While braking all the back EMF produced by the motor will get dissipated at MOSFET side and the flow of current in braking mode will be opposite to the flow of current in motoring mode as shown in the Figure 4. A reciprocally related relation between stopping time of the motor and frequency of the PWM signal is shown in Figure 12.

TABLE VI. STOPPING TIME CORRESPONDING TO POTENTIOMETER VALUES

S.No	Potentiometer Mapped Value	Frequency (Hz)	Stopping Time (ms)
1	450	149	1289
2	400	132	1401
3	350	116	1635
4	300	98	1931
5	250	82	2313

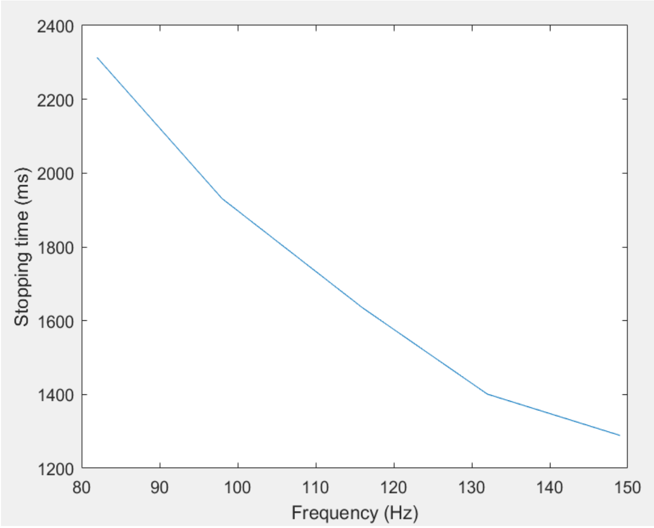

Figure 12. Stopping time for the motor at different frequency

V. Conclusion

This paper presents the motoring and the braking control of BLDC motor control method in four different control modes: motoring, coasting, braking and regenerative braking using Hall Effect Sensor for measuring rotor position to generate PWM signal for the three phase inverter. Using the potentiometer, the speed of the motor can be varied and the frequency of PWM for braking can be varied with result in a variation of stopping time. The results of the experiments have shown variation in speed at different values of the potentiometer, variation in stopping time at a constant speed with different values of the potentiometer.

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