Development of BLDC Motor Controller using Sensor-based Method

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***Abstract*— In this paper, the development of a Speed Controller of a Brushless DC motor using a 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

The absence of brushes distinguishes a brushless DC (BLDC) motor, which is an electric motor that runs on a direct current (DC) power source. 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 offer good speed control across a wide operating speed range. The electronic controller's capability to accurately regulate the motor's rotation speed through adjustments to the amplitude and frequency of the current delivered to the motor windings makes this possible. The absence of brushes prevents mechanical wear and a rise in the motor's temperature [1].

With all of these advantages, BLDC motors are a better choice for industrial applications. The rotor position data needs to be detected for BLDC motors to guarantee proper commutation. Approaches fall into two categories: sensor-based control methods and non-sensor-based methods. The sensor-based control method for BLDC motors senses the position of the rotor and regulates the motor's commutation by using sensors like encoders or Hall Effect sensors. Nevertheless, sensorless control avoids all the needs associated with traditional sensors, such as encoders controlling BLDC motors or Hall Effect sensors. This method measures the back EMF (Electromotive Force) that the motor produces in order to estimate the motor's position and velocity [2], [3]. This project makes use of an Arduino UNO microcontroller, a 3-phase inverter, an 8-pole BLDC motor with Hall Effect sensors installed in the stators, and other parts. The sensor-based control technique approach has been taken into consideration. It is generally considered to be more precise and stable in controlling the motor than sensor-less control. The Hall Effect position sensor assists the controller in accurately locating the rotor so that it can regulate the current passing through the motor windings.

As a result, motor action is smoother and more accurate, especially at low speeds and in abnormal situations. 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 a speed and brake regulator. Variation of potentiometer value will lead to a change in the frequency of the PWM signal, which will vary the speed of the motor, apply the brake, coast the motor ,or apply regenerative brake depending upon the 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 selected experimental 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

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High side and three IRFP460N Low side MOSFETs. The basic circuit is given in Fig. 2. Total of six gates of a 3-phase inverter are connected to digital pins (D8 to D13) of the Arduino UNO [13] forPulse Width Modulation.

The output of Hall Effect sensors is given to digital pins (D4 to D6) of the Arduino UNO, A Pull-up of 10KΩ has been given to each Hall Effect Sensor, and 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 the analog pin (A0) of theArduino UNO microcontroller. The Arduino has 10-bit ADC, the actual numbers in the range of 10 bit ADC are 0 to 1023. Fig. 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

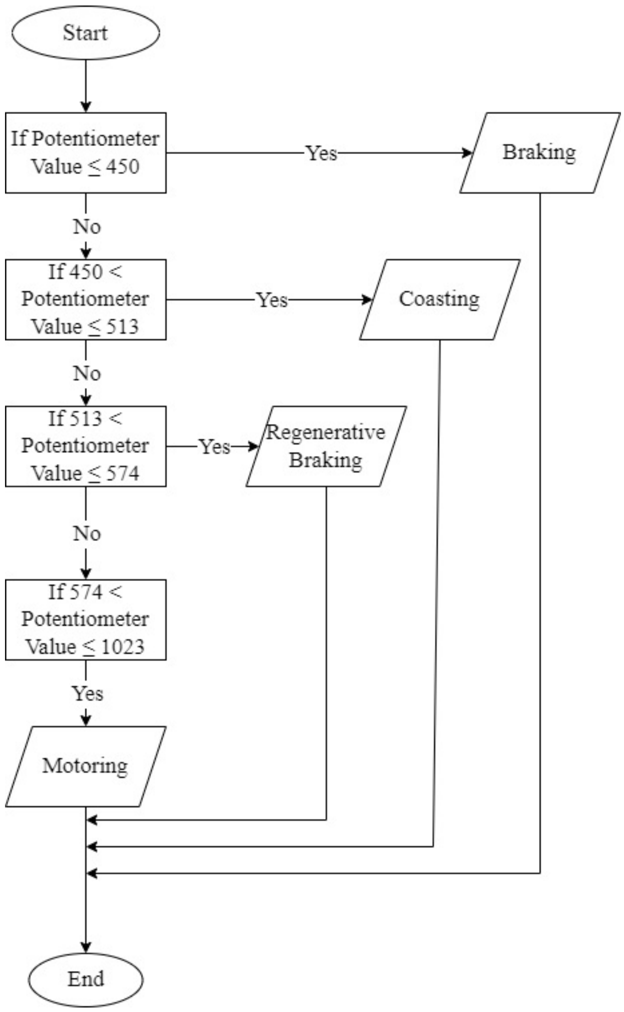

Fig. 1. Flowchart of Potentiometer Conditions

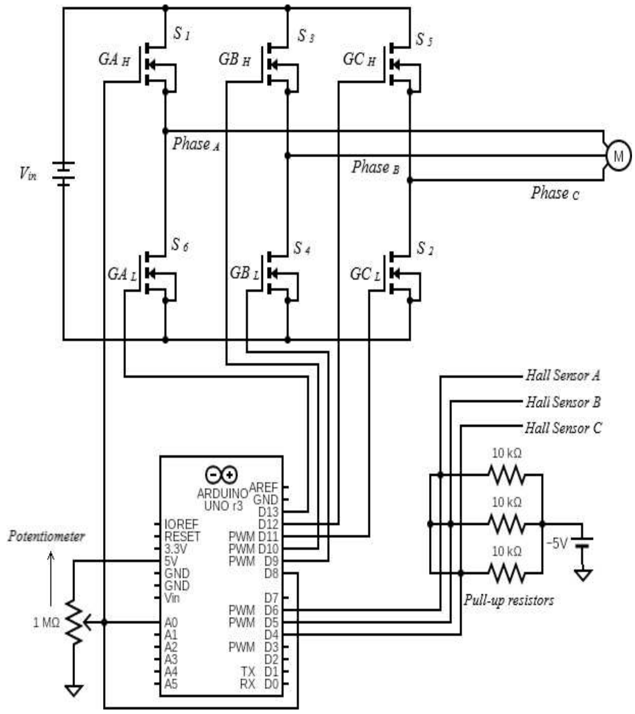

Fig. 2. Three Phase BLDC Motor Controller

III. Switches Sequence And Pulse Width Modulation

To start a BLDC motor, the rotor's position is required, and this information will be gathered by the 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 a higher motor speed.

Table I and Table II show the switch sequence for motoring and braking conditions. 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. The process of controlling these switches in six distinct timing sequences is known as trapezoidal control or six-step control [6], [7]. providing no PWM signal to the inverter will directly cut off the input power supply of the motor which 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 Fig. 3. The phase difference between the two phases is 120 degrees as shown in Fig. 3.

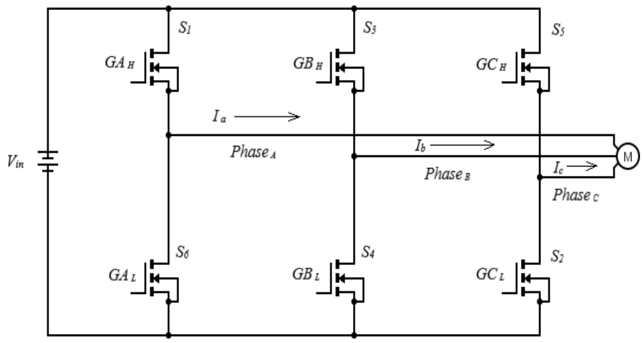

Fig. 3. Flow of Current from Inverter to Motor [9]

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	L	L	H	L	L
1	0	0	L	H	mSpeed	L	L	L
1	0	1	L	L	mSpeed	L	L	H
0	0	1	L	L	L	L	mSpeed	H
0	1	1	L	L	L	H	mSpeed	L
0	1	0	mSpeed	H	L	L	L	L

** L - low, H -high

A. Switches Sequence and Pulse Width Modulation for Braking Condition

One way to achieve braking of the BLDC motor is by simultaneously activating all low-side MOSFETs, which creates a path for the current to flow through the MOSFETs as shown in fig.4. 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	L	L	L	H	L	bSpeed
1	0	0	L	H	L	bSpeed	L	L
1	0	1	L	L	L	bSpeed	L	H
0	0	1	L	bSpeed	L	L	L	H
0	1	1	L	bSpeed	L	H	L	L
0	1	0	L	H	L	L	L	bSpeed

** L - low , H- high

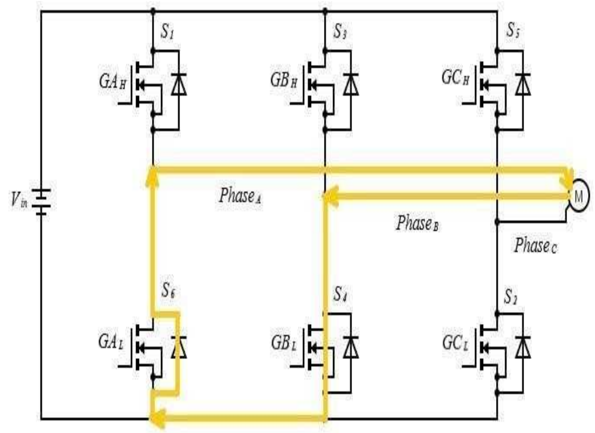

Fig. 4. Flow of Current from Motor to Inverter [9]

B. Switching Sequence for Regenerative Braking Condition

Regenerative braking is the technique of using the motor's generator function to reverse the current in the motor-battery circuit when the vehicle is decelerating. 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].

Regenerative braking causes the current in the winding to flow in the opposite direction, back into the battery. All switches are turned off during this operating mode, enabling current to return to the battery through the freewheeling diodes. By altering the PWM duty cycle, which switches the current flow between regeneration and coasting, the amount of braking may be controlled.

When every low-side switch is turned off, regeneration reaches its peak. The duty cycle is changed from high to low as a result. Regenerative braking can be maximized by unplugging the inverter circuit from the control source that manages the inverters' switching sequence [12].

Figure 5 depicts the current flow when phase A and B winding pairs receive electrical energy. In this case, the current path comprises passing via the high-side switch's freewheeling diode, S1, continuing through the battery, and finally flowing through the low-side switch, S4, connected with the low-phase.

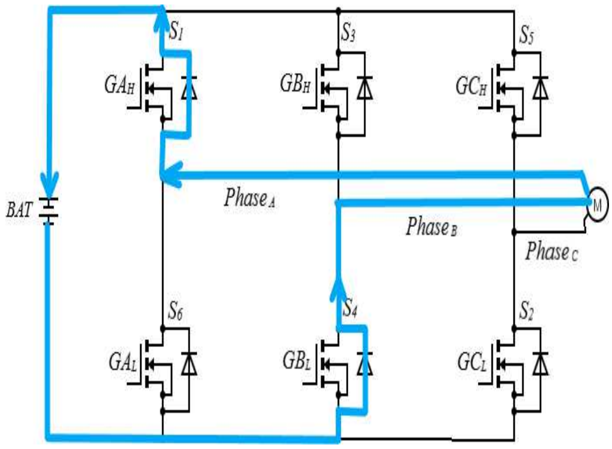

Fig. 5. Flow of Current for Regenerative [9]

IV. EXPERIMENTAL RESULTS

Fig. 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 a 3-phase Inverter. A set of experiments for motoring and braking cases was conducted to confirm the efficiency of the Sensor-based control method.

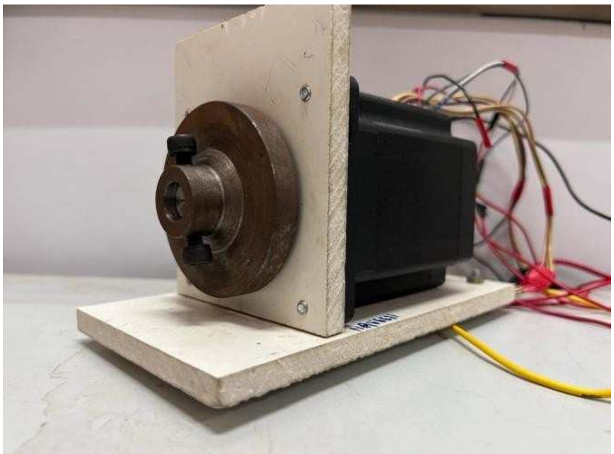

Fig. 6. BLDC Motor with designed load

TABLE III. MOTOR SPECIFICATIONS

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

TABLE IV. IRFP460N MOSFET SPECIFICATIONS

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

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. The speed of the motor is measured by using a Hall sensor installed in the stator and verified by Digital Tachometer. A load of 750 grams is shown in Fig. 7. It is connected to the shaft of the motor to provide inertia to the motor. The frequency of the PWM signal is measured using an oscilloscope. The stopping time is calculated by the microcontroller using a Hall Effect position sensor. Fig. 8 shows the hardware setup of the entire circuit.

Fig. 7. Load

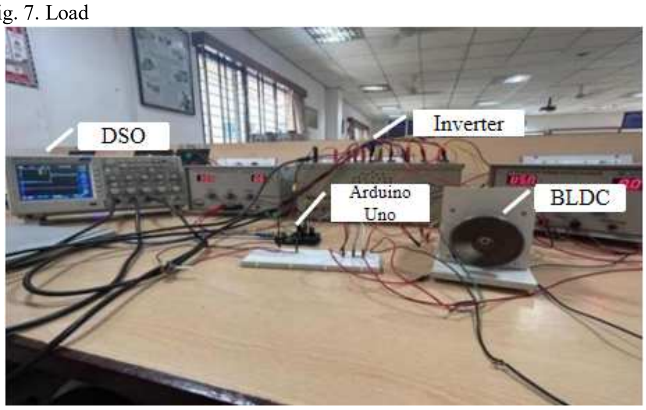

Fig. 8. Hardware Setup

In the first experiment, the value of the potentiometer is kept at 700 from the mapped range such that it will work in motoring conditions. The supply voltage to the inverter is 30 Volts. Keeping the 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 Table V. Fig. 9 shows the PWM signal of gates GA_H , GC_L, and GB_H.

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

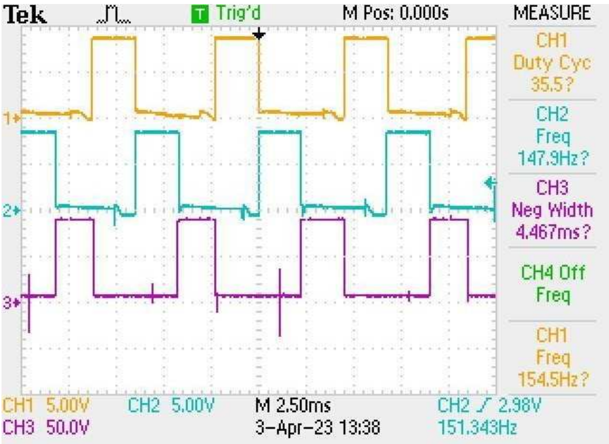

Fig. 9. Variation in PWM Signals

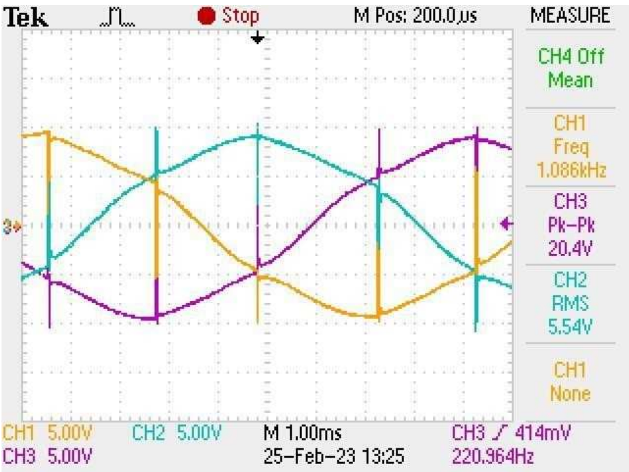

Fig. 10. Phase difference in 3 Phases

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

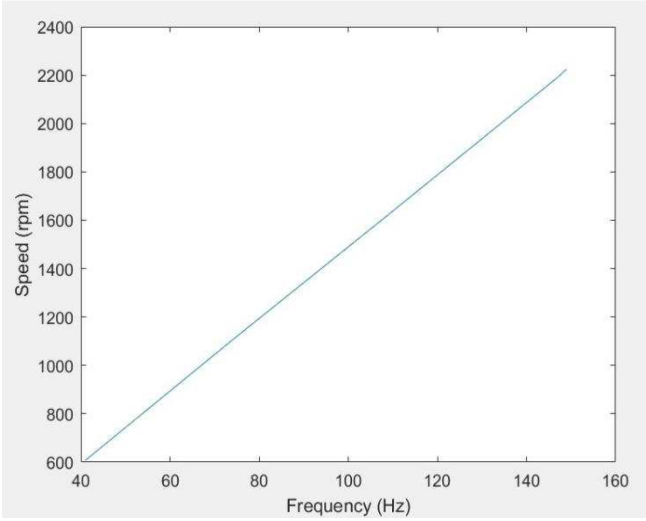

Fig. 11. Speed corresponding to different values of Frequency.

In the second experiment, the supply voltage to the inverter is 30 Volts. Keeping the supply voltage constant and keeping the motor speed at 2225 rpm the experiment results have been taken. The Potentiometer value has been manually shifted from the motoring condition to the braking condition. For testing in each case of braking the motor speed is kept at 2225 rpmand supply voltage 30 Volts.

As the potentiometer value is decreased the frequency also decreases and the stopping time of the motor increases as shown in Table VI. While braking all the back EMF produced by the motor will get dissipated at the MOSFET side and the flow of current in braking mode will be opposite to the flow of current in motoring mode as shown in Fig. 4. A reciprocally related relation between stopping time of the motor and frequency of the PWM signal is shown in Fig. 12.

TABLE VI. STOPPING TIME CORRESPONDING TO POTENTIOMETER VALUES

S.No	Potentiometer Mapped Values	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

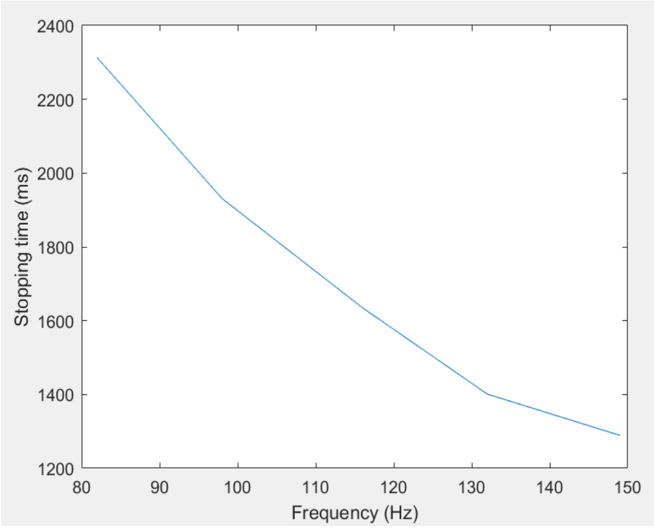

Fig. 12. Stopping time for the motor at different frequency

V. CONCLUSION

This paper presents a control method for BLDC motor operation and braking in four different modes: motoring, coasting, braking, and regenerative braking. It utilizes a Hall Effect Sensor to measure rotor position and generate PWM signals for a three-phase inverter. By adjusting a potentiometer, the motor speed can be varied, and the PWM frequency for braking can be adjusted, resulting in variations in stopping time. In comparison to the Sensorless model, the proposed system achieves the necessary reference speed much more quickly and smoothly while maintaining constant rotor torque. Additionally, regenerative braking is made possible by the flywheel's energy storage The future scope is to explore employing advanced control algorithms such as fuzzy logic, model predictive control(MPC), and neural networks to achieve faster response times, smoother speed control, and smaller torque control.

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