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Speed Control of BLDC Motor for Electric Vehicle

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Abstract -Nowadays, there are more and more variable speed drive systems in small-scale and large-scale applications such as the electric vehicle industry, household appliances, medical equipment and other industrial fields. led to the development of BLDC (Brushless DC) motors. BLDC drive has many advantages such as higher efficiency, better speed torque characteristics, high power density and low maintenance cost compared to other conventional motors. Most BLDC motors use a proportional integral (PI) controller and a pulse width modulation (PWM) scheme for speed control. This article describes the simulation model of BLDC motor drive control with the help of MATLAB - SIMULINK simulation software. The built simulation model includes BLDC motor dynamic block, Hall sensor signal generation block, inverter converter block and PI controller.

Keywords: Brushless DC motor (BLDCM), Electric Vehicles (EVs), Hall sensors, Microcontroller.

I .INTRODUCTION

Brushless DC Motors (BLDC) use permanent magnets and an electronic commutator, offering better efficiency, reliability, and durability compared to traditional DC motors. The use of electronic commutators eliminates the friction and wear associated with brushes, leading to higher efficiency, reliability, and durability. BLDC motors have higher power-to-weight ratios, which means they can produce more power per unit of weight compared to brush DC motors. This makes them ideal for applications where size and weight are critical factors. With fewer mechanical parts (no brushes to wear out), BLDC motors generally have a longer lifespan and require less maintenance. The elimination of brushes reduces the risk of sparking and electromagnetic interference, which is especially important in applications such as electric vehicles and sensitive electronic equipment. BLDC motors are widely used in electric vehicles and hybrid cars, where efficient and reliable motor control is essential for optimal performance. Microcontrollers improve control accuracy by providing precise timing and control over motor operations. They can optimize motor performance across different speed ranges, ensuring that the motor operates efficiently under various conditions. By minimizing power losses, microcontrollers help in reducing the overall system cost. Microcontroller-based systems improve control accuracy by providing precise timing and control over motor operations. They can optimize motor performance across different speed ranges, ensuring that the motor operates efficiently under various conditions. By minimizing power losses, microcontrollers help in reducing the overall system cost. Microcontrollers can execute complex algorithms that adjust the motor's operation in real time, providing smoother and more efficient performance. They enable features such as speed control, torque control, and fault detection, which are essential for reliable motor operation. In the context of electric vehicles, microcontroller-based systems play a crucial role in achieving precise speed control, enhancing the driving experience andoverall vehicle performance. Hall sensors provide rotor position feedback, which is essential for efficient commutation. By providing accurate information about the rotor's position, Hall sensors enable precise timing of the current switching in the motor windings. This ensures smooth and efficient motor operation, particularly at low speeds. The feedback from Hall sensors allows the motor controller to adjust the current flow and maintain optimal performance. Hall sensors are especially valuable for applications requiring precise motor control at low speeds. They ensure that the motor maintains its torque and efficiency even at slower rotational speeds, which is important in electric vehicles where smooth acceleration and

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deceleration are critical for driver comfort and safety.

BLDC motors, microcontroller-based systems, and Hall sensors collectively contribute to the

advancement of modern motor control technologies. The efficiency, reliability, and durability of BLDC motors make them suitable for electric vehicle applications. Microcontroller-based systems enhance control accuracy and optimize motor performance, while Hall sensors provide the necessary feedback for efficient motor operation. Incorporating these technologies into electric vehicles leads to improved performance, reduced maintenance costs, and greater overall efficiency. As technology continues to evolve,

we can expect further innovations in motor control systems, making them even more integral to the future of electric transportation. Brushless DC Motors (BLDC) utilize permanent magnets and electronic commutators, offering significant advantages such as enhanced efficiency, reliability, and durability over traditional DC motors. By eliminating brushes, BLDC motors reduce friction and wear, resulting in longer lifespans, higher power-to-weight and minimized maintenance.

These attributes make them ideal for applications requiring compact, lightweight, and high-performance solutions, such as electric vehicles and precision equipment. Microcontroller-based systems further elevate BLDC motor functionality by enabling advanced control features like speed optimization, torque regulation, and fault detection. These systems execute complex algorithms in real time, ensuring smooth, efficient performance across varying conditions while reducing power loss. Hall sensors complement this setup by providing precise rotor position feedback, essential for effective commutation and low-speed performance.

Together, BLDC motors, microcontrollers, and Hall sensors are revolutionizing motor control technologies, driving advancements in efficiency, reliability, and sustainability across industries.BLDC motors, microcontroller-based systems, and Hall sensors collectively contribute to the advancement of modern motor control technologies. The efficiency, reliability, and durability of BLDC motors make them suitable for electric vehicle applications. Microcontroller-based systems enhance control accuracy and optimize motor performance,

While Hall sensors provide the necessary feedback for efficient motor operation. Incorporating these technologies into electric vehicles leads to improved performance, reduced maintenance costs, and greater overall efficiency. As technology continues to evolve, we can expect further innovations in motor control systems, making them even more integral to the future of electric transportation.

II .PROBLEM FORMULATION

Efficient speed control of Brushless DC (BLDC) motors in Electric Vehicles (EVs) presents a critical challenge due to the need for balancing performance, energy efficiency, and system reliability. The dynamic load conditions, varying road profiles, and temperature variations significantly impact motor performance, necessitating robust control algorithms. Traditional methods relying on fixed gain controllers often struggle to adapt to such complexities, leading to suboptimal speed regulation and increased power losses. Moreover, precise rotor position feedback and effective PWM modulation are essential to achieve seamless operation across a wide speed range. This research aims to analyse these influencing factors and design an adaptive control strategy that ensures improved speed regulation, reduced energy consumption, and enhanced reliability for BLDC motors in EV applications.

III .SOLUTION TO THE PROBLEM

An adaptive Proportional-Integral (PI) controller integrated with a Pulse Width Modulation (PWM) scheme offers a robust solution for achieving precise speed control in Brushless Direct Current (BLDC) motors. The adaptive PI controller adjusts to dynamic changes in the motor's operating conditions, ensuring consistently optimal performance across varying load and environmental factors. Such adaptability is crucial for industrial and automotive applications, where precision and reliability are non-negotiable.

Rotor position feedback, typically obtained from Hall Effect sensors or advanced sensor less techniques, plays a pivotal role in enabling accurate processes this speed error and dynamically adjusts the proportional and integral gains to minimize the error effectively. This adaptive approach ensures enhanced stability and reduced response time under diverse operating conditions.

To implement the speed control mechanism, PWM signals are generated using sophisticated techniques such as Space Vector PWM (SVPWM).

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This method optimizes the motor's performance by reducing switching losses, enhancing torque efficiency, and minimizing oscillations. These PWM signals precisely control the voltage applied to the motor windings, thereby achieving the desired speed and torque characteristics.

The practical implementation of this solution can be accomplished using versatile hardware platforms like microcontrollers (e.g., ARM Cortex-based MCUs) or Field Programmable Gate Arrays (FPGAs). The development process is further streamlined by employing simulation and design tools such as MATLAB and Simulink. These tools enable the modelling, testing, and fine-tuning of the adaptive PI control system before deployment.

By employing an adaptive PI controller with PWM, this innovative approach achieves precise speed control, enhances energy efficiency, and minimizes system oscillations, making it an ideal solution for modern BLDC motor applications.

IV .EXPERIMENTAL SET UP & ITS RESULTS

Figure 1 shows a block diagram of a BLDC motor speed controller using two closed-loop systems. In this case, the inner loop is used to regulate and sense the electrode power and the outer loop is used to control the speed. The motor speed controller helps regulate the DC bus voltage. To control the system, a DC source is required and its value depends on the motor speed (rpm) and its power. This system also requires a controller, in which case a PID controller is used to ultimately control the output voltage of the inverter . A sensor is an integral part of a closed loop controller control the speed of the motor. Main function of the sensor is to convert the position and physical condition of the motor shaft into an equivalent electrical signal control circuit. Typically, BLDC motors require a controller just like AC. The voltage waveform for its operation should use an inverter circuit to convert the DC power voltage into an AC voltage equivalent to the mains voltage for normal operation. The BLDC motor specifications are as shown in Table 1.

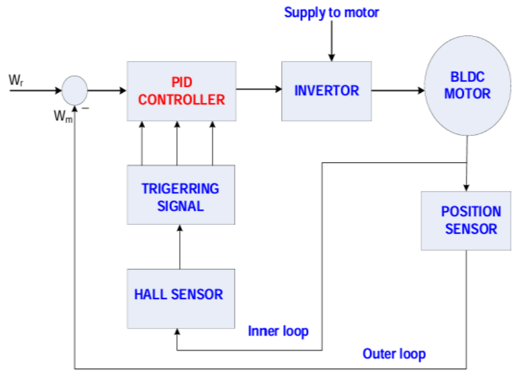

Fig.1.Block Diagram of BLDC Motor Speed Control.

The Back Electro Motive Force (BEMF) Typically, a 3-phase BLDC motor uses six electronic switches (power transistors) to produce 3-phase voltage simultaneously to a full-bridge configuration power converter. The transistors have a rotor position, which will be defined as the switching sequence. Most of the cases motor starter is monitoring by using three hall sensor devices. The hall sensors provide the information to the decoder block for producing the sign of reference current signal vector to the back electromotive force (BEMF). The MATLAB simulation block diagram for generating the back EMF of the decoder is shown in Fig. 2, and Table 1 shows the decoder sequences of the proposed 3-phase PID controller for the BLDC motor to rotate in the clockwise direction.

Table 1: Truth table for generation of EMF_A, EMF_B, EMF_C

Truth Table for generation of EMF_A,EMF_B,EMF_C

Ha	Hb	Hc	EMF_A	EMF_B	EMF_C
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	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

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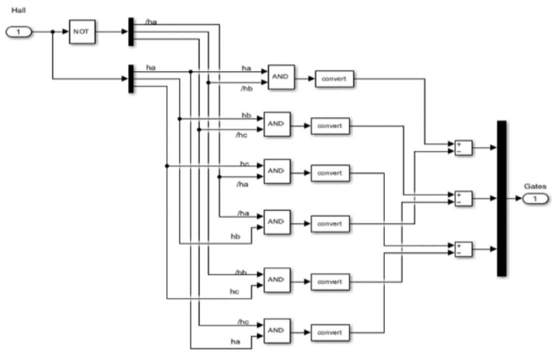

Fig. 2. Back EMF of Decoder for MATLA Drive.

Similar reasoning we have, Figure 3 shows the functional block diagram of switching of 3-phase inverter for MATLAB simulation and Table 2 shows the decoding sequence of the proposed 3-phase PI controller for a BLDC motor rotating in counter-clockwise direction of motion.

Table 2: Truth table for generation of Pulses for Inverter

EMF_A	EMF_B	EMF_C	Q1 =S1	Q2 =S4	Q3 =S3	Q4 =S6	Q5 =S5	Q6 =S6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

For proper operation of a BLDC motor, it is necessary to keep the angle between the stator and rotor flux close to 90 degrees. With six-step control, the motor has a total of six possible stator flux vectors. The stator flux vector must be changed at a certain rotor position. However, with a six-step control technique it is not possible to keep the angle between the rotor flux and the stator flux at 90 degrees. The real angle varies from 60 degrees to 120 degrees. These issues are shown in table 3, figure 4, and figure 5.

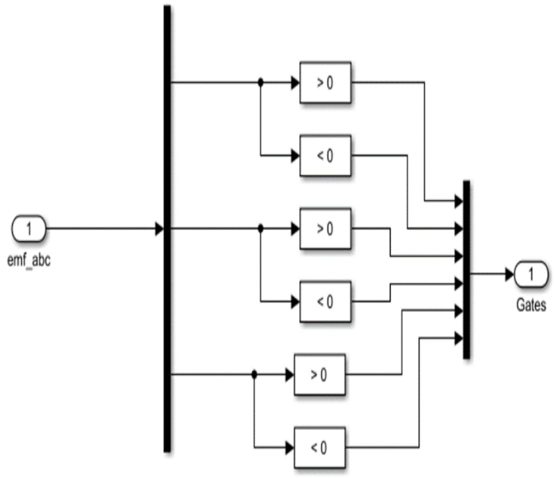

Fig. 3. Inverter Switching for MATLAB Drive

Table 3: Generation of Signal for Hall Effect Sensors

That_elec(θ_e)	Ha	Hb	Hc	State
0-60	1	0	0	4
60-120	1	1	0	6
120-180	0	1	0	2
180-240	0	1	1	3
240-300	0	0	1	1
300-360	1	0	1	5

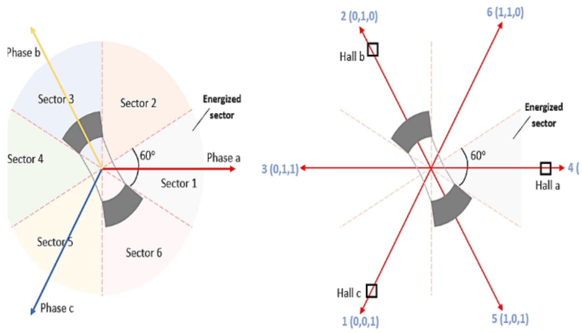

Fig.4.Six-step commutation process of BLDC moto

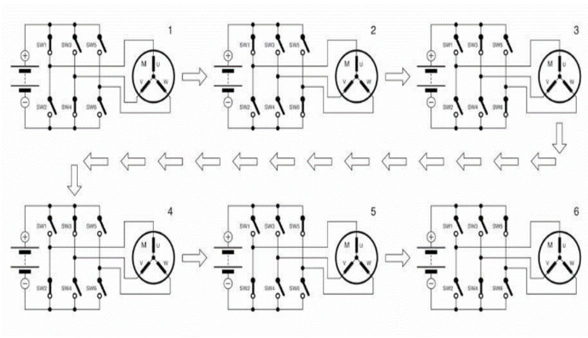

Fig.6.Simplified circuit diagram showing how the BLDC motor phases are controlled using a three-phase bridge. The switches are typically implemented using MOSFETs or IGBTs.

The six-step commutation process in a Brushless DC (BLDC) motor is a method used to control its operation by sequentially energizing specific pairs of motor windings. A BLDC motor typically has three windings, and at any given time during operation, two of these windings are powered while the third remains unpowered. This creates a magnetic field that interacts with the rotor's permanent magnets, producing torque and enabling rotation.

The process is called "six-step" because it involves six distinct steps in the energization sequence for one complete electrical cycle. Each step corresponds to a unique combination of energized windings (e.g., AB, AC, BC, BA, CA, CB). By switching between these six states in a controlled manner, the stator's magnetic field rotates, which causes the rotor to follow and spin continuously. This ensures that the motor operates smoothly and efficiently, maintaining a constant torque.

The timing of these commutation steps is critical and is determined by the rotor's position. To achieve this, rotor position sensors—such as Hall-effect sensors or encoders—are used. These sensors provide feedback to the motor controller about the rotor's location, enabling precise switching of the windings. In sensor less BLDC motors, the rotor position is estimated using back EMF (Electromotive Force) generated by the unpowered winding, which simplifies the motor design but requires sophisticated algorithms.

The above shows that the six-step commutation process ensures efficient energy conversion, minimal torque ripple, and smooth operation, making it widely used in various applications such as electric vehicles, drones, HVAC systems, and robotics. This method's ability to precisely control the motor's speed and position makes BLDC motors highly versatile and reliable.

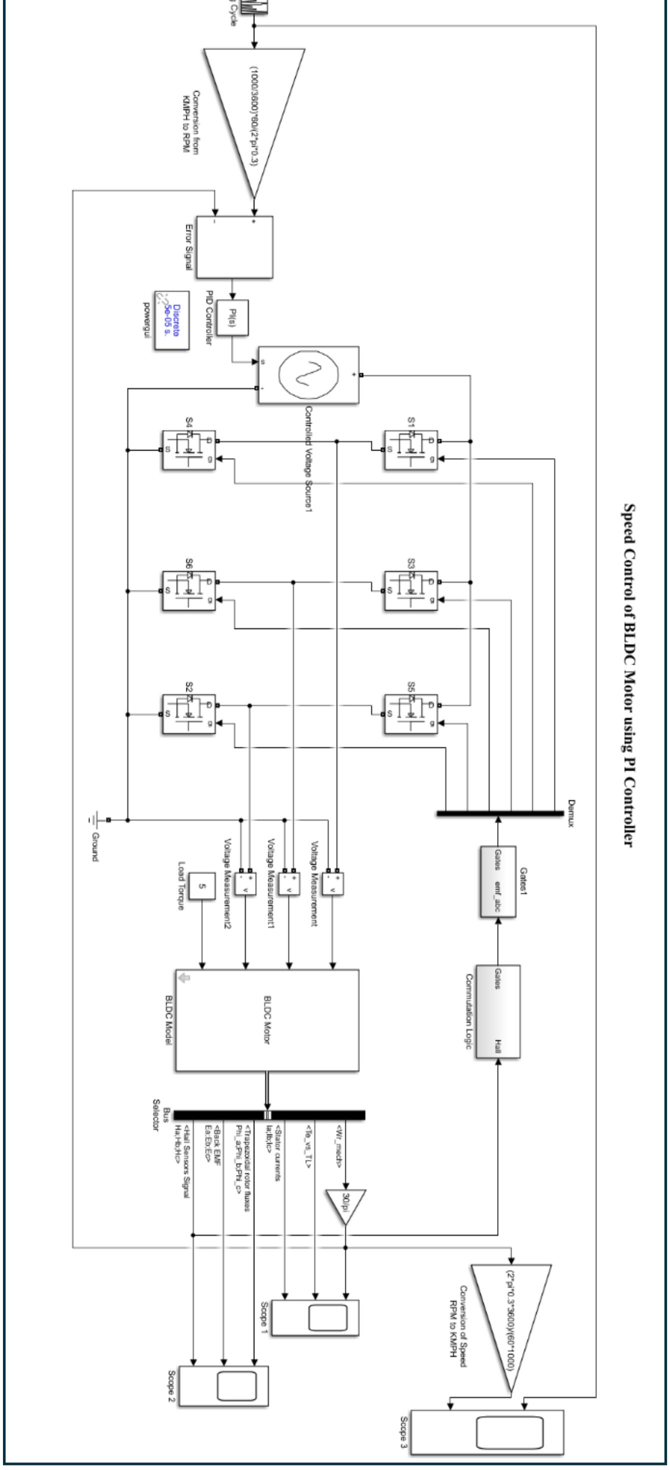

Fig.7.Schematic of PID controller

Table 4: Values of the PI controller parameters

Method	Values of the PI Controller Parameters	
	KP	KI
PI	0.75	50

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Fig.8. Mat lab Simulink model of Controller for BLDC motor

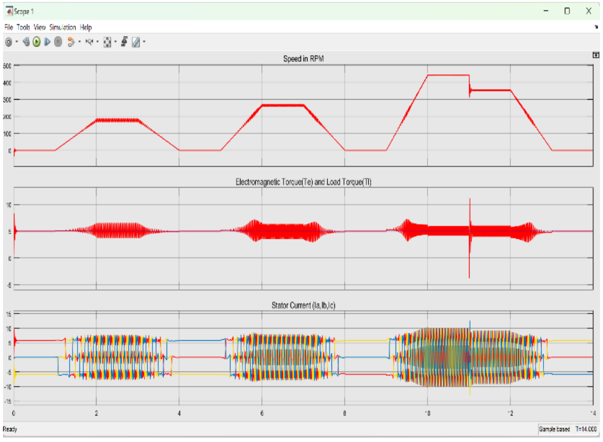

Fig.9. Simulation results: Speed in RPM, Electromagnetic Torque (Te) and Load Torque (Tl), Phase Stator Current of the BLDC Motor

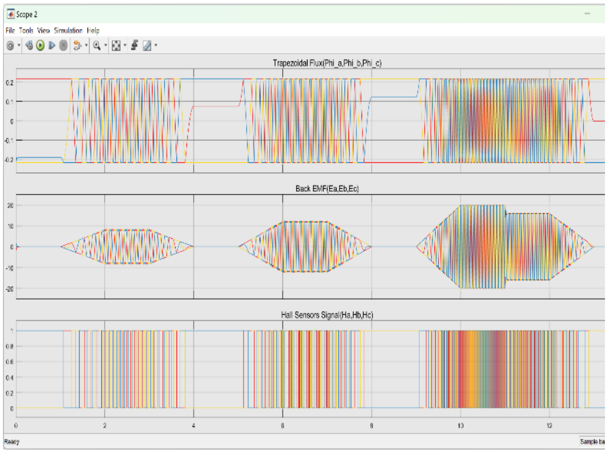

Fig.10.Simulation results: Trapezoidal Flux Phi_a, Phi_b, Phi_c, BLDC Motor 3-Phase Back Electromotive Force, BLDC Motor Hall Effect Signal

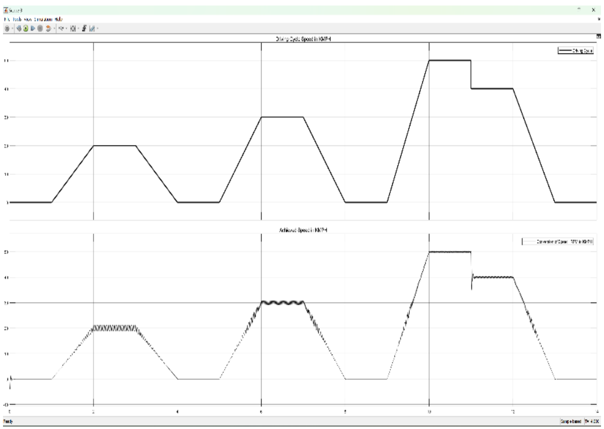

Fig.11.Achived speed and divining cycle

V. Conclusions

Simulation results in the this paper, a BLDC motor with three-phase inverter has been simulated in 120 degree conduction mode using a Hall sensor. The PI controller is designed and simulated for closed-loop operation of the BLDC motor. Simulation results show that the peak overshoot is reduced when using the PI controller, resulting in speed control achieving the desired results. The simulation of a brushless motor with a Mat lab tool -Simulink is done in detail and exactly as with the actual engine model. The results of the article are the basis for surveying and researching the design of the BLDC motor control system the result is the basis for helping to study more deeply about PID controller for BLDC engine.

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