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Performance Enhancement of BLDC Motors through Adaptive Speed Control

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Abstract

In the modern era, the growing demand for electricity calls for more efficient and reliable operation of electrical devices. This project presents the development of a novel Brushless DC (BLDC) motor system, offering enhanced performance compared to traditional motors. BLDC motors function by electronically inverting the stator and rotor configuration found in permanent magnet DC motors, operating with a rectangular waveform supply. A key benefit of the BLDC motor is the elimination of brushes, which significantly reduces maintenance and enhances durability. Furthermore, the rectangular interaction between current and magnetic flux enables the generation of higher torque. The hardware implementation of this motor system demonstrates its effectiveness, with speed control managed by a Proportional-Integral (PI) controller. This control strategy helps suppress torque and speed oscillations, ensuring precise and stable operation from low to high speeds. BLDC motors play a vital role in today's industrial applications due to their high efficiency, reliability, and cost-effectiveness. Their evolution reflects major advancements in motor technology, offering practical solutions for modern engineering challenges.

Keywords: *BLDC Motor, Microcontroller, Hall Effect Sensor, PWM Technique, MOSFET*

I. INTRODUCTION

- *History and Advantages of BLDC Motors*

The evolution of Brushless DC (BLDC) motors can be traced back to the early 1960s when researchers began exploring alternatives to brushed DC motors for improved efficiency and performance. The initial breakthrough occurred in 1962, credited to T.G. Wilson and P.H. Trickey, who introduced the concept of electronically commutated motors. However, the widespread adoption of BLDC motors was delayed due to limitations in magnet and transistor technology. It was not until the 1980s that significant progress was made.

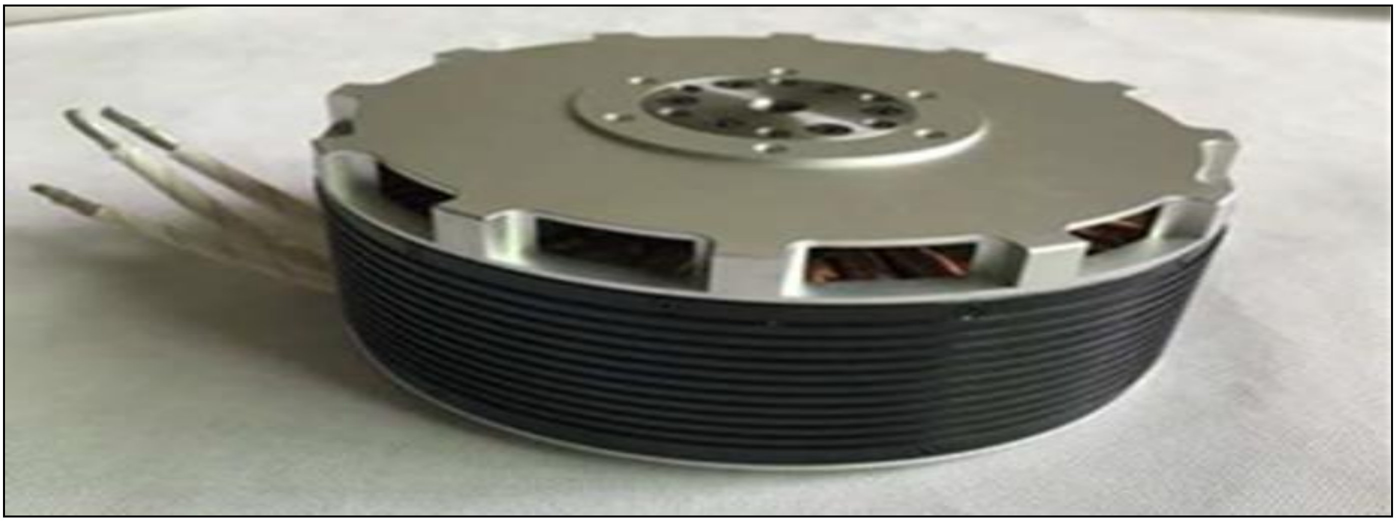

Fig 1 Brushless DC Motor

The advent of high-performance permanent magnet materials, coupled with the development of advanced power transistors, enabled BLDC motors to match—and in many cases surpass—the power output of traditional brushed motors. By the late 1980s, Robert E. Lordo of POWERTEC Industrial Corporation introduced high-power BLDC motors that were capable of delivering ten times the output of their earlier counterparts. Since then, the technology has matured significantly, and today, nearly all major motor manufacturers offer a diverse range of BLDC motors suited for both low-power and high-power applications across various industries. BLDC motors offer numerous advantages over conventional brushed motors. Their design eliminates brushes and the mechanical commutator, which leads to higher efficiency, longer operational life, and reduced maintenance requirements. The absence of brushes also minimizes friction, reduces electrical noise, and eliminates sparking, making BLDC motors ideal for sensitive or hazardous environments such as medical devices, aerospace systems, and explosive atmospheres. One of the key performance benefits is the higher torque-to-weight ratio and better efficiency in converting electrical energy to mechanical power. This is largely due to precise electronic commutation controlled by microcontrollers, digital signal processors (DSPs), or Field Programmable Gate Arrays (FPGAs). These controllers enable features such as speed regulation, micro-stepped motion control, and holding torque at zero speed—functionalities not typically available in brushed motors. Furthermore, because the rotor lacks windings, it is not affected by centrifugal forces, and the stationary windings can be cooled more efficiently through conduction. This allows the motor to be completely enclosed, offering protection from contaminants such as dust and moisture. However, thermal management remains critical, as excessive heat can degrade the magnets and insulation, thereby limiting the motor's power-handling capabilities. Due to their robust construction and advanced control capabilities, BLDC motors are widely used in applications that demand high-speed performance, low noise, maintenance-free operation, and enhanced reliability. These characteristics have solidified their position as a cornerstone in modern motor technology.

- *Advantages and Technical Insights of BLDC Motors*

Brushless DC (BLDC) motors present several distinct advantages over traditional brushed DC motors, making them a preferred choice in modern applications. One of the most significant benefits is their high torque-to-weight ratio, which allows for more torque per watt of electrical input—resulting in improved energy efficiency. Additionally, BLDC motors offer greater reliability due to the absence of brushes, which eliminates mechanical wear from brush-commutator interactions and extends the motor's operational lifespan. The lack of brushes also eliminates the generation of ionizing sparks and significantly reduces electromagnetic interference (EMI), making BLDC motors suitable for environments sensitive to electrical noise or where sparking poses a safety hazard, such as explosive or flammable settings. Furthermore, BLDC motors operate with reduced acoustic noise, making them ideal for applications requiring silent operation, such as in medical devices or consumer electronics. Structurally, BLDC motors are designed with the windings placed on the stator, which allows for direct conduction-based cooling via the housing. Unlike motors with rotor windings, BLDC motors are not subject to centrifugal forces acting on internal windings, thus enabling more compact and enclosed designs. This configuration not only enhances thermal performance but also protects the internal components from dust, moisture, and other contaminants, reducing the need for regular maintenance. Commutation in BLDC motors is achieved electronically, using control systems based on microcontrollers, digital signal processors (DSPs), or Field Programmable Gate Arrays (FPGAs). Unlike brushed motors, where mechanical brushes handle commutation, electronic commutation enables features such as speed regulation, torque control, micro-stepped movement for fine positional accuracy, and the ability to hold torque at zero speed. These control strategies can be tailored to specific applications, improving system responsiveness and efficiency. Despite their advantages, the thermal limitations of BLDC motors must be carefully managed. Excessive heat can degrade permanent magnets and damage insulation on the stator windings, thereby limiting the maximum power the motor can safely handle. Proper heat dissipation strategies, such as heat sinks or active cooling systems, are crucial in high-performance applications. From an efficiency standpoint, BLDC motors outperform brushed motors, particularly under light-load and no-load conditions, due to minimized mechanical losses and optimal switching frequencies determined by position sensor feedback. However, under heavy load conditions, their efficiency is comparable to that of well-engineered brushed motors. BLDC motors are widely adopted in applications requiring high-speed performance, precise control, and maintenance-free operation. These include electric vehicles, aerospace systems, robotics, HVAC systems, and industrial automation. They are also suitable for hazardous environments, where sparking must be avoided, or in areas where electromagnetic compatibility is critical. Although BLDC motors and stepper motors may share structural similarities, their operational principles differ significantly. Stepper motors are primarily used for discrete angular positioning and typically lack internal rotor position sensors. In contrast, BLDC motors are optimized for continuous rotation and often integrate Hall effect sensors or encoders for real-time rotor position feedback. Well-designed BLDC motor systems can maintain zero-speed holding torque, similar to stepper motors, while also offering the benefits of smooth, high-speed rotation and dynamic control.

- *Principle of Operation*

A Brushless DC (BLDC) motor is a type of permanent magnet synchronous machine that operates using rotor position feedback and an inverter-based electronic control system to manage the armature currents. Unlike conventional brushed DC motors where the commutation is mechanical, the BLDC motor utilizes electronic commutation, eliminating the need for brushes and the associated maintenance—resulting in a more durable and efficient motor solution. Often described as an "inside-out" DC motor, the BLDC configuration places the permanent magnets on the rotor and the windings on the stator. This arrangement leads to improved thermal performance, as the heat generated in the windings can be directly dissipated through the motor housing. BLDC motors are broadly categorized into two main types based on the shape of their back Electromotive Force (EMF):

- *Trapezoidal BLDC Motors*
- *Sinusoidal BLDC Motors*

In trapezoidal BLDC motors, the back-EMF waveform has a trapezoidal shape. To ensure smooth and ripple-free torque output, these motors require quasi-square wave current excitation. Due to their relatively simpler construction, control strategy, and lower cost, trapezoidal BLDC motors are widely adopted in various industrial and commercial applications. In contrast, sinusoidal BLDC motors generate a sinusoidal back-EMF and require sinusoidal phase currents for optimal torque production. These motors provide smoother rotation and lower torque ripple but demand more sophisticated control algorithms and higher-resolution position feedback systems. Their operation relies heavily on accurate rotor position tracking at every instant, necessitating the use of advanced encoders or high-resolution sensors. The waveform of the back-EMF in both types of BLDC motors is determined by the rotor magnet geometry and the spatial distribution of the stator windings. While sinusoidal motors are generally preferred in high-performance and precision-driven applications such as robotics and aerospace, trapezoidal motors are favored in cost-sensitive and general-purpose uses due to their simplicity and efficiency. BLDC motors are available in various configurations (single-phase, three-phase, and multi-phase), but the three-phase BLDC motor is the most prevalent due to its balance between performance, efficiency, and control complexity. This configuration ensures minimal torque ripple and high reliability.

Figure 2 illustrates the cross-sectional view of a typical three-phase BLDC motor and the phase energizing sequence used to generate torque through electronic commutation.

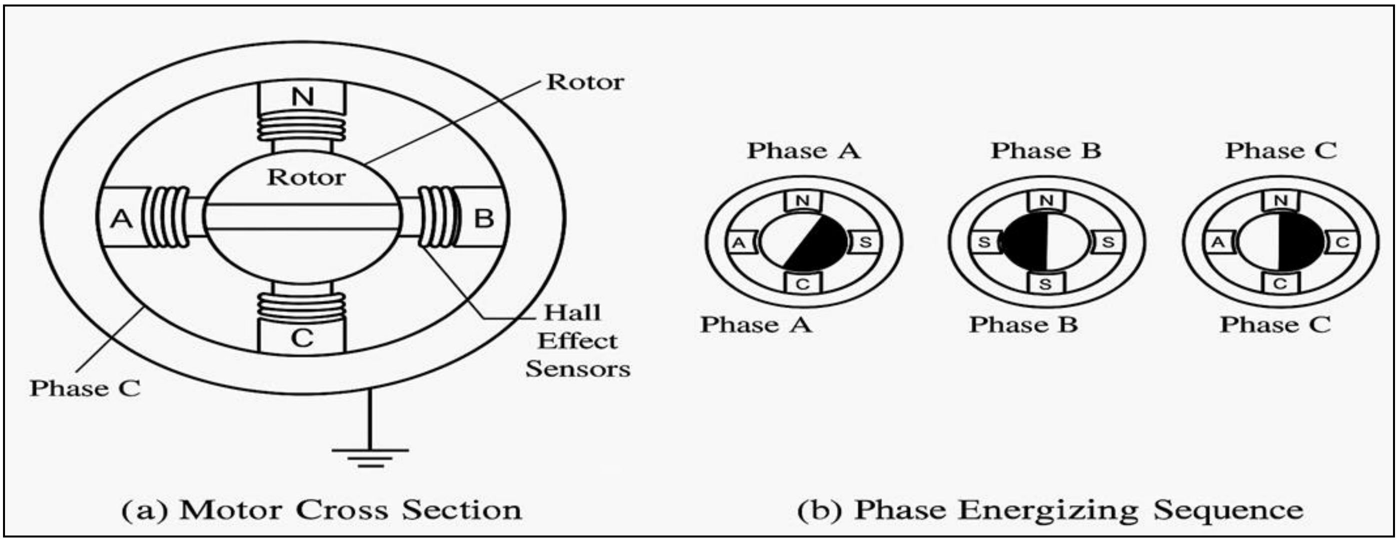

Fig 2 BLDC (a) Motor Cross Section (b) Phase Energizing Sequence

Typically, a Brushless dc motor is driven by a three-phase inverter with, what is called, six-step commutation. The conducting interval for each phase is 120° by electrical angle. Six-step commutation. The conducting interval for each phase is 120° by electrical angle. Fig.1 shows a cross section of a three-phase star connected motor along with its phase energizing sequence. Each interval starts with the rotor and stator field lines 120° apart and ends when they are 60° apart. Maximum torque is reached when the field lines are perpendicular. The commutation phase sequence is like AB-AC-BCBA-CA-CB. Each conducting stage is called one step. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60° so that current is in phase with the back EMF. The commutation timing is determined by the rotor position, which can be detected by Hall sensors as shown in the Fig.3 (H1, H2, and H3). Current commutation is done by inverter as shown in a simplified from in Figure 4. The switches are shown as bipolar junction transistors but IGBT switches are more common. Table I shows the switching sequence, the current direction and the position sensor signals.

II. SYSTEM DESCRIPTION AND METHODOLOGY

This chapter elaborates on the structural, operational, and control-oriented aspects of the proposed BLDC motor system. The configuration of the motor, the function of rotor position sensors, inverter switching mechanisms, the adaptive control approach, and the simulation environment form the core of the implementation. The performance of the system is evaluated under different operating scenarios to validate the control strategy.

➢ *BLDC Motor Configuration*

A Brushless DC (BLDC) motor is an electronically commutated synchronous machine powered by a DC supply through an inverter. Unlike brushed motors, BLDC motors lack mechanical commutators and brushes, thereby significantly reducing maintenance and enhancing reliability. The rotor is typically a permanent magnet while the stator is made up of multiple windings, usually arranged in a three-phase configuration.

In this research, a three-phase, Y-connected BLDC motor is utilized, characterized by a trapezoidal back electromotive force (EMF). The commutation process is governed electronically using rotor position feedback. For effective torque production and low torque ripple, the stator current waveform must align with the back-EMF, both in magnitude and phase.

The electromagnetic torque (Te) generated is expressed as:

$$T_e = \frac{1}{\omega_e} \sum_{i=a}^{c} e_i(t) \cdot i_i(t)$$

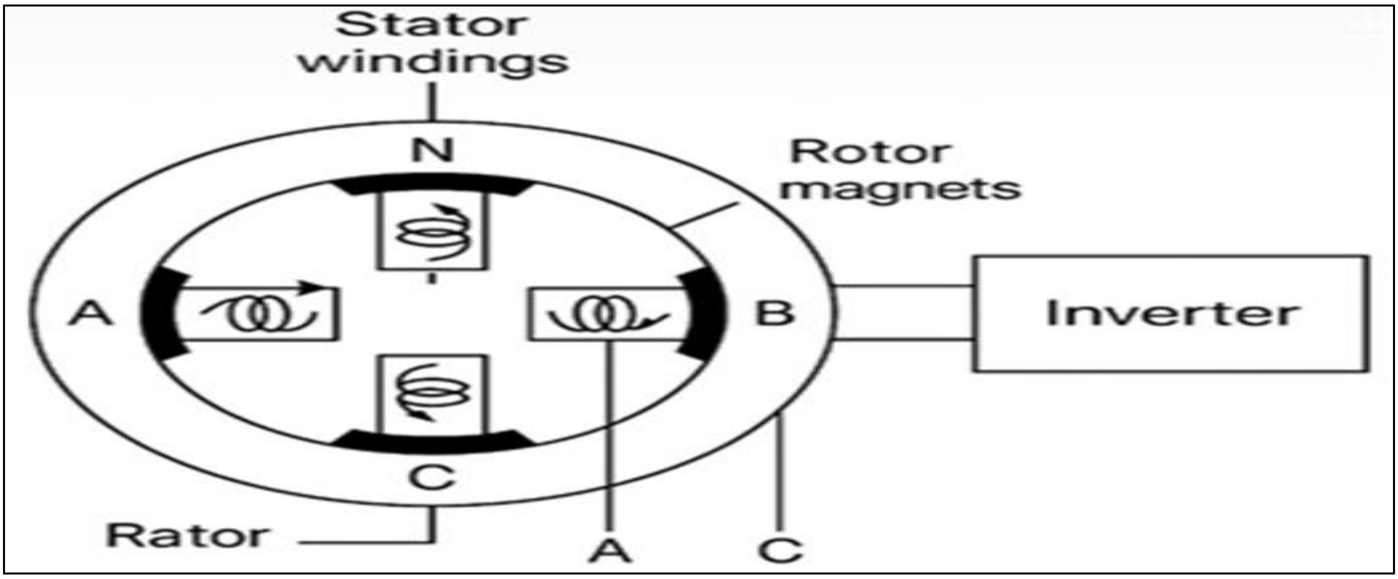

Fig 3 Three-Phase BLDC Motor Configuration
(Insert a labeled schematic diagram showing the stator winding layout, rotor magnets, and connection to inverter)

➢ *Role of Hall Sensors and Inverter Switching Logic*

Precise commutation in BLDC motors is achieved through position detection of the rotor. Hall-effect sensors mounted within the motor provide digital outputs representing the rotor position every 60° electrical. These signals form a three-bit binary code which corresponds to six unique states in one electrical cycle.

The Hall signals directly influence the logic used for inverter commutation. A six-step inverter consisting of six IGBT switches is used to drive the motor. In each step, two phases are energized while one remains floating. The switching sequence is carefully controlled to ensure that the direction and magnitude of the stator current always remain in phase with the back-EMF, thereby maximizing torque production.

The switching logic table is summarized below:

Table 1 Hall Signal Interpretation and Inverter Commutation Logic
(Insert a timing diagram of Hall sensor outputs and corresponding switching pattern of VSI switches)

Hall A	Hall B	Hall C	Upper Switch ON	Lower Switch ON
1	0	1	S1, S4	Others OFF
1	0	0	S1, S6	Others OFF
1	1	0	S3, S6	Others OFF
0	1	0	S3, S2	Others OFF
0	1	1	S5, S2	Others OFF
0	0	1	S5, S4	Others OFF

➢ *Overview of Control Architecture*

The control system follows a closed-loop feedback architecture comprising both speed and current control loops. The goal is to maintain the motor speed at a desired reference value despite load disturbances or changes in operating conditions.

- Major Components:

✓ Speed Reference Input: Defines the target motor speed.
✓ Speed Controller (PID/Adaptive): Processes the speed error and generates control signals.
✓ Torque Reference Generator: Converts speed control signal into torque demand.

- ✓ Reference Current Generator: Produces phase current references aligned with back-EMF.
- ✓ Hysteresis Current Controller: Maintains actual current within a defined band around the reference.
- ✓ PWM Generator: Produces gating pulses based on current and voltage control inputs.
- ✓ Voltage Source Inverter (VSI): Modulates DC voltage to three-phase AC output.
- ✓ Position Feedback (Hall Sensors): Provides real-time rotor position information.

The system continuously adjusts the motor's input voltage based on speed error to maintain the desired performance level.

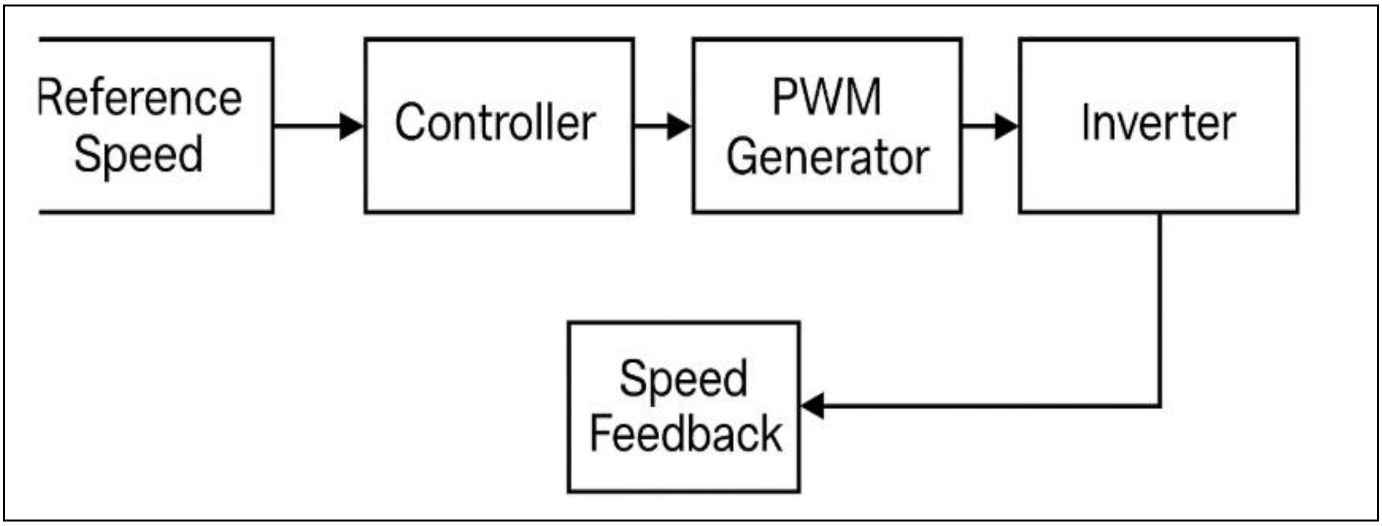

Fig 4 Block Diagram of BLDC Motor Control Architecture
(Insert a block diagram showing reference speed input → controller → PWM generator → inverter → motor → speed feedback loop)

- *Adaptive Speed Control Strategy*

Conventional PI or PID controllers with fixed gains may not offer sufficient robustness when system parameters or external conditions vary. Therefore, an adaptive control strategy is introduced, allowing the controller to update its parameters in real time based on the behavior of the motor and operating conditions.

- Key Features:

- ✓ Error Calculation: $e(t)=\omega_{ref}(t)-\omega_{act}(t)$
- ✓ Adaptive Gain Tuning: Controller gains K_p, K_i, and K_d are updated using error derivative and integral trends or fuzzy inference logic.
- ✓ Torque Computation: The controller's output signal determines the required torque and, consequently, the current amplitude.
- ✓ Current Reference Generation: The torque signal is used to generate quasi-square current waveforms in sync with back-EMF for each phase.
- ✓ Hysteresis Current Regulation: Ensures that actual currents track reference values within defined tolerance.

This approach enables fast response, low overshoot, and enhanced steady-state accuracy under dynamic conditions.

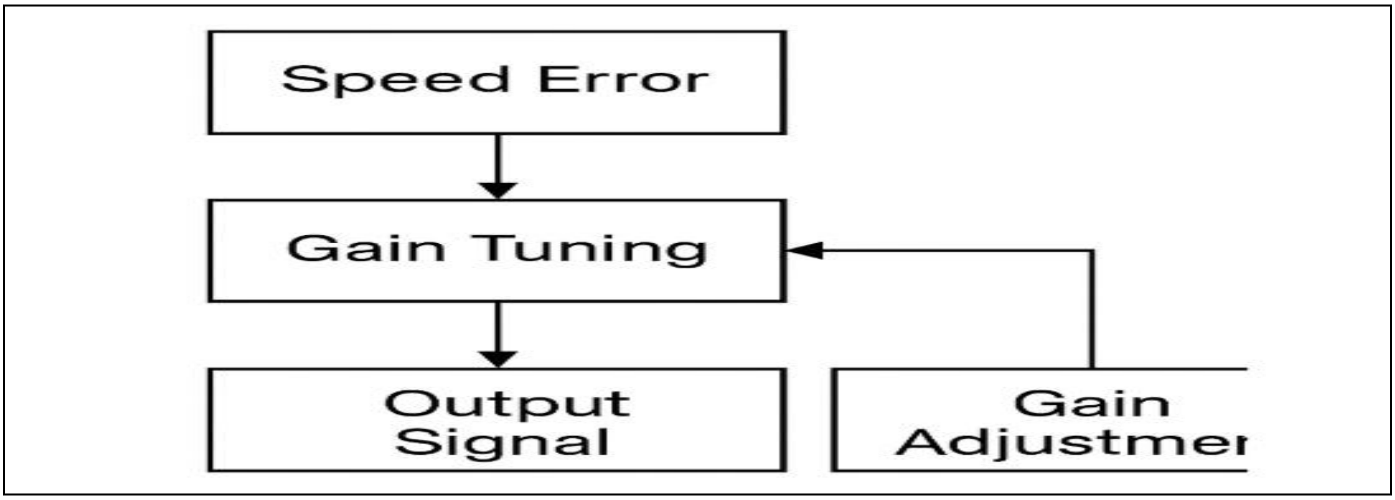

Fig 5 Flowchart of Adaptive Control Logic
(Flowchart should illustrate the process from speed error input to gain tuning and output signal generation)

➢ *Modeling and Simulation Environment* (MATLAB/Simulink)

MATLAB/Simulink is employed as the primary tool for system modeling and simulation. The modeling is divided into four key sections:

- *Electrical Subsystem:*
  Three-phase BLDC motor modeled using standard equations of motion and electrical dynamics. Back-EMF is modeled as trapezoidal functions synchronized with rotor position.

- *Control Subsystem:*
  Adaptive PID control implemented using embedded MATLAB function blocks. Speed reference and feedback system built using Simulink control blocks.

- *Power Electronics Subsystem:*
  Six-switch VSI modeled with IGBT blocks. PWM switching pulses generated using carrier-based comparison logic.

- *Sensor and Feedback Subsystem:*
  Hall-effect sensors simulated using rotor position decoder. Speed estimation block calculates actual rotor speed from position feedback.

Simulation results such as speed response, current waveforms, torque ripple, and inverter switching patterns are extracted and analyzed to evaluate controller performance.

➢ *Six-Step Commutation In BLDC Motors:*

Typically, a Brushless DC (BLDC) motor is powered using a three-phase voltage source inverter that operates based on a technique known as six-step (or 120°) commutation. In this scheme, each of the three stator windings conducts current for 120 electrical degrees per cycle, ensuring that at any given time, only two of the three phases are actively conducting, while the third phase remains unpowered (floating). This results in a total of six unique switching combinations per electrical revolution—each referred to as a "step."Figure 1 illustrates the cross-sectional view of a star-connected three-phase BLDC motor along with its corresponding phase energizing sequence. During each commutation interval, the relative angle between the magnetic fields of the stator and rotor starts at 120° and reduces to 60° by the end of the interval. The maximum electromagnetic torque is produced when the rotor and stator magnetic field vectors are orthogonal (90° apart).

The typical commutation sequence for a three-phase BLDC motor follows the pattern:

$$AB \rightarrow AC \rightarrow BC \rightarrow BA \rightarrow CA \rightarrow CB$$

This six-step sequence enables smooth and continuous rotation of the rotor by sequentially energizing the correct pair of stator windings in synchronization with the rotor position. To ensure that the current supplied by the inverter is in phase with the back-EMF of the motor (which is essential for optimal torque generation), commutation must occur precisely every 60 electrical degrees. Accurate commutation timing is critical and is generally achieved by tracking the rotor position using Hall-effect position sensors. These sensors (denoted as H1, H2, and H3 in Figure 2) detect the rotor's angular location and trigger commutation signals accordingly. The inverter circuit responsible for driving the motor is depicted in Figure 3 in a simplified form. While the figure may use bipolar junction transistors (BJTs) for illustration purposes, modern implementations commonly employ Insulated Gate Bipolar Transistors (IGBTs) or MOSFETs, which provide faster switching speeds and higher efficiency. The logic governing the commutation process—including the switching sequence, direction of current flow, and the corresponding Hall sensor outputs—is summarized in Table I. This table acts as the reference for the controller to determine which two transistors to activate at any given rotor position.

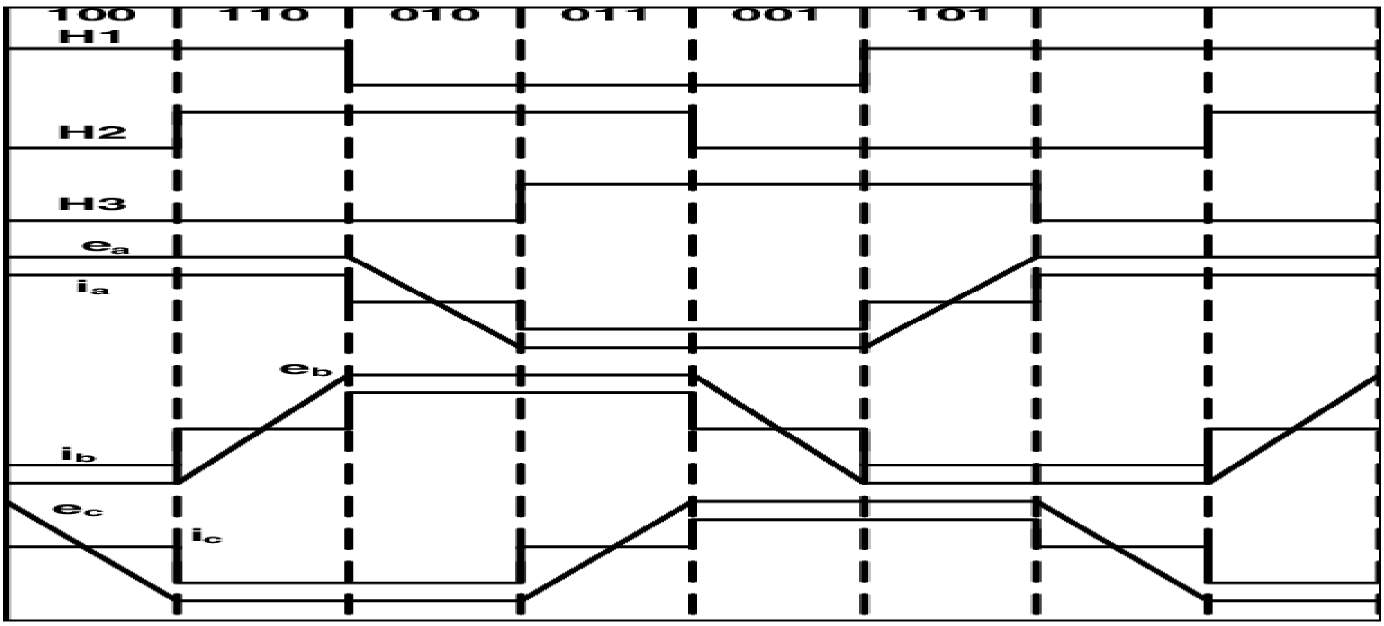

Fig 6 Ideal Back-Emf's, Phase Currents, and Position Sensor Signals

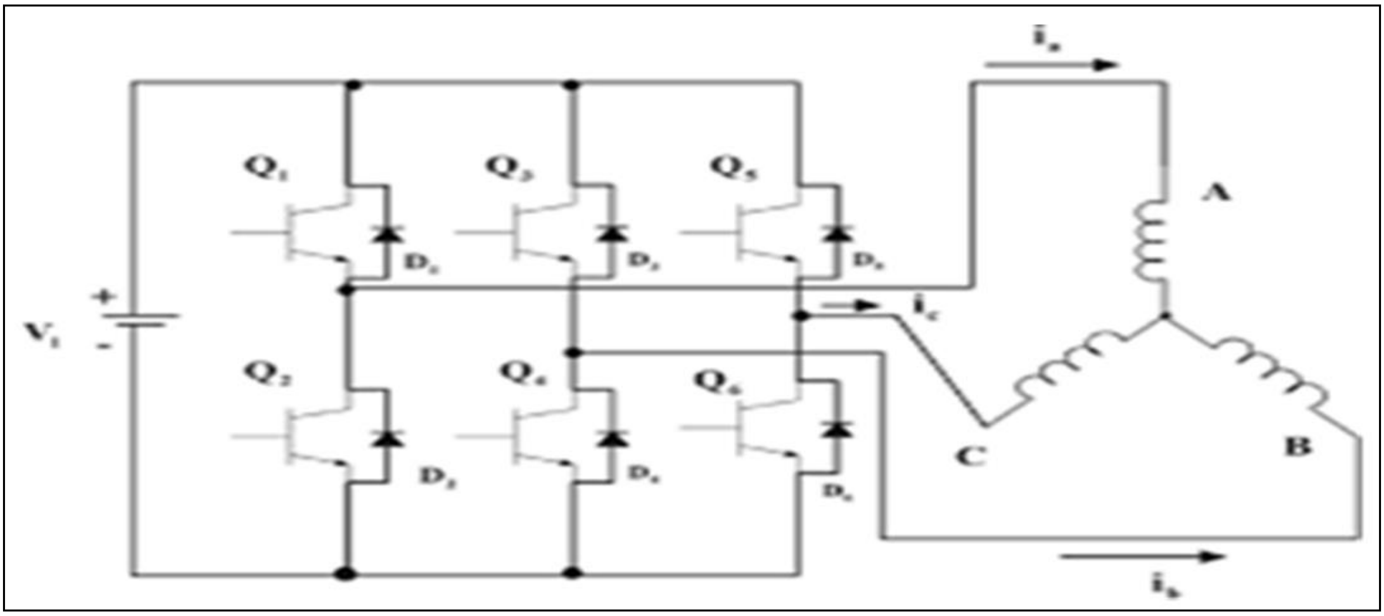

Fig 7 Simplified BLDC Drive Scheme

Table 2 Simplified BLDC Drive Scheme

Switching Interval	**Seq. Number**	**Pos. Sensors**			**Switch Closed**		**Phase Current**		
		H1	**H2**	**H3**			A	B	C
0^0-60^0	0	1	0	0	Q1	Q4	+	-	off
60^0-120^0	1	1	1	0	Q1	Q6	+	off	-
120^0-180^0	2	0	1	0	Q3	Q6	off	+	-
180^0-240^0	3	0	1	1	Q3	Q2	-	+	off
240^0-300^0	4	0	0	1	Q5	Q2	-	off	+
300^0-360^0	5	1	0	1	Q5	Q4	off	-	+

- *BLDC Motor Speed Control – Controlled Voltage Source Method*

In servo systems, position feedback is integral to the control loop, and velocity information can be extracted from the position data itself. This eliminates the need for a dedicated velocity sensor, simplifying the system.

BLDC motors operate using voltage pulses that are synchronized with the rotor's position, which is typically detected using Hall-effect sensors. By modifying the voltage applied to the motor terminals, the speed of the motor can be precisely controlled.

This voltage adjustment is commonly achieved through Pulse Width Modulation (PWM). The motor is driven via a three-phase bridge circuit consisting of six switches, and the voltage supplied to the motor can be varied by changing the PWM duty cycle.

The motor’s speed and torque are directly related to the magnetic field strength produced in the stator windings, which is dependent on the current flowing through them. Therefore, by adjusting the applied voltage (which in turn regulates the current), both the speed and torque of the motor can be effectively controlled.

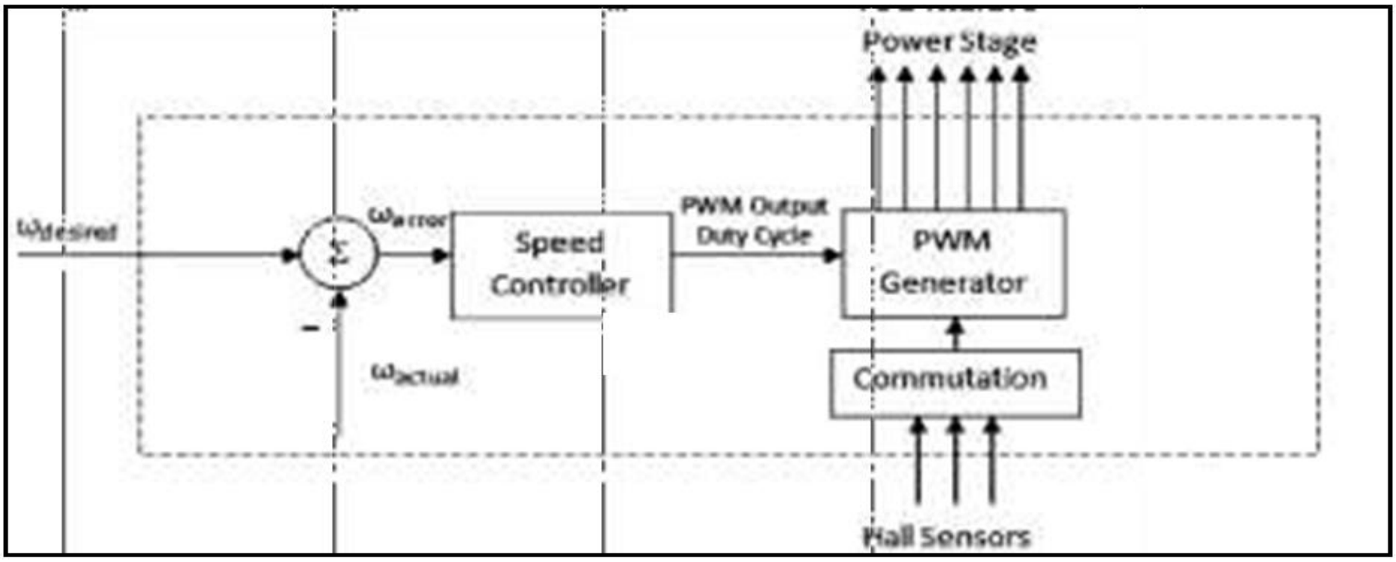

Fig 8 Schematic of a Speed Controller

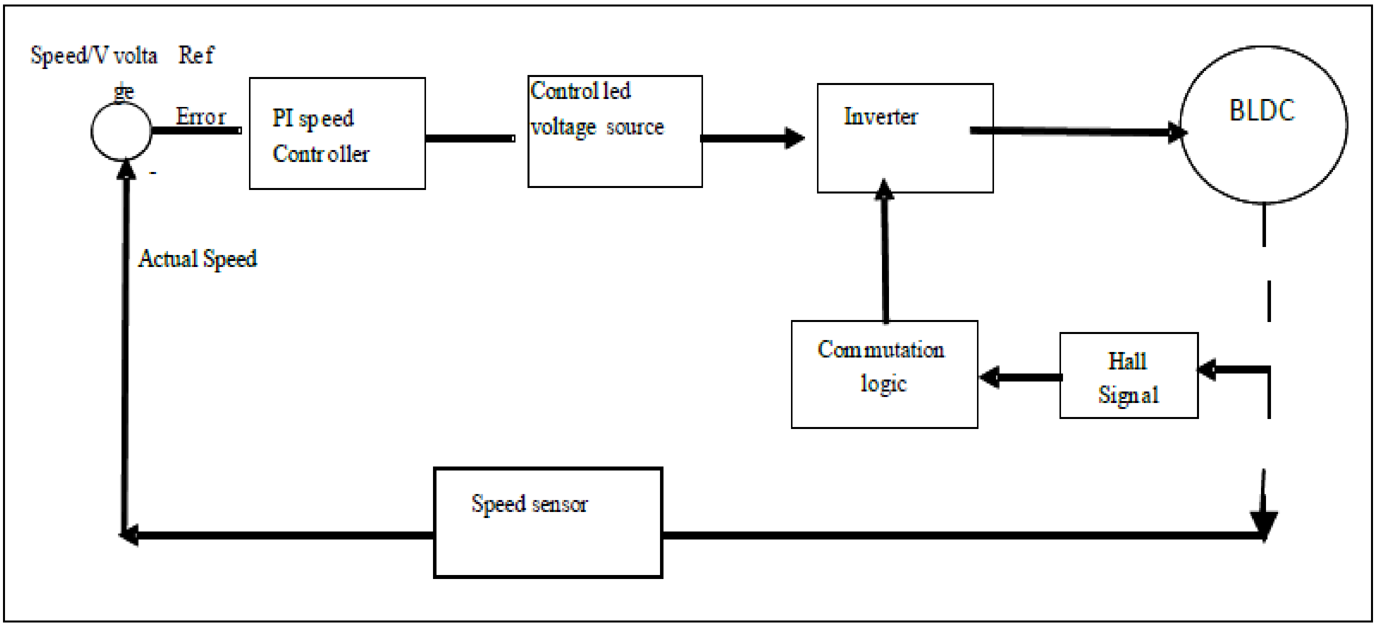

Fig 9 Closed Loop Speed Control

Figure 9 illustrates the closed-loop speed control system of a BLDC motor. In this setup, a speed controller manages the motor's operation by comparing the desired speed with the actual speed. The error between these two values is processed by a Proportional-Integral (PI) controller, which adjusts the duty cycle of the PWM signals accordingly. These PWM signals regulate the average voltage applied to the motor windings. By modifying the duty cycle, the system effectively controls the voltage amplitude, allowing the motor to maintain the target speed with precision.

➢ *Hysteresis Current Modulation Technique For BLDC Motor Drive*

In this technique, a three-phase inverter based on Insulated Gate Bipolar Transistors (IGBTs) is used to drive a Brushless DC (BLDC) motor. The Pulse Width Modulation (PWM) gating signals required to switch the IGBT devices are generated by a hysteresis current controller. This controller ensures that the motor current remains within a predefined hysteresis band over a 60° electrical interval corresponding to one-sixth of an electrical revolution of the rotor.

The current controller actively regulates the actual current to follow the reference current within this hysteresis band, as illustrated in Figure 7. The reference currents, generated by a dedicated current reference generator, are quasi-square waveforms aligned with the back-electromotive force (back-EMF) in motoring mode and shifted 180° out of phase in braking mode. These currents are synchronized with the rotor position, typically detected using Hall-effect sensors.

The amplitude of the reference currents is determined based on the desired torque, which is derived from the output of a Proportional-Integral (PI) controller. The PI controller receives the speed error—calculated as the difference between the reference speed and the actual rotor speed—and processes it to generate a torque command. This torque command is then limited to ensure system stability and safe operation before being used to compute the reference current.

A feedback loop is established by continuously monitoring the rotor speed using a speed sensor. This feedback is fed back into the PI controller, enabling real-time adjustments and accurate tracking of the reference speed. As a result, the system operates as a fully closed-loop speed control drive, ensuring precise regulation of the motor performance under varying load conditions.

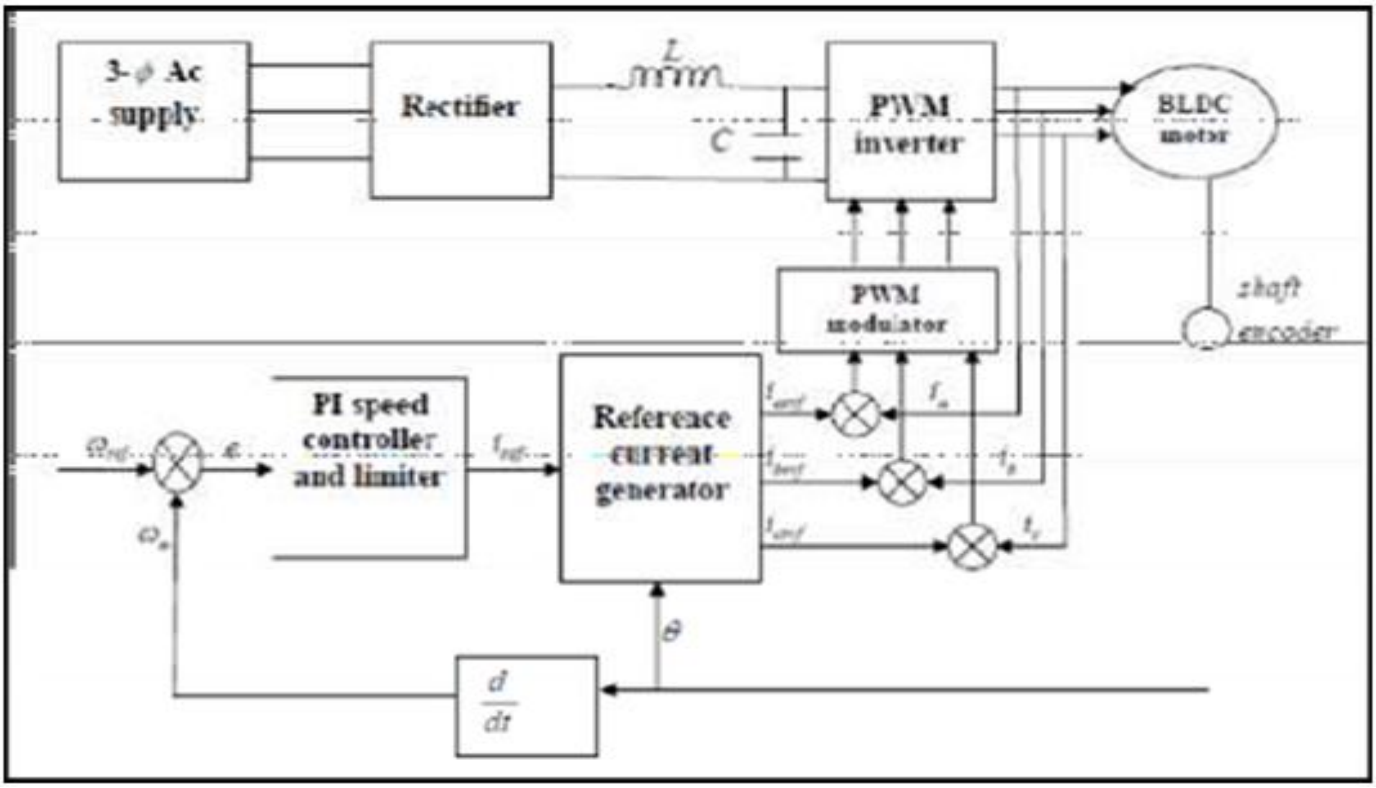

Fig 10 Block Diagram for Closed Loop Control of BLDC Motor

➢ *Speed Control Strategy*

Pulse Width Modulation (PWM) is one of the most widely used techniques for controlling the speed of Brushless DC (BLDC) motors due to its simplicity and effectiveness. In this method, a high-frequency chopper signal with a variable duty cycle is logically combined with the switching signals of a Voltage Source Inverter (VSI). By adjusting the duty cycle of the PWM signals, it becomes possible to modulate the average voltage applied to the motor phases, thereby regulating the motor speed accordingly.

Conventional analog-based control techniques are often limited by their susceptibility to external noise and their sensitivity to variations in temperature, supply voltage, and component characteristics. Moreover, these methods lack the flexibility and scalability offered by digital control approaches.

In this work, PWM signals are digitally generated using a Spartan-3A Field Programmable Gate Array (FPGA). A VHDL (VHSIC Hardware Description Language) program is developed to control the switching of the inverter devices. The generation of PWM signals is based on a comparison between a reference value and a carrier waveform. A counter within the FPGA generates a triangular waveform, which acts as the carrier signal. The value in the comparator register is then continuously compared with this carrier waveform. When the comparator value is less than the instantaneous value of the triangular wave, the corresponding PWM output is activated, forming the desired switching pattern. This technique allows for precise control of the inverter output and hence accurate speed regulation of the BLDC motor.

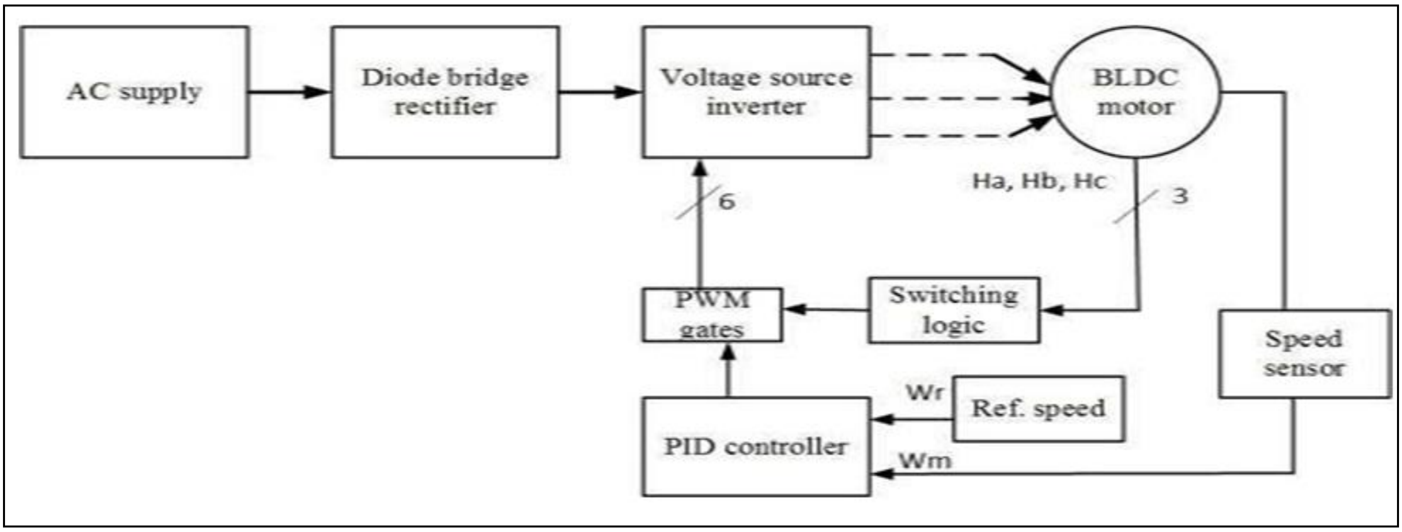

Fig 11 Block Diagram for PWM Inverter Control of BLDC Motor

The switching logic for controlling the Voltage Source Inverter (VSI) is derived from rotor position information obtained through Hall-effect sensors. Based on these Hall signals, the commutation sequence is determined to generate appropriate gating signals for the inverter switches. Simultaneously, the actual motor speed is continuously compared with the reference speed to generate a speed error signal. This error is processed by a Proportional-Integral-Derivative (PID) controller, which adjusts the control signal to regulate the motor speed effectively.

The gating signals for the inverter are generated using a Pulse Width Modulation (PWM) technique. In this method, a rectangular reference signal of amplitude ArA_rAr is compared with a high-frequency triangular carrier waveform of amplitude AcA_cAc. The intersection points of the reference and carrier waves determine the switching instances. The frequency of the carrier waveform sets the fundamental frequency of the output voltage, while the amplitude of the reference signal controls the duty cycle of the pulses.

The modulation index, defined as the ratio Ar/AcA_r/A_cAr/Ac, serves as the control parameter that governs the output voltage amplitude. By adjusting ArA_rAr within the range of 0 to AcA_cAc, the duty cycle can be varied from 0% to 100%, enabling fine-tuned control over the inverter output. The number of PWM pulses per half cycle is directly influenced by the frequency of the carrier wave. Figure 5 illustrates the generation of gating pulses using the PWM technique implemented in MATLAB/Simulink.

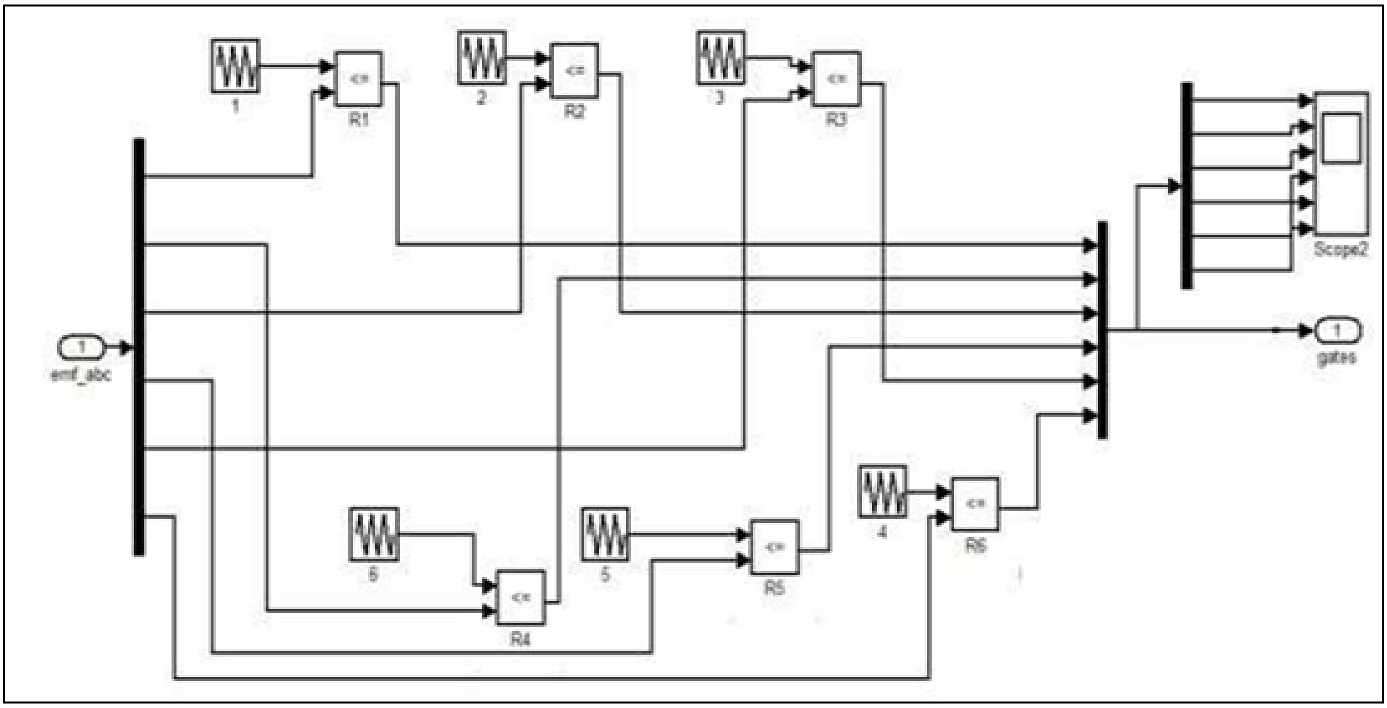

Fig 12 Simulink Model of Pulse Width Modulation Technique

III. CIRCUIT DESCRIPTION

➢ *Power Supply Circuit*

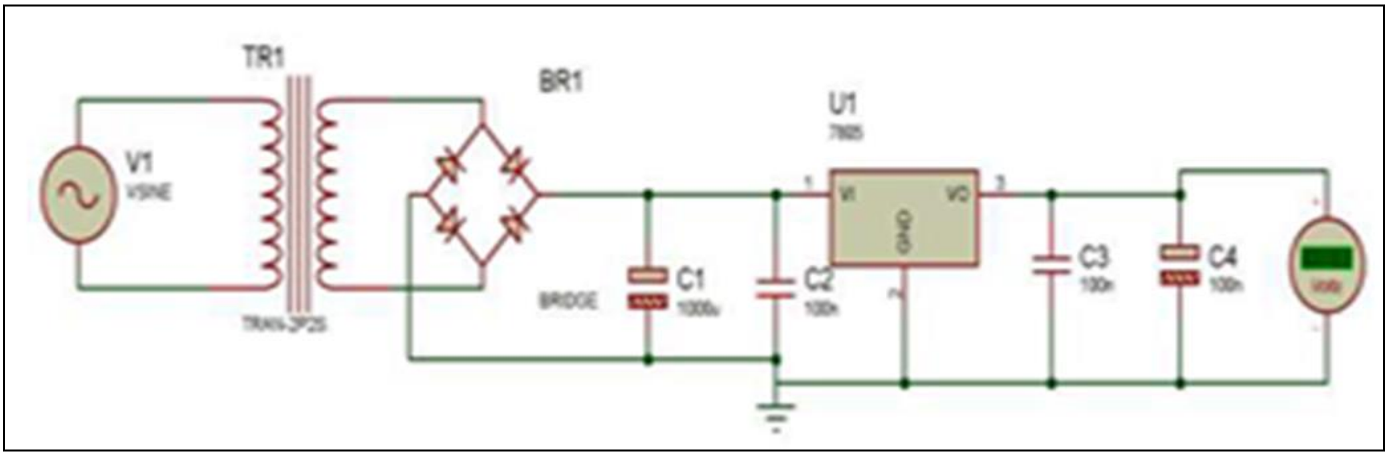

Fig 13 Power Supply (5V) Circuit

Fig 14 Volt Meter Reading (5V)

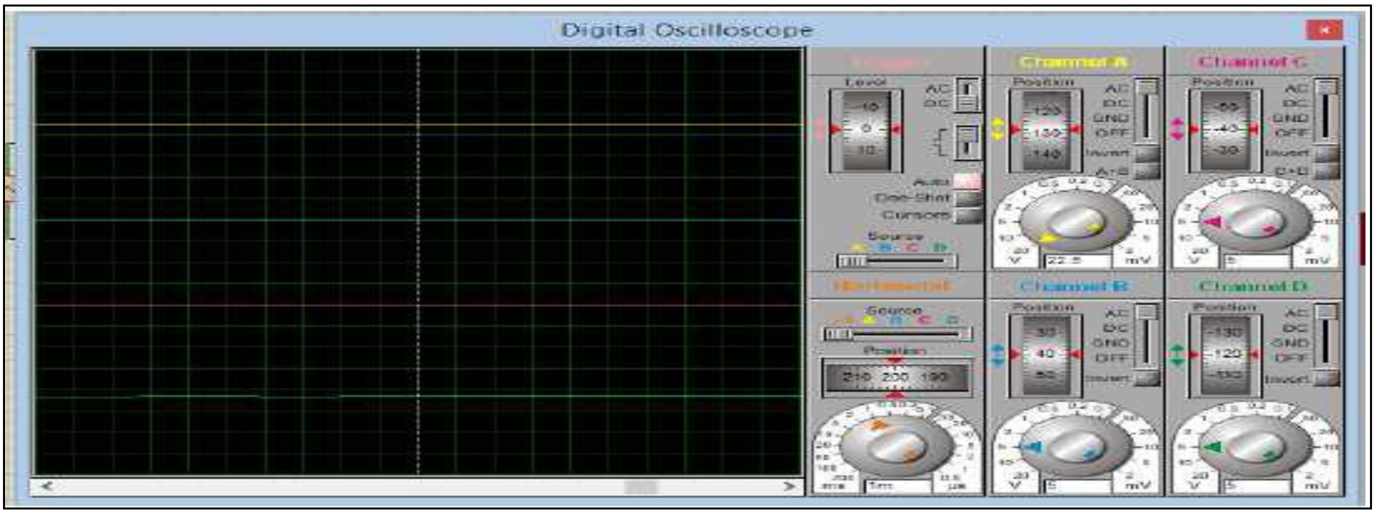

Fig 15 Power Supply DC Wave form on Oscilloscope

The above Circuit diagram shows the simulation of power supply for 5V and its give the 5V pure DC Voltage as output which is also shown in "Fig.14".

➤ *Circuit Diagram of Speed Control of BLDC Motor*

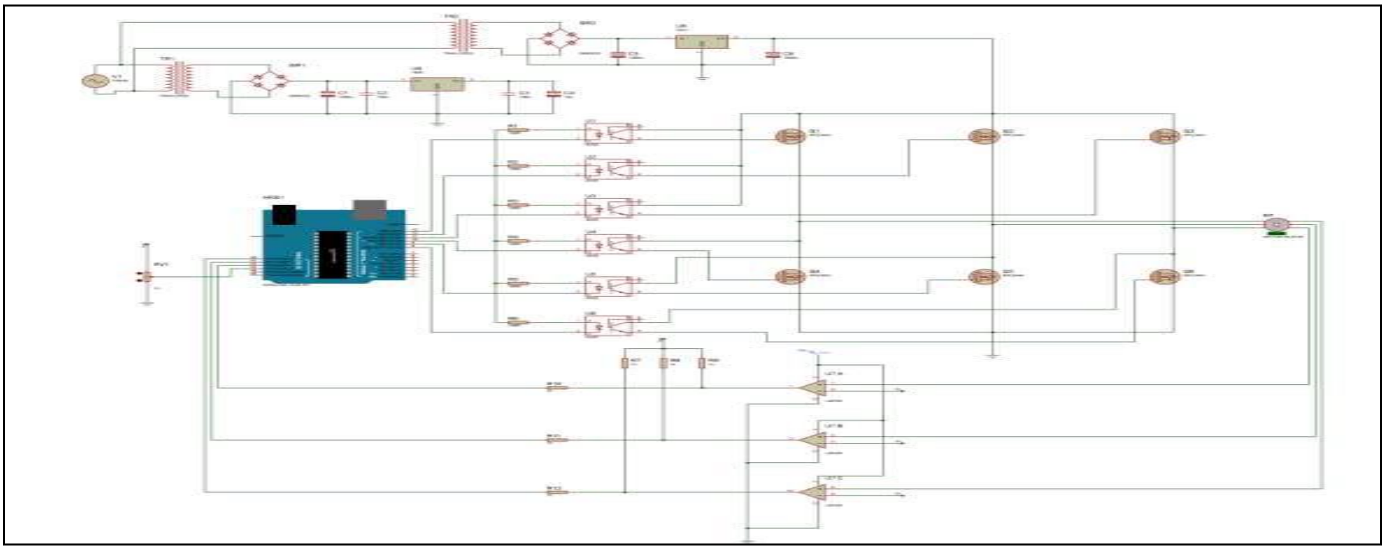
Fig 16 Circuit Diagram of Speed Control of BLDC Motor

➤ *Description: -*

An electronic Brushless DC Controller (also known as a Driver, or Electronic Speed Controller), replaces the mechanical commutation system utilized by a Brush DC Motor, and is required by most Brushless DC Motors to operate. In a Brushless DC Motor controller, either a Hall Effect Sensor or Back EMF (Electromotive Force) is used to identify the position of the rotor. Understanding the orientation of the rotor is crucial to operating the Brushless DC Motor. The Hall Effect uses three hall sensors within the Brushless DC Motor to help detect the position of the rotor.

This method is primarily used in speed detection, positioning, current sensing, and proximity switching. A Hall sensor can act as an on/off switch in a digital mode when combined with circuitry. The DC supply to give Inverter Bridge which is converting into three phase AC supply which is supply to motor. As a inverter circuit six MOSFET IRFZ44N bridge is used. Switches of Inverter Bridge are turned on-off as per the sequence generated by the controller. Output of Inverter Bridge is applied to three stator windings of BLDC motor. Opto-couplers MCT2E are used for providing isolation between controller side voltage and motor side voltage. Depending on switching sequence of inverters, current in the stator windings keeps on changing and accordingly magnetic field is generated and rotor which is made up of permanent magnet starts rotating in synchronism with the stator. As per the programming done the controller generates 6 PWM sequence which is given as inputs to the switches of the inverters which converts dc supply to ac required for running the motor. For control speed of motor variable register are used which is Vary the duty cycle. So, using this variable register user can increase or decrease speed of motor. Hall sensors sense the position of rotor and gives digital output to controller at that time controller generate PWM for energized next stator winding and operate inverter circuit to drive motor. So motor drive as per switching sequence of MOSFET Bridge. Hall sensors are mounted at 120-degree angle of motor shaft. The hall sensors are unipolar type which is sense the only south pole of the rotor magnet. As a controller Arduino ATMEGA328 microcontroller is used required DC supply.

- *MOSFET Driver Circuit (Opto Coupler):-*

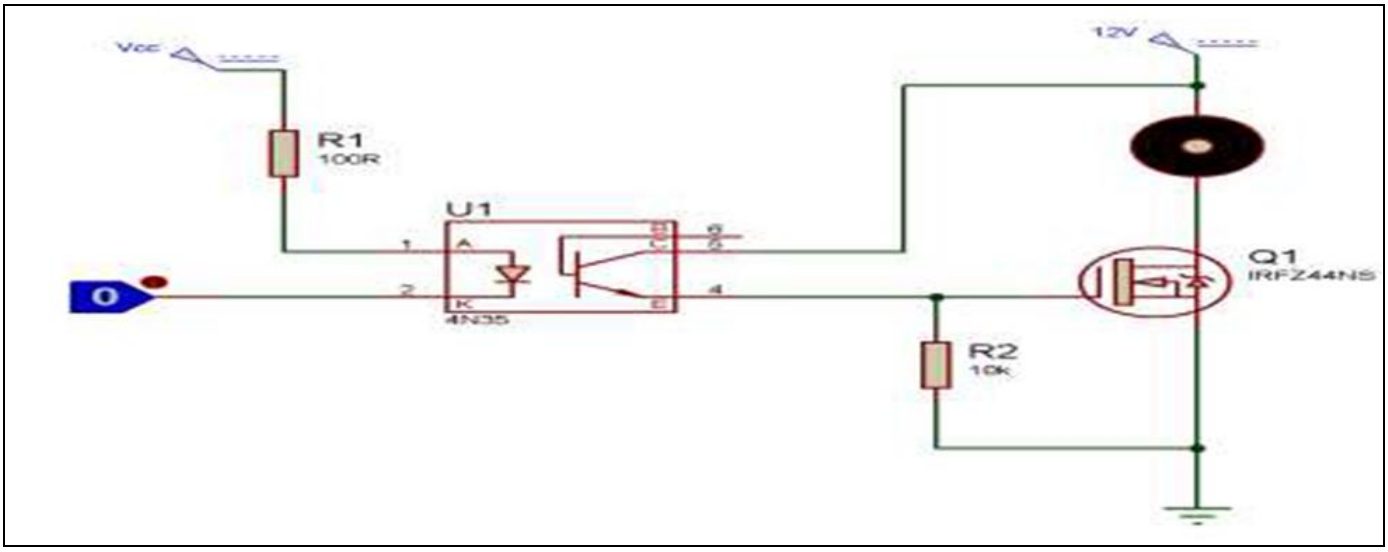

Fig 17 MOSFET Driver Circuit (Opto Coupler)

Opto-coupler is provided isolation between controller circuit and power circuit. The figure 16 shows the hardware of opto-coupler circuit and figure 17 shows proteus simulation of opto-coupler which is provided isolation between controller side 12V supply and MOSFET bridge side 12V supply. In this circuit we use MCT2E opto-coupler. Controller through gate pulses supplies to opto-coupler which are drive the motor. In figure 3.5, 3.6 and 3.7 shows the gate pulse width 20%, 50% and 80% Duty cycle respectively.

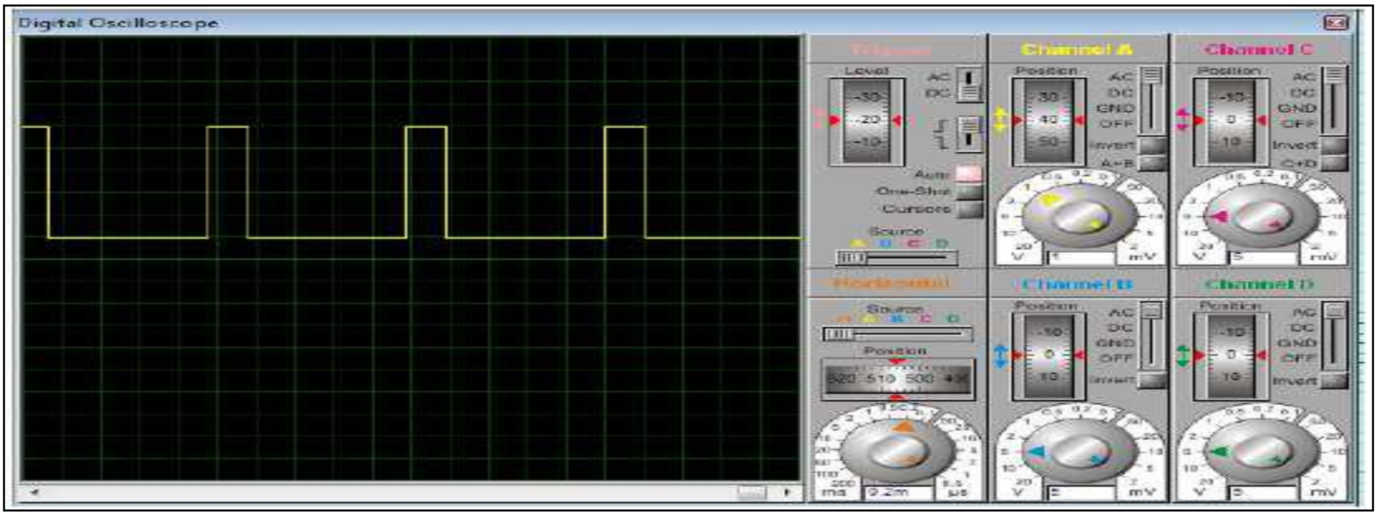

Fig 18 For 20% Duty Cycle.

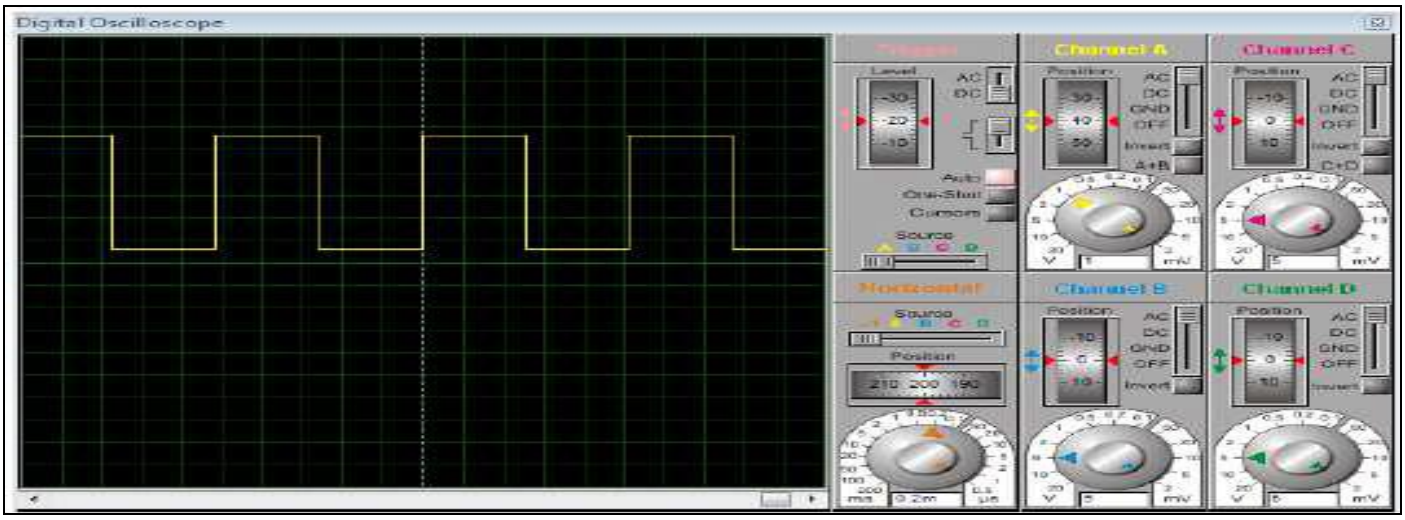

Fig 19 For 50% Duty Cycle.

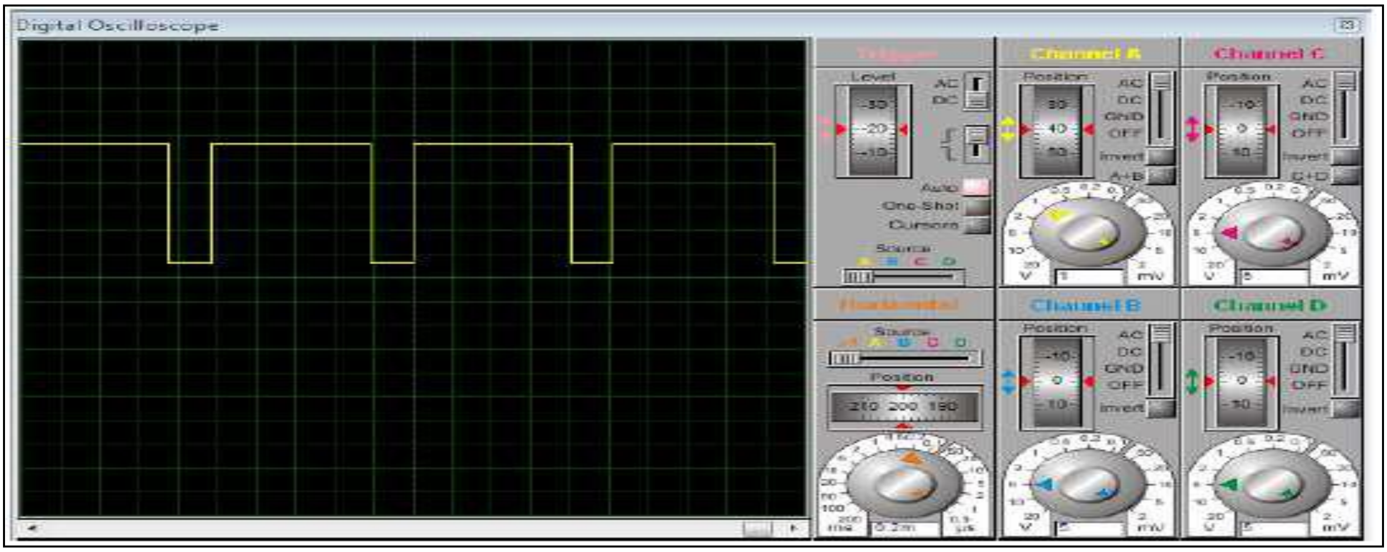

Fig 20 For 80% Duty Cycle.

IV. METHODOLOGY

- *Block Diagram*

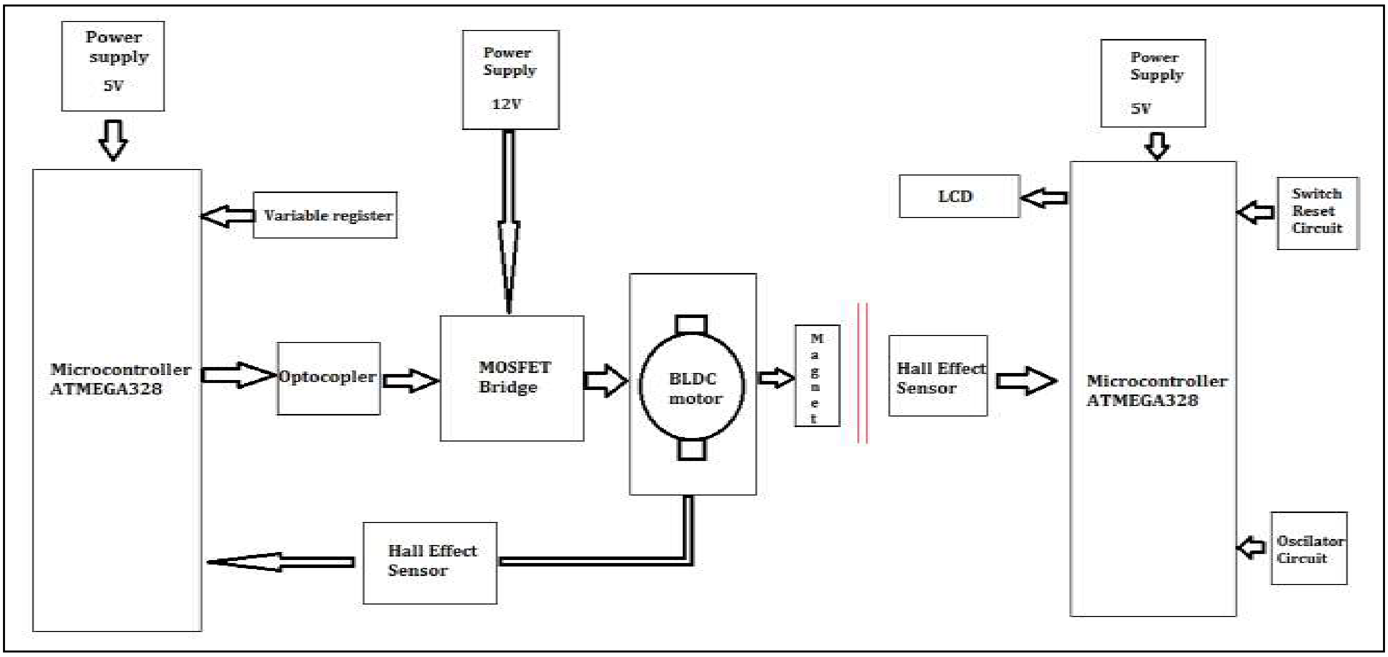

Fig 21 Block diagram

- *Description:*

The basic block diagram of speed control of permanent magnet brushless direct current motor is shown in figure 21. It consists of basically three blocks: controller (ATMEGA328), Inverter, BLDC motor and RPM measuring circuit. To drive BLDC motor, three phase six inverter bridge is used. In this bridge MOSFETs are used. Switches of Inverter Bridge are turned on-off as per the sequence generated by the controller. Output of Inverter Bridge is applied to three stator windings of BLDC motor. Opto-couplers are used for providing isolation between controller side voltage and motor side voltage. Depending on switching sequence of inverters, current in the stator windings keeps on changing and accordingly magnetic field is generated and rotor which is made up of permanent magnet starts rotating in synchronism with the stator. The position of rotor is sensed by the hall sensor. The output of hall Effect sensor are digital and it is applied to the controller for generating switching sequence for the inverter to energized next winding of stator. As per the programming done the controller generates 6 PWM sequence which is given as inputs to the switches of the inverters which converts dc supply to ac required for running the motor. For control speed of motor variable register is used which is set the duty cycle. So, using this variable register user can increase or decrease speed of motor. For RPM measuring circuit ATMEGA328 controller are used which is worked as contactless tachometer. In this RPM measuring circuit interface with LCD which is shows the RPM of Brushless Direct Current Motor. In this RPM measurement circuit hall sensor is used for sense pulse of rotor magnet and showing the rpm of motor.

- *Use of ECU:*

A sensor determines the position of the rotor, and based on this information the controller decides, which coils to energize.

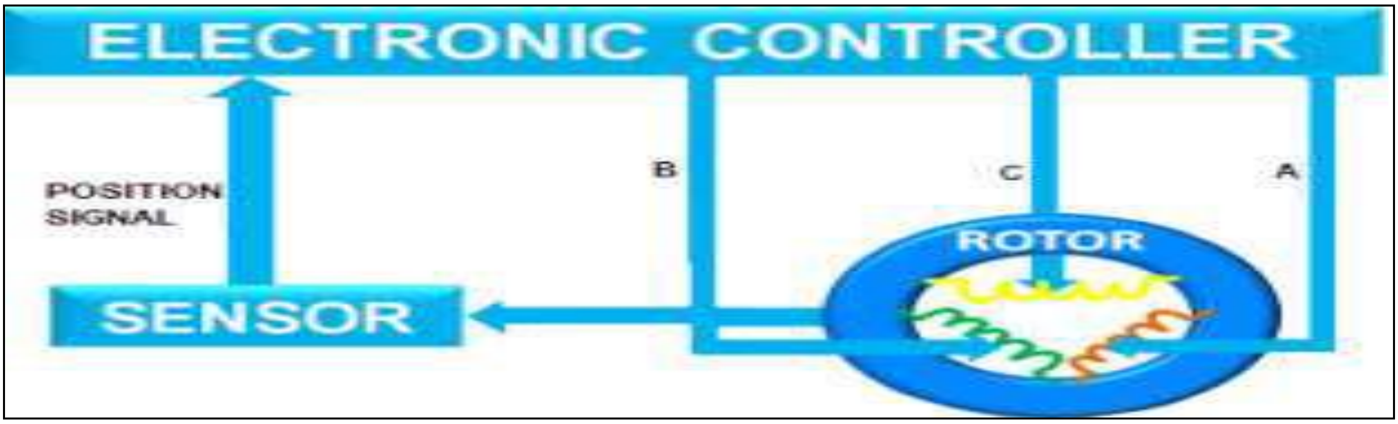

Fig 22 ECU

V. CONCLUSION

This research presented a comprehensive approach to enhancing the performance of Brushless DC (BLDC) motors through the implementation of an adaptive speed control strategy. The system architecture was designed using a closed-loop feedback mechanism, integrating rotor position sensing via Hall-effect sensors, PWM-based voltage source inverter control, and an adaptive PID controller for dynamic speed regulation. The adaptive control methodology demonstrated superior responsiveness compared to conventional PI/PID controllers by continuously adjusting controller gains in response to system variations and external disturbances. Modeling and simulation in MATLAB/Simulink effectively validated the proposed control framework. Results showed improved speed tracking, reduced torque ripple, and enhanced dynamic response under varying load conditions. The implementation of a hysteresis current controller ensured precise current regulation, contributing to overall system stability. Comparative analysis with traditional methods further emphasized the effectiveness of the adaptive scheme in minimizing rise time, overshoot, and steady-state error.

The study provides valuable insights into modern control strategies for electric drives, laying the groundwork for real-time hardware implementation using FPGA or DSP platforms. Future work can explore sensor less control techniques and the integration of machine learning algorithms to further improve adaptability and performance in advanced motor drive applications.

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