BLDC MOTOR CONTROL SYSTEM IN ELECTRIC VEHICLES

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Abstract

The BLDC motor control system equipped with a practical speed control feature is developed to operate BLDC motors typically used in electric vehicle applications. Its main purpose is to manage the motor's rotational direction—both forward and reverse—and to adjust throttle input for precise speed control. This study emphasizes the implementation of an effective and user-friendly speed control mechanism to enhance motor performance and gather experimental data on its behavior. The Convenient Speed Control device functions properly, efficiently managing the BLDC motor to enable smooth forward and reverse movement, as well as manual throttle adjustment. Test results show that the forward motion produces higher voltage output compared to reverse motion. At maximum forward speed, the voltage reaches 38 volts, whereas at full reverse, it records 21 volts. Furthermore, tests at varying speed levels reveal that phase voltage increases proportionally with speed. At Speed 1, the average phase voltage is about 8 volts; at Speed 2, it rises to around 17 volts; and at Speed 3, the highest voltage, averaging 21 volts across all phases, is achieved. These findings confirm that the controller effectively responds to speed variations and maintains stable motor performance under different operating conditions.

Keywords : BLDC, data, speed

1. INTRODUCTION

Unlike conventional induction motors, BLDC (Brushless DC) motors do not experience slip because the magnetic fields in the stator and rotor rotate synchronously, sharing the same frequency and speed. A BLDC motor is an electromagnetic device that converts electrical energy into mechanical energy. It has become one of the primary choices for modern electric vehicle propulsion systems due to its high efficiency and compact design. One of the key advantages of the BLDC motor is its electronically controlled commutation system, which eliminates the need for brushes used in conventional DC motors. This not only reduces friction and wear but also enhances durability and minimizes maintenance requirements. Sliding Mode Control (SMC) is a nonlinear control method used in control systems to make them robust and stable even when there are disturbances, uncertainties, or changes in system parameters. By utilizing sensors or sensorless methods, the rotor position can be accurately detected to regulate the current in each stator winding [1–2].

Electric vehicles are a type of transportation that use a BLDC (Brushless DC) motor as the main driving component and draw their power from rechargeable batteries. The main advantage of electric vehicles lies in their ability to operate without producing exhaust emissions, making them highly environmentally friendly. In addition, these vehicles feature a simpler mechanical design compared to fossil-fueled vehicles, resulting in easier maintenance and lower operating costs. With high energy efficiency, electric vehicles are capable of delivering optimal performance while supporting efforts to reduce carbon emissions. The development of charging infrastructure continues to advance, offering greater convenience and accessibility for users to recharge their batteries. Along with technological progress and increasing public awareness of environmental issues, electric vehicles have become an increasingly popular choice among modern consumers who value sustainability and cleaner air quality [3].

Power electronic components are now widely used in various aspects of life, both in industrial and household applications. One of their main applications is in the speed control systems of BLDC (Brushless DC) motors, which are commonly found in electric vehicles, trains, drones, and other modern transportation devices [4]. To control two three-phase BLDC motors simultaneously, two three-phase inverters are typically employed. An inverter changes the steady flow of DC power into the back-and-forth flow of AC power. This approach was discussed by Tsutomo Kominami and Yasutaka Fujimoto in their journal paper titled “A Novel Nine-Switch Inverter for Independent Operation of Two Three-Phase Loads.” The nine-switch inverter concept enables more efficient, flexible, and space-saving operation, as a single inverter can independently control two three-phase loads. Proper use of inverters is crucial to maintaining the performance and reliability of BLDC motors [5–6].

The electric motor is the main component that enables an electric vehicle to move. The selection of the motor type is adjusted according to the vehicle’s requirements and specifications. One of the most commonly used motors is the Direct Current (DC) motor due to its simplicity of operation, particularly its ability to change the direction of rotation by simply reversing the polarity of the power supply. DC motors are also known for their high rotational speed (RPM) and ease of speed control. However, with advances in technology, Brushless Direct Current (BLDC) motors have become increasingly popular because they offer several advantages over conventional DC motors. BLDC motors do not use brushes, which reduces wear and maintenance, and they provide better energy efficiency and lower noise levels [7]. Therefore, this research focuses on the Electronic Control System for BLDC motors in electric vehicles. By implementing BLDC motors, it is expected that electric vehicles can achieve optimal performance, more precise speed control, and higher energy efficiency.

2. REVIEW OF LITERATURE

In 2025, Zuber Basha Shaik and Samineni Peddakrishna conducted a study on the Autonomous Vehicle Electronic Control Unit (AV-ECU). In manual mode, the driver has full control of the vehicle through the ignition key, emergency checks, and mechanisms for determining direction and speed. The transition to autonomous mode involves the integration of the AV-ECU, which manages the Electric Vehicle Electronic Control Unit (EV-ECU). The utilization of advanced sensors, electronic control units, actuators, and real-time data acquisition demonstrates the practical implementation of autonomous driving technology, with an emphasis on safety, efficiency, and its potential application in real-world environments.

In 2024, Syed Shehryar Ali Naqvi, Harun Jamil, and Naeem Iqbal conducted research on the integration of the Electronic Control Unit (ECU) in electric vehicles. The rapid development of electric vehicles (EVs) has driven innovation in vehicle control systems, particularly through the use of ECUs. The ECU plays a crucial role in managing various vehicle functions such as braking systems, electric motor drive control, power distribution, and vehicle stability. In modern EV systems, the integration of the ECU and its subsystems has become essential to achieving optimal performance, energy efficiency, and driving comfort. In 2023, Riththika Sukanan effectdan and Sachin Gajjar conducted research on the implementation of the Electronic Control Unit (ECU) in electric vehicles. The ECU functions as the main control center of the vehicle, managing various operations through a microcontroller by interpreting input from sensors to ensure smooth and efficient vehicle performance. With the advancement of electric vehicle (EV) technology, the use of microcontrollers such as Arduino has become a practical and cost-effective solution for developing vehicle control systems.

In 2023, Arihant Swaminathan, Ashwin Nirmal, Kishore Krishna, and Kruthik Soundappan conducted research on the Electronic Control Unit (ECU) in hybrid electric vehicles aimed at reducing costs. Electric vehicles (EVs) have experienced rapid and multifaceted growth in recent years, driven by technological advancements and the increasing demand for environmentally friendly transportation. One of the key drivers of this progress is the effective use of microcomputers to establish strong connections between various vehicle components. In modern EV systems, coordination among components has become increasingly complex, requiring an intelligent and reliable central control unit. This system enables the vehicle to automatically respond to changes in operational and environmental conditions, enhancing both safety and efficiency. With the ability to control parameters such as speed, safe following distance, and battery status, the ECU plays a crucial role in supporting overall vehicle performance and ensuring user safety.

Widya Cahyadi, Muh Fazauddiyak Sa'id, and Ali Rizal Chaidir conducted research related to the Electronic Control Unit (ECU) in electric vehicles 2020. To improve the efficiency of electric vehicles, an ECU equipped with a fuzzy logic control system was implemented to automatically regulate vehicle speed when navigating turns. With the integration of fuzzy logic control and steering angle sensors, the vehicle's power consumption during cornering can be reduced, resulting in higher overall energy efficiency.

Jefri Lianda, Muhammad Afridon, Zamhuri, Dea Fitriana, and Gusti Eviani conducted research on an IoT-based battery capacity control system for electric vehicles. The Blynk application provides real-time information on the amplitude and voltage percentage of the battery. The NodeMCU ESP8266 proved to function effectively, maintaining a stable connection while connected to the internet. In the Blynk application, the recorded average voltage difference was 0.74%. The SSR relay serves to cut off power to the electric vehicle when the battery voltage reaches approximately 46.3 volts or when the battery capacity drops to 0.16%. This system is designed to ensure efficient power management, protect the battery from further damage, and maintain optimal vehicle performance according to power requirements.

3. METHOD

This study employs an experimental method and focuses on the design, implementation, and testing of an electronic control system for a Brushless DC (BLDC) motor in an electric vehicle. Figure 1 illustrates the BLDC motor used in this system. For the BLDC motor to operate properly, it is essential to determine the rotor position inside the motor. This positional information is required to accurately control the stator windings, applying the correct voltage polarity to attract or repel the rotor magnets, thereby enabling rotation. Typically, the rotor position is detected using Hall Effect sensors mounted on the stator. Hall Effect sensors are electronic devices that detect the presence and strength of a magnetic field. They work based on the Hall Effect a phenomenon where a voltage difference is generated across a conductor when it carries an electric current and is exposed to a magnetic field perpendicular to the current. These sensors function by detecting changes in the magnetic field generated by the rotor as it moves. The data obtained from the sensors are then used by the control system to precisely regulate the voltage applied to the stator windings.

Fig. 1. 48-Volt BLDC Motor

In the implementation of the convenient speed control system for controlling the Brushless Direct Current (BLDC) motor in electric vehicles, several key components play essential roles in the overall motor control process. The most vital component is the BLDC motor itself, which functions as the main driving unit of the electric vehicle. This motor is responsible for converting electrical energy into mechanical energy to propel the vehicle. In addition to the BLDC motor, the convenient speed control component serves as the central unit of the motor control system. It not only regulates motor speed but also ensures that the motor operates efficiently and responsively during operation. With proper configuration, the system can adjust the motor's power output according to the vehicle's needs, providing smooth and optimal control. The combination of the BLDC motor and an effective convenient speed control system enables the electric vehicle to operate with maximum performance and high energy efficiency. The analysis of this system's implementation aims to understand its working principles and to optimize BLDC motor control for improving the overall performance of electric vehicles.

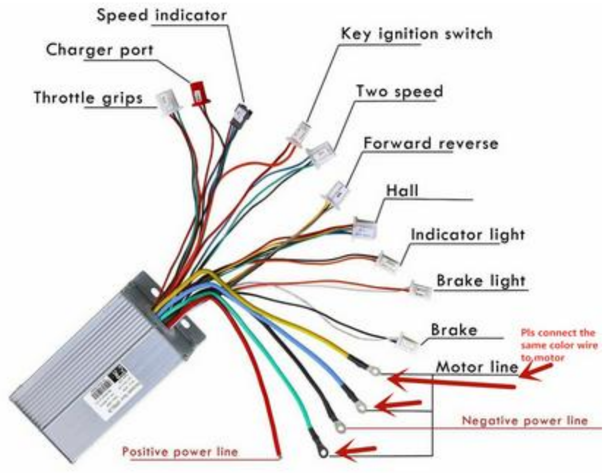

Fig. 2. Convenient Speed Control

The working system in the implementation and analysis of the convenient speed control for the Brushless Direct Current (BLDC) motor in electric vehicles involves several important operational processes. These processes are illustrated in Figure 2, which shows the numbering and arrangement of the main control functions within the system. Each function has a specific role in regulating the speed and rotational direction of the BLDC motor according to the operational requirements of the electric vehicle. The control system operates by receiving input signals from the user, processing rotor position data, and adjusting the output voltage applied to the stator windings. The numbering in Figure 2 helps clarify the workflow of the control system, from input reception to full motor control. With this structured and integrated system, BLDC motor speed can be managed efficiently and responsively, thereby improving the performance and reliability of the electric vehicle during operation.

The main components of the BLDC motor control system and their functions are as follows. First, the negative battery cable, which is connected to the negative terminal of the battery, serves as the primary power source. Then, there are three motor phase cables that connect the controller to the three phases of the BLDC motor, including neutral and grounding connections. The positive battery cable is connected to the positive terminal of the battery to supply the necessary electrical current for motor operation. Next, the controller system has the function of reversing the rotation direction of the BLDC motor according to the driver's needs. The battery output is also provided to supply power to other components in the system. The ignition key, connected to the vehicle's ON/OFF switch, functions to activate or deactivate the entire system. The throttle component regulates motor speed based on driver input, while the brake light is integrated to signal other road users when the vehicle is braking.

The hardware and control system are essential components required to support and facilitate the completion of this research on the Electronic Control System for BLDC motors in electric vehicles. The overall system design can be seen in Figure 3, which illustrates the arrangement of components and the interconnections between parts within the implemented system.

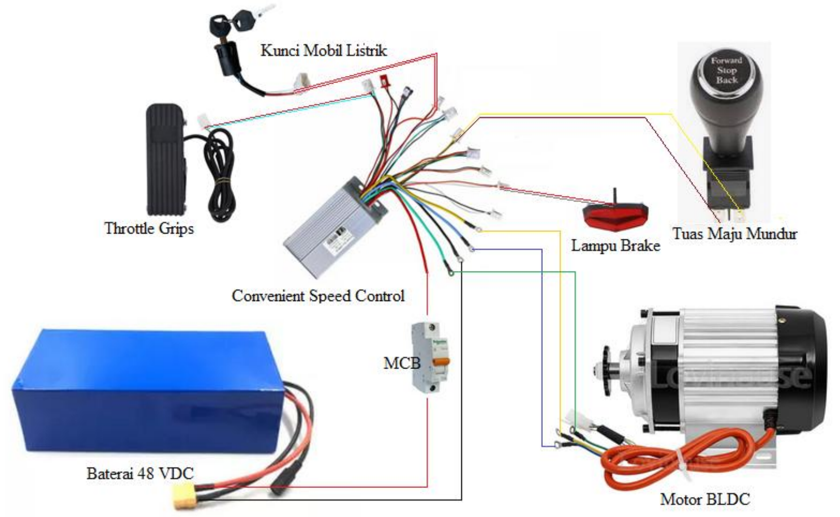

Fig. 3. Hardware Design

The technical specifications of each component used in this research are as follows:

1. 48 VDC Battery (15 Amperes) – Serves as the main electrical power source.
2. 20-Ampere MCB (Miniature Circuit Breaker) – Functions as an overcurrent protection system.
3. Convenient Speed Control – Provides ease, comfort, efficiency, and safety in controlling the electric motor's speed.
4. 700-Watt BLDC Motor – Serves as the main driving motor for the electric vehicle.
5. Throttle – Acts as the input speed control device used by the driver to regulate the power delivered to the electric motor.
6. Ignition Key – Functions as a switch to operate the electric vehicle.
7. Forward-Reverse Lever – Serves as the control device for determining the rotational direction of the electric motor, allowing the driver to select forward or reverse motion.

4. RESULT & DISCUSSION

Based on the experiments conducted, data collection was carried out in stages through multiple trials to ensure a high level of accuracy and consistency in the obtained results. This process is essential to ensure that the final test outcomes can serve as a strong foundation for analyzing the performance of the BLDC motor in electric vehicles. During each experiment, no-load conditions were maintained consistently to observe the motor's natural response to input voltage without the influence of external loads. The experimental data are presented in Table 1.

The research results and discussion should be presented clearly. Tables, figures/graphs, or photographs may be included to enhance the clarity of the findings. The discussion constitutes the most critical part of the paper. It is recommended that the explanation not only describes the data or research findings, but also provides an interpretation of the overall results, a comparison with previous relevant studies, and answers to the research problems addressed.

Table 1. Forward Test Without Load

No	Conductor Voltage AB	Conductor Voltage AC	Conductor Voltage BC	Description
1	10 volt	10 volt	10 volt	Speed 1
2	20 volt	20 volt	20 volt	Speed 2
3	38 volt	38 volt	38 volt	Speed 3

In the first test, the BLDC motor was operated under no-load conditions, and the measurement results showed that the voltage across each conductor was 10 volts. This represents the initial output voltage value when the system was first activated. Subsequently, in the second test, the voltage increased to 20 volts on each conductor. This rise indicates a change in the motor's operating condition or an improvement in the efficiency of converting electrical energy into mechanical motion. Finally, in the third experiment, the recorded voltage increased significantly, reaching 38 volts on each conductor.

The results obtained from the series of experiments show a significant upward trend in voltage as the number of tests increased. This rise not only reflects a quantitative change but also indicates an improvement in the performance of the BLDC motor tested under no-load conditions. The gradual increase in voltage at each testing stage can be interpreted as the motor's natural response to system warming, power supply stabilization, and adaptation to repeated operating conditions. This phenomenon serves as an important indicator in understanding the performance characteristics of BLDC motors, especially when applied in electric vehicle systems that rely heavily on electrical efficiency and operational stability. A motor that consistently demonstrates voltage improvement across multiple test stages signifies its potential to deliver more optimal power output when operating under real-world conditions

Table 2. Reverse Test Without Load

No	Conductor Voltage AB	Conductor Voltage AC	Conductor Voltage BC	Description
1	8 volt	8 volt	7 volt	Speed 1
2	17 volt	17 volt	16 volt	Speed 2
3	21 volt	21 volt	21 volt	Speed 3

In the first reverse test, the BLDC motor was operated under no-load conditions, and the measurement results showed that the voltage across each conductor was 10 volts. This represents the initial output voltage value when the system was first activated. In the second test, the voltage increased to 20 volts on each conductor, indicating a change in the motor's operating condition or an improvement in the efficiency of converting electrical energy into mechanical motion. Finally, in the third test, the recorded voltage rose significantly to 38 volts on each conductor, demonstrating a strong response from the motor as the system continued to stabilize during reverse operation.

The data collection process was carried out alternately and repeatedly for each pair of conductors to ensure a high level of measurement accuracy. This approach minimizes potential measurement errors and increases the reliability of the results for further analysis. In addition, the variation in speed used during each test made it possible to observe how changes in motor speed affect the voltage between conductors when the motor operates in reverse mode. The data obtained from this test provide valuable insights into the electrical behavior of the electric vehicle system during reverse maneuvers, which commonly occur in everyday driving scenarios. Analysis of the output voltage under these conditions is essential for assessing motor stability, energy conversion efficiency, and the system's responsiveness to direction changes. Such information not only aids in optimizing motor control design, but also serves as a technical foundation for developing an electric vehicle system that is reliable, efficient, and responsive in both forward and reverse operating conditions.

The phase voltage testing of the BLDC motor was carried out at three different speed levels to observe the voltage response across conductors AB, AC, and BC. At speed level 1, the measured voltages were 8 volts on conductor AB, 8 volts on conductor AC, and 7 volts on conductor BC, indicating a relatively low voltage during the initial rotation. When the speed was increased to level 2, there was a noticeable rise in voltage, with 17 volts recorded on conductors AB and AC, and 16 volts on conductor BC. Subsequently, at speed level 3, all phases showed a balanced voltage of 21 volts. These results demonstrate that the voltage between conductors increases proportionally with the motor's speed, indicating that the BLDC motor control system operates effectively and proportionally in adjusting output voltage relative to speed input.

5. CONCLUSION

The Convenient Speed Control has functioned properly according to its intended role in the electric vehicle drive system. This device effectively controls the BLDC motor, allowing the vehicle to move both forward and backward while providing manual control through the accelerator pedal. Based on the test results, the voltage recorded during forward motion was higher than that during reverse motion. At full forward speed, the voltage reached 38 volts, whereas at full reverse speed it was only 21 volts. This voltage difference reflects the distinct performance characteristics of the motor depending on the direction of motion, while also demonstrating the stability and reliability of the control system.

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