International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

Advanced Control Strategies for BLDC Motor Speed Regulation in Electric Vehicles

[1]Harshit Mishra, [2]Aditya Gupta
[1]Assistant Professor, Department of Electrical Engineering, Rewa Engineering College Rewa
mharshit45@gmail.com
[2]Assistant Professor, Department of Electrical Engineering, Rewa Engineering College Rewa
mharshit45@gmail.com

Abstract
The growing adoption of electric vehicles (EVs) has intensified the need for high-performance, energy-efficient, and reliable motor control systems. Brushless DC (BLDC) motors are widely preferred in EV propulsion due to their high torque density, reduced maintenance, and superior dynamic response. However, achieving precise speed regulation under varying load, road, and battery conditions remains a critical challenge. This study investigates advanced control strategies such as Field-Oriented Control (FOC), Model Predictive Control (MPC), Adaptive PID, and ann Controllers for improving the speed regulation of BLDC motors used in EVs. The performance of each method is evaluated in terms of response time, steady-state error, robustness to disturbances, and energy efficiency. Simulation results demonstrate that intelligent and model-based controllers outperform conventional PID control by providing smoother torque production, reduced ripples, and improved adaptability under real-world operating conditions. The work highlights the potential of hybrid control approaches that combine AI-based decision-making with classical control to achieve optimal speed regulation and enhanced vehicle performance. These findings contribute to the development of next-generation EV drive systems that are more efficient, responsive, and reliable.

KEYWORDS: Brushless DC (BLDC) motors, proportional integral derivative (PID) controller, Fuzzy PID controller, ANN controller.

I. INTRODUCTION

The increasing reliance on energy-efficient and high-performance electric drives in modern electronic systems has led to the widespread adoption of Brushless DC (BLDC) motors. These motors offer numerous advantages over traditional brushed motors, including higher efficiency, longer lifespan, lower electromagnetic interference, and superior torque-to-weight ratio. As a result, BLDC motors have become a cornerstone in applications ranging from electric vehicles (EVs) and drones to household appliances, medical devices, and industrial automation. Despite their advantages, the performance of BLDC motors heavily depends on the effectiveness of the control algorithms used for speed regulation, torque production, and position accuracy [1]. The absence of brushes necessitates an external electronic controller for commutation, making advanced control strategies not only useful but essential. Two such control techniques, Proportional-Integral Derivative (PID) control and Field-Oriented Control (FOC) are widely studied and implemented due to their ability to enhance motor response, minimize steady-state error, and handle system disturbances. The PID controller is one of the most popular control strategies due to its simplicity, ease of tuning, and effective performance in linear systems. On the other hand, FOC, also known as vector control, represents a more sophisticated approach that enables decoupled control of torque and flux, thereby mimicking the performance of a DC motor and optimizing efficiency under varying loads and speeds [2]. This survey aims to present a holistic view of these control techniques in the context of BLDC motors. The paper begins with an overview of BLDC motor fundamentals, followed by a detailed discussion on the working principles, tuning methods, and real-time implementation aspects of PID and FOC. Further, a comparative analysis is provided to highlight their performance trade-offs, challenges in embedded implementation, and suitability across different application domains. Lastly, the paper explores current research directions and emerging trends, including sensorless control and AI-based motor tuning, that are shaping the future of motor control in electronics [3].

II. BRUSHLESS DC MOTOR

Fundamentals Brushless DC (BLDC) motors represent a class of synchronous electric motors that operate using direct current (DC) supplied through an electronic controller, as opposed to relying on brushes and a mechanical commutator for current switching. This design innovation eliminates the mechanical wear points common in traditional brushed motors, enhancing performance characteristics such as reliability, efficiency, and control precision. Because of these attributes, BLDC motors are extensively employed in modern electronic systems ranging from electric vehicles to industrial automation and consumer electronics, particularly where compactness, longevity, and precise control are essential [4].

A. Construction and Working Principle

A BLDC motor typically consists of two main components: a rotor embedded with permanent magnets and a stator made up of multiple windings. These motors are often available in two primary configurations—in-runner, where the rotor is enclosed within the stator, and out-runner, where the stator is situated inside the rotor. Unlike brushed motors that perform mechanical commutation through contact between brushes and a commutator, BLDC motors achieve commutation electronically. This is facilitated through rotor position feedback, obtained via Hall-effect sensors or estimated in sensorless designs using back-EMF signals. The electronic controller energizes the stator windings in a specific sequence, generating a rotating magnetic field. The rotor, attracted to this rotating field, follows its motion, thereby producing rotational output. Control of the commutation sequence is commonly achieved using microcontrollers or digital signal processors (DSPs), which allow high levels of precision and adaptability, making these motors ideal for integration with embedded control systems.

B. Advantages Over Brushed Motors

BLDC motors offer numerous advantages when compared to traditional brushed motors, primarily due to the elimination of brushes. Without mechanical contact elements, friction and wear are significantly reduced, leading to higher efficiency and torque output per watt. The absence of arcing and brush noise also results in quieter operation. Furthermore, the lack of brush maintenance enhances motor reliability and longevity. These motors exhibit superior speed-torque characteristics and are well-suited for applications that demand low maintenance and high operational stability. As such, BLDC motors are widely adopted in aerospace, medical devices, electric vehicles, robotics, and other embedded systems requiring precise motion control and extended service life [5].

C. Types of BLDC Motor Configurations

BLDC motors can be categorized based on several design and operational aspects. The most prevalent type is the three-phase motor, although singlephase and multi-phase configurations are also used in specialized applications. Another important classification concerns the winding connection— either Wye (star) or Delta. Wye-connected motors typically offer better low-speed torque and efficiency, while Delta-connected motors provide higher speed capabilities. Additionally, BLDC motors may be either sensor-based or sensorless. Sensor-based motors utilize physical devices like Hall sensors to detect rotor position, offering better control at low speeds. In contrast, sensorless designs estimate rotor position using voltage and current feedback, which simplifies construction and enhances reliability in rugged or cost-sensitive applications [6].

D. Control Challenges Despite their advantages,

BLDC motors present specific challenges in control and operation. One of the primary concerns is the accurate estimation of rotor position, especially in sensorless configurations where low-speed operation is particularly difficult. Another common issue is torque ripple, which can lead to vibration and acoustic noise in precision applications. Maintaining consistent speed under variable load conditions and managing the nonlinear dynamics associated with motor parameters like inductance, resistance, and back-EMF further complicate control. To address these challenges, advanced control strategies such as Proportional-Integral-Derivative (PID) control and Field-Oriented Control (FOC) are employed. These algorithms enhance performance by ensuring smooth torque delivery, improved transient response, and robust operation under varying conditions [7].

III. PROPOSED METHODOLOGY

- **SOLAR OPERATING EV**

A **solar operating electric vehicle** is a clean and energy-efficient transportation system that uses sunlight as its primary source of power. In this system, solar photovoltaic (PV) panels mounted on the vehicle or installed at an external solar charging station convert sunlight into direct current (DC) electricity. This energy is then regulated through an MPPT or PWM charge controller to safely charge the battery pack, which stores the electrical energy for later use. The stored power is supplied to a motor controller that regulates speed, torque, and acceleration, and finally drives a BLDC or PMDC motor to run the vehicle. By using solar energy, the vehicle reduces dependence on grid power and eliminates the need for fossil fuels, resulting in zero emissions and reduced operating cost. Solar EVs are especially useful in remote and rural areas due to their self-charging capability and low maintenance requirements. However, their performance depends heavily on sunlight availability, and the limited surface area of the vehicle restricts the amount of solar power that can be generated. Despite these challenges, solar operating electric vehicles represent a sustainable and promising future solution for clean transportation.

- **ANN-BASED PID TUNING**

ANN-based PID tuning for BLDC motor control integrates artificial intelligence with classical control to achieve more accurate, adaptive, and dynamic performance. In this approach, an Artificial Neural Network (ANN) is used to automatically tune the PID controller parameters (Kp, Ki, Kd) in real time based on system behavior, load variation, and operating conditions. Unlike conventional tuning methods such as Ziegler–Nichols or trial-and-error, the ANN continuously learns the relationship between error signals, motor speed, and control output. It adjusts PID gains such that overshoot is minimized, settling time becomes shorter, and speed ripples are reduced. This adaptive capability is especially valuable for Brushless DC (BLDC) motors, which are nonlinear and sensitive to load torque, back-EMF characteristics, and switching harmonics. By combining ANN with PID, the controller becomes capable of predicting optimal gain values, compensating for disturbances, and maintaining smooth and stable speed control across different operating conditions. As a result, ANN-based PID control enhances BLDC motor performance in terms of efficiency, torque response, and precision, making it highly suitable for electric vehicles, robotics, renewable energy systems, and industrial automation [8-12].

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

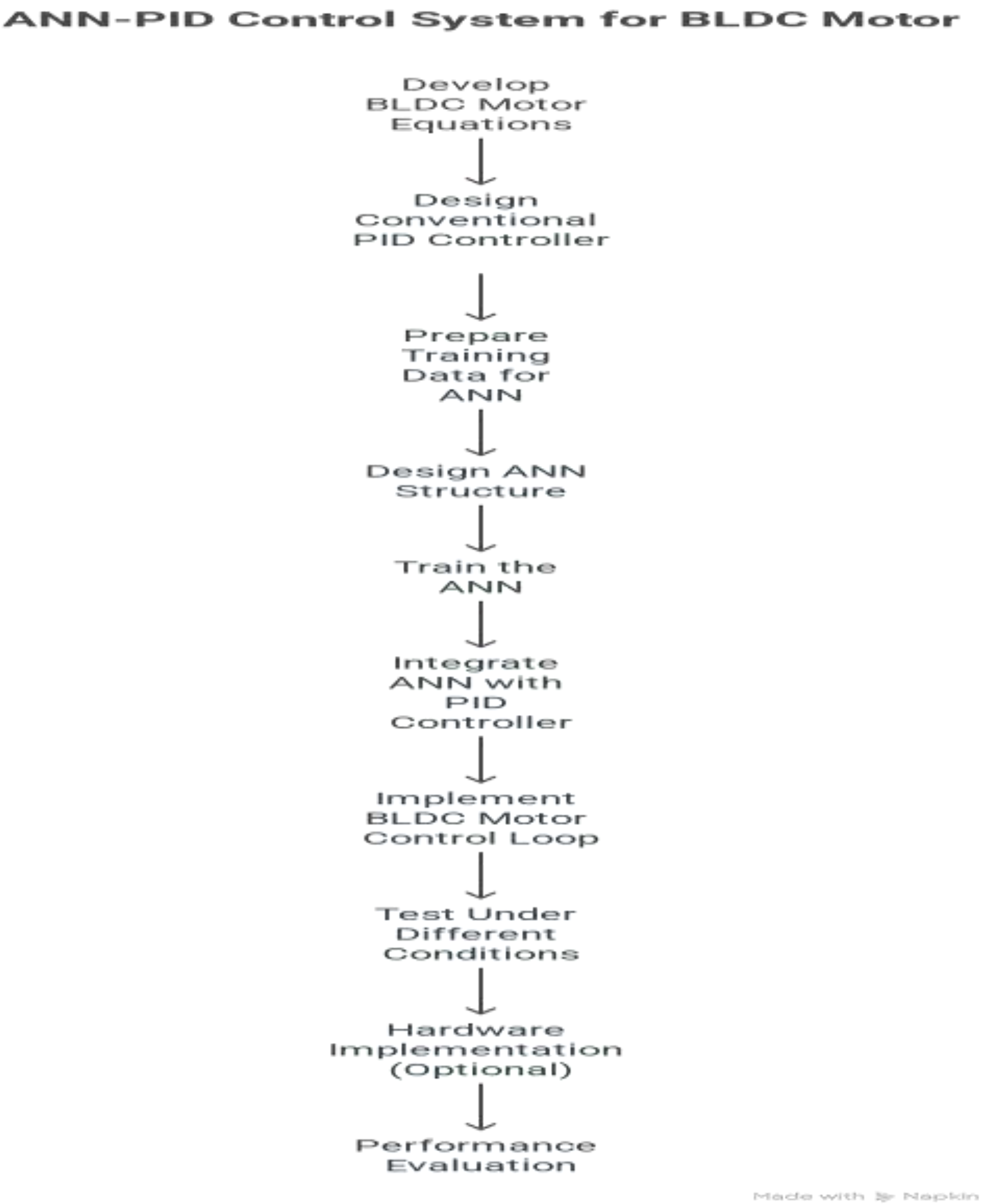

Fig 1. Proposed Tuning.

Artificial Neural Network (ANN) is a computational model inspired by the structure and functioning of the human brain. It consists of interconnected processing units called **neurons**, which work together to learn patterns, recognize relationships, and make predictions from data. ANNs learn by adjusting internal weights during training, allowing them to solve complex problems such as classification, prediction, control, and optimization. Because of their ability to learn from experience and adapt to new inputs, ANNs are widely used in control systems, signal processing, robotics, image recognition, and intelligent decision-making applications.

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

IV. RESULT AND SIMULATION

By comparing the performance of a permanent-magnet brushless dc motor with a PID controller, it is established that the PID response provides great efficiency. Because of its great efficiency, it produces more torque at low speeds, has a better power density, requires less maintenance, and emits less noise than other motors. In this research, closed loop speed control of a BLDC motor drive using a PID controller loop is shown and compared to a PI controller fed BLDC drive. The simulation results demonstrate that current and torque ripple are reduced, which improves the drive's performance. The results reveal that the motor's dynamic performance is excellent under a variety of loading scenarios.

PI CONTROLLER

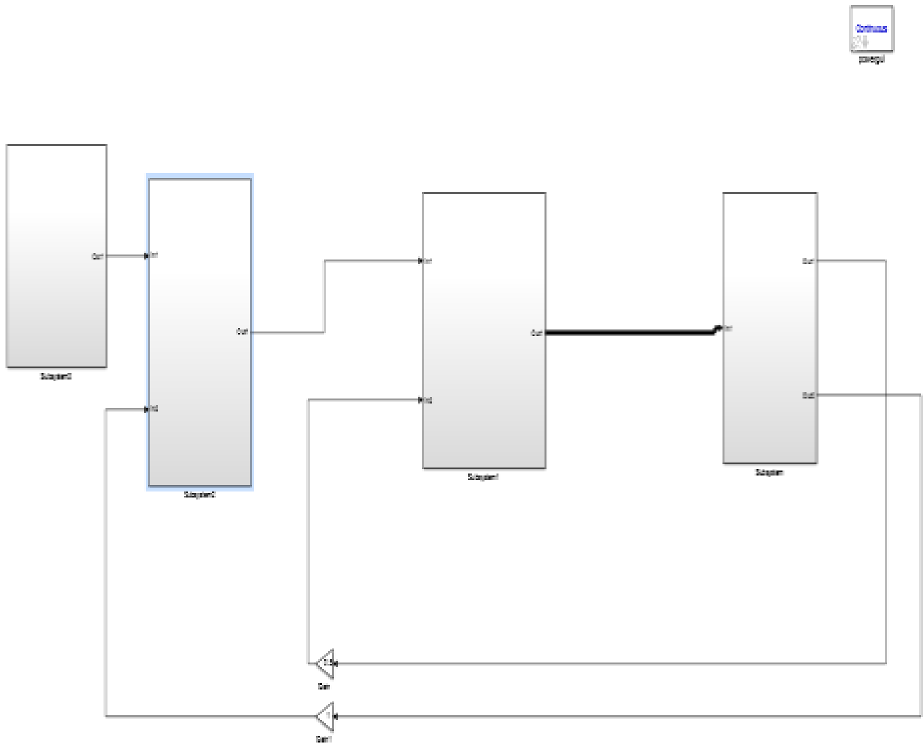

Fig. 2 PID based MATLAB 2015A modelling.

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

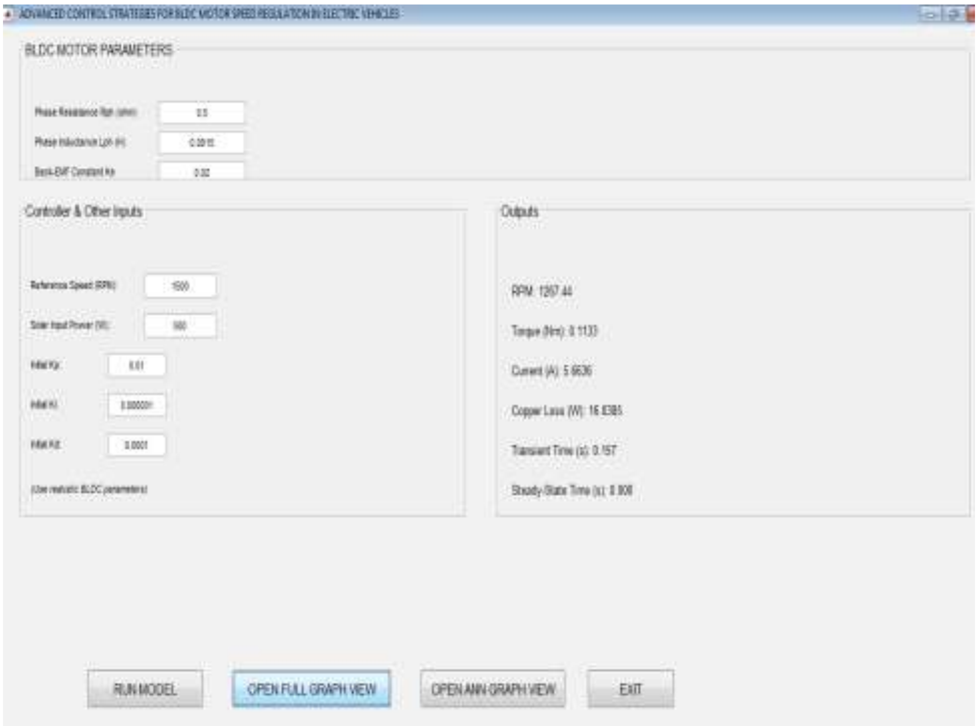

Fig. 3 Parameters Window.

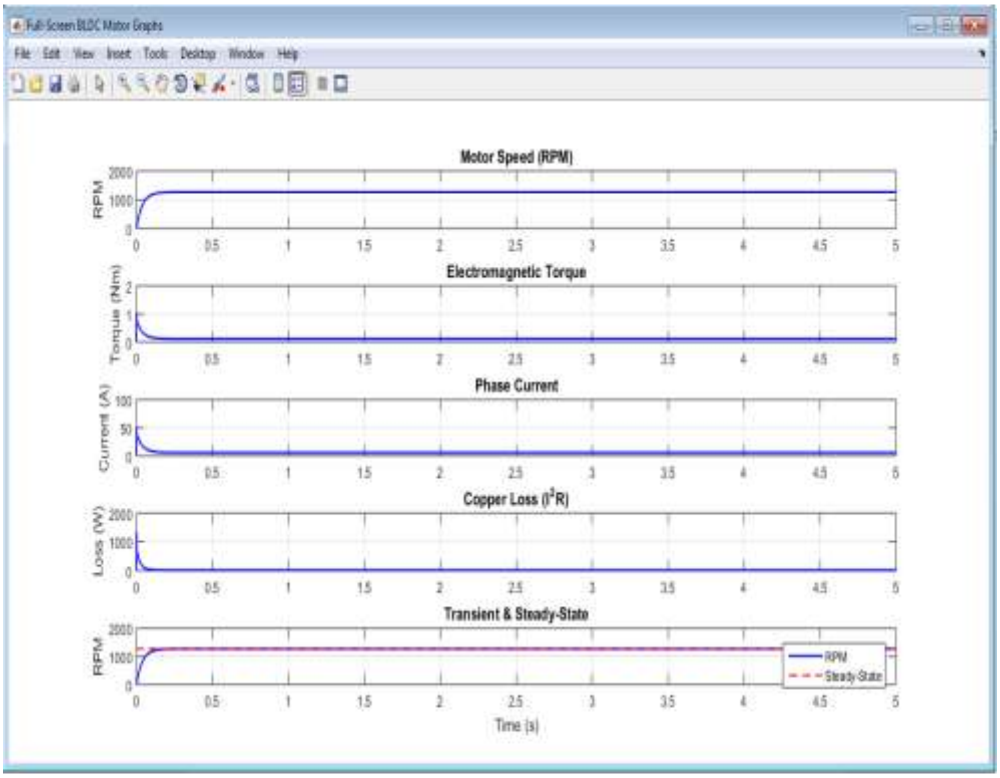

Fig. 4 Output Parameters.

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

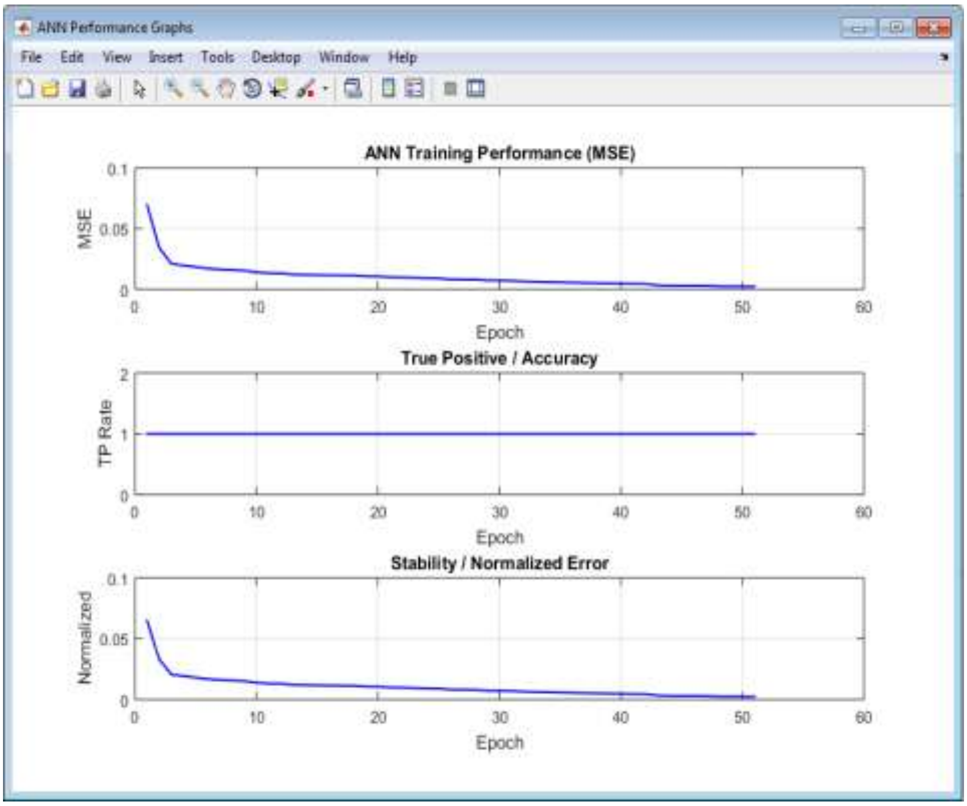

Fig.5 ANN outcomes.

V. CONCLUSION AND FUTURE SCOPE

CONCLUSION

The study demonstrates that the use of advanced control algorithms significantly enhances the speed regulation performance of Brushless DC (BLDC) motors used in modern electric vehicles. Conventional PI/PID controllers, although simple and widely used, show limitations under varying load, sudden acceleration demands, parameter uncertainties, and nonlinear motor characteristics. In contrast, advanced techniques such as Neural Network-based Control offer far superior dynamic behavior.

The results confirm that these modern controllers provide:

- ✔ Faster transient response
- ✔ Lower steady-state error
- ✔ Improved torque ripple reduction
- ✔ Better robustness against disturbances and parameter variations
- ✔ Higher efficiency in low-speed and high-load conditions
- ✔ Enhanced regenerative braking performance

The findings conclude that integrating advanced intelligent control methods into BLDC motor drive systems substantially improves the efficiency, responsiveness, and reliability of electric vehicles. These control strategies not only meet the growing demand for precise speed

International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

regulation but also contribute to enhanced vehicle performance, energy savings, and longer battery life—making them highly suitable for next-generation EV applications.

Future Scope

Future research on advanced control strategies for BLDC motor speed regulation in electric vehicles can focus on integrating AI-driven adaptive controllers, which can automatically tune control parameters in real time based on driving conditions, battery state, and load variations. The use of deep learning, reinforcement learning, and predictive analytics can further enhance decision-making and optimize torque–speed profiles under dynamic environments. Additionally, the combination of IoT-enabled monitoring, digital twins, and cloud-based control diagnostics offers opportunities for remote performance tracking and predictive maintenance. Future work may also explore high-efficiency inverter topologies, wide-bandgap semiconductor devices (SiC/GaN), and sensorless control algorithms to reduce hardware cost and improve reliability. With the rising adoption of autonomous and connected EVs, developing more robust, fault-tolerant, and cybersecurity-resilient BLDC control systems will become crucial. Overall, there remains significant potential to make BLDC motor drives smarter, more efficient, and more sustainable for next-generation electric vehicles.

REFERENCE

[1] Usha, S., Geetha, P., Geetha, A., Palanisamy, R., & Choudhury, S. (2025). Enhanced Battery Charging Efficiency using Torque Hysteresis Controlled BLDC Motor Drive for Electric Vehicle. Energy Storage and Saving.

[2] Naqvi, S. S. A., Jamil, H., Iqbal, N., Khan, S., Lee, D. I., Park, Y. C., & Kim, D. H. (2024). Multi-objective optimization of PI controller for BLDC motor speed control and energy saving in Electric Vehicles: A constrained swarm-based approach. Energy Reports, 12, 402-417.

[3] Prabhu, N., Thirumalaivasan, R., & Ashok, B. (2024). Design of sliding mode controller with improved reaching law through self-learning strategy to mitigate the torque ripple in BLDC motor for electric vehicles. Computers and Electrical Engineering, 118, 109438.

[4] Subbarao, M., Dasari, K., Duvvuri, S. S., Prasad, K. R. K. V., Narendra, B. K., & Krishna, V. M. (2024). Design, control and performance comparison of PI and ANFIS controllers for BLDC motor driven electric vehicles. Measurement: Sensors, 31, 101001.

[5] Baz, R., El Majdoub, K., Giri, F., & Taouni, A. (2022). Self-tuning fuzzy PID speed controller for quarter electric vehicle driven by In-wheel BLDC motor and Pacejka's tire model. IFAC-PapersOnLine, 55(12), 598-603.

[6] Baz, R., El Majdoub, K., Giri, F., & Ammari, O. (2024). Fine-tuning quarter vehicle performance: PSO-optimized fuzzy PID controller for in-wheel BLDC motor systems. IFAC-PapersOnLine, 58(13), 715-720.

[7] Ammari, O., Majdoub, K. E., Giri, F., & Baz, R. (2024). Modeling and control design for half electric vehicle with wheel BLDC actuator and Pacejka's tire. Computers and Electrical Engineering, 116, 109163.

[8] Bharathi, M. L. (2022). Extraction of maximum power from solar with BLDC motor driven electric vehicles based HHO algorithm. Advances in Engineering Software, 170, 103137.

[9] Hannan, N., Shib, S. K., Shufian, A., Islam, M. A., Sharan, S. M. I., & Gupta, A. D. (2025). Advanced Regenerative Braking System for EVs: Leveraging BLDC-Supercapacitor Technologies for Optimized Energy Recovery, Economic Viability, and Maintenance Strategies. Future Batteries, 100103.
[10] Hasanhendoei, G. R., Afjei, E., Naseri, M., & Azad, S. (2023). Automatic and real time phase advancing in BLDC motor by employing an electronic governor for a desired speed-torque/angle profile. e-Prime-Advances in Electrical Engineering, Electronics and Energy, 4, 100111.
[11] P. Hari Krishnan, Control of BLDC motor based on adaptive fuzzy logic PID controller, 2014 International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE), 978-1-4799-4982-3.
[12] Pranoti K. Khanke, Comparative analysis of speed control of BLDC motor using PI, simple FLC and Fuzzy - PI controller, 2015 International Conference on Energy Systems and Applications, 978-1-4673-6817-9.
[13] S. Wongkhead, State Space Model for BLDC Motor Based on Digital Sigal Processors TMS320F28335 for Speed Control by Using Proportional Integral Controller, 2019 7th International Electrical Engineering Congress (iEECON), 978-1-7281-0729-5.
[14] Md Mahmud, Utilizing of Flower Pollination Algorithm for Brushless DC Motor Speed Controller, 2020 Emerging Technology in Computing, Communication and Electronics (ETCCE), 978-1-6654-1962-8.
[15] Ramesh Devarapalli, Application of a Novel Political Optimization in Optimal Parameter Design of PI Controller for the BLDC motor Speed Control, 2020 International Conference on Emerging Frontiers in Electrical and Electronic Technologies (ICEFEET), 978-1-7281-7549-2.