IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834, p- ISSN: 2278-8735.Volume 21, Issue 4, Ser. 1 (July – August 2026), PP 28-31
www.iosrjournals.org

Control Techniques For BLDC Motors In Electric Vehicles: Progress, Challenges, And Research Opportunities

Author

Abstract
Recent advances in electric vehicle (EV) propulsion have triggered a growing interest in developing efficient, reliable, and controlled electric drives. Brushless DC (BLDC) motors are gaining increasing importance in the field of EVs due to their high efficiency, compact design, high torque, and low maintenance. At the same time, the development of advanced control strategies capable of handling the challenging requirements, including speed, torque, energy efficiency, and reliability, remains a critical task. This article reviews recent developments in BLDC motor control strategies for EVs. A particular emphasis is placed on proportional-integral (PI) and proportional-integral-derivative (PID) regulators, pulse-width modulation (PWM), sensorless control, fuzzy logic, adaptive control, sliding-mode control, model predictive control, and artificial intelligence. In addition, the main challenges in torque ripple minimization, parameter variations, computational complexity, and reliability are discussed in detail. Finally, the emerging research trends from 2021 to 2023 are identified and highlighted.
Keywords: *Brushless DC motors, electric vehicle, motor control, sensorless control, artificial intelligence, torque ripple reduction, model predictive control*

Date of Submission: 27-07-2026 Date of Acceptance: 07-08-2026

I. Introduction

The emerging trends towards sustainable transport have intensified scientific and industrial efforts to develop new vehicle powertrain solutions, which are environmentally friendly and economically viable. Among these alternatives, battery electric vehicles (BEVs) are considered as one of the most promising solutions for passenger cars, commercial vehicles, light buses, and even heavy-duty trucks. The drive system concept plays a crucial role in determining the overall energy efficiency and reliability of BEVs. The brushless DC (BLDC) motor drive has been identified as a favorable solution due to its high energy density, compact size, high efficiency, and minimal maintenance requirements [1].

BLDC motors typically use a permanent magnet synchronous design in which the rotor magnetic field is generated by permanent magnets mounted on the rotor surface. Mechanical commutation is replaced by electronic commutation, resulting in reduced maintenance and high efficiency [2]. These advantages open the possibility for a wide range of BLDC motor applications, from small E-bikes and E-scooters to transportation vehicles for commercial purposes.

Nevertheless, the operating conditions of the motor in EVs involve highly dynamic processes related to acceleration/deceleration and varying road loads. Thus, the conventional approaches to motor speed control cannot always guarantee the required performance and ride comfort. Moreover, the control system should provide stable torque, address nonlinearities and imbalances in a rotating mechanism, and ensure reliable operation despite parameter variations and unmodeled dynamics [3]. Therefore, there is an emergent need to implement novel, smart, and self-learning algorithms for achieving the required torque response and energy efficiency while maintaining system reliability and minimizing maintenance.

This review article discusses recent trends in BLDC motor control strategies for EVs. In particular, it presents an overview of conventional control algorithms, including pulse-width modulation (PWM), proportional-integral (PI) and proportional-integral-derivative (PID) regulators, sensorless control concepts, and fuzzy logic controllers. In addition, such advanced strategies as adaptive control, sliding-mode control, robust control, and model predictive control are discussed. Finally, promising research directions such as artificial intelligence, digital twins [4], and wide bandgap power electronics are identified.

II. BLDC Motor Drive Topology

The majority of BEVs have a standard propulsion system comprising the traction battery, power converter, motor controller, BLDC motor, and reduction gear. The controller regulates the power electronics inverter in accordance with the given motor torque and speed command to meet the driver demand. BLDC motors have several advantages for EV applications as compared to other motor types, including high torque-to-weight ratios, high efficiency, maintenance-free operation, low cost, and a compact design [5]. For EVs, the key performance characteristics of BLDC motors are related to high torque density, wide constant power speed range, and high-efficiency operation. Thus, they are considered as one of the most attractive motor drives for low and medium power EVs [6]. At the same time, BLDC motors involve several distinctive challenges associated with torque ripple, parameter variations, and the need for advanced control algorithms to ensure stable and reliable operation [7].

III. Conventional BLDC Motor Control Approaches

PI/PID Regulators

PI/PID regulators are among the most common control laws used to regulate BLDC motor speed in a closed-loop system. The basic idea of PI/PID control is to continuously adjust the inverter switching frequency in accordance with the deviation between reference and measured motor speed [8]. In addition, the PID controllers usually involve a derivative term proportional to the rate of change of the error signal. Although PI/PD/PID controllers are simple to use, their performance largely depends on the choice of proportional and integral gains. In practice, the PID gains are usually tuned in real-time to address parameter variations and achieve the best performance [9].

PWM Modulation

In general, Pulse-Width Modulation (PWM) is an efficient method used to regulate the average voltage at the motor terminals. Specifically, PWM allows the inverter switches to be turned on and off in a specific pattern so that the resulting output voltage waveform has the desired shape [10]. Various PWM methods have been developed to reduce the harmonic content of the motor voltage/current spectra so that the torque ripple is minimized [11]. For instance, space vector PWMs have been widely applied to achieve the highest DC bus voltage utilization while providing a near-sinusoidal motor current waveform [12]. As a result, the voltage harmonics are minimized, and torque ripple is significantly reduced, which is critical for high-performance EV traction applications.

IV. Advanced BLDC Motor Control Approaches

Sensorless Control

Hall-effect sensors or optical encoders typically measure the rotor position in conventional BLDC motors. However, the use of these sensors involves additional costs and complexity. Therefore, there has been an increasing interest in developing sensorless control algorithms that allow estimating the rotor position on the basis of electrical quantities such as phase voltages and currents [13]. In particular, the back-EMF signal can be used to determine the zero-crossing instant, which further allows identifying the rotor position [14]. Nevertheless, the application of back-EMF-based observers is limited to high-speed motor operation since its magnitude is proportional to speed. More advanced observer techniques, such as sliding-mode observers, can provide accurate rotor position estimation at low and zero speeds [15].

Fuzzy Logic and Adaptive Control

Fuzzy logic controllers (FLCs) have been applied in various control systems to address nonlinearities and achieve the desired closed-loop response. The FLCs provide reliable performance by incorporating human expertise and operational rules. Fuzzy logic controllers have been applied to BLDC motor drives for speed control and torque estimation [16]. Generally, FLCs require extensive expert knowledge and system identification data to be effective. More advanced adaptive control methods can be used to handle parameter variations and achieve robust performance [17].

Sliding-Mode Control

Sliding-Mode Control (SMC) is a nonlinear control method largely used in robotics and mechatronics. SMC is well-known for its outstanding disturbance rejection ability and simple implementation algorithm [18]. The main idea of SMC is to design a switching surface such that the system state trajectories reach and slide along this surface, which results in a stable and accurate control system [19]. However, SMC suffers from uncontrollable switching oscillations at high frequencies, which are referred to as chattering [20]. Several modifications to the conventional SMC method have been proposed to address this issue and prevent torque ripples [21].

V. Model Predictive And Intelligent Approaches For BLDC Motor Control

Model Predictive Control

Model predictive control (MPC) has been increasingly used in various fields of engineering, from robotics to power systems. This control method has been applied to BLDC motors to enhance the system's tracking capability and power efficiency [22]. Generally, an MPC controller predicts the next state of the system and calculates the optimal control output by minimizing a predefined cost function. In particular, finite control set model predictive control (FCS-MPC) has been demonstrated as an efficient approach for torque control in BLDC motor drives [23]. Unlike conventional control methods, FCS-MPC directly calculates the optimal voltage vectors that should be applied to the motor inverter. Hence, it provides a faster dynamic response and superior torque-tracking capability as compared to traditional current controllers [24]. However, FCS-MPC requires intensive computation and advanced system modeling to be efficient.

Artificial Intelligence in Motor Control

The emerging progress in artificial intelligence (AI) has enabled researchers to develop new control systems for various applications, including EVs. In particular, AI algorithms, such as neural networks and deep learning, can be used to identify a set of rules related to torque, speed, and current of the BLDC motor [25]. In particular, AI can be used to train a neural network to estimate the motor torque and improve the estimation accuracy. Moreover, AI is a powerful tool that helps minimize the computational complexity of FCS-MPC and improve the closed-loop system response [26].

VI. Main Challenges Of BLDC Motor Drives In Evs

Although BLDC motors have several advantages over conventional brushed motors, there are still some challenges related to torque ripples, efficiency, parameter variations, and sensor reliability. First and foremost, torque ripples should be minimized to ensure ride comfort and reduce mechanical stress on rotating parts. Advanced control methods, including direct torque control and predictive control, have been proposed to address this issue [27].

In addition, motor efficiency should be maximized to achieve the longest driving range. In particular, battery energy should be optimized during acceleration, cruising, and regeneration to extend the driving range of EVs. Future research should also consider parameter variations and their impact on the control system [28]. Finally, advanced sensorless methods should be investigated to address the reliability issues associated with position and speed sensing [29].

VII. Research Trends And Future Directions

AI Enabled Autonomous Motor Control

Researchers continue to explore the possibility of using AI to develop autonomous and self-learning motor control algorithms. In particular, there is a growing interest in deep learning and reinforcement learning methods for achieving higher-level autonomy in EVs [30]. For instance, an autonomous motor control algorithm can be used for real-time speed/torque control and prediction while minimizing the computational burden. Future developments in this direction will include self-driving motor controllers, energy prediction, and torque optimization.

Digital Twin Modeling for Smart Motor Control

Another emerging direction is the use of digital twins in motor control applications to maximize system performance while minimizing maintenance costs. A digital twin is a virtual prototype that can be used to monitor and predict the performance of the physical system in real-time [31]. In the context of EV propulsion systems, digital twins can be used to optimize the operation of the traction motor and battery. Moreover, digital twins can also be used to predict mechanical degradation and support condition monitoring [32]. As a promising technology for smart and autonomous EVs, the concept of a digital twin can be further explored for advanced motor control applications.

Wide Bandgap Power Electronics

Power electronics play a critical role in the performance of the inverter and motor drive system. The emerging trends in power electronics include the growing use of wide bandgap semiconductor materials, such as silicon carbide and gallium nitride. The development of these advanced power semiconductor materials allows for higher switching frequencies, faster switching, and reduced conduction losses [33]. Hence, these materials can be used in conjunction with advanced motor control algorithms to design high-efficiency and compact power electronic converters and inverters.

Intelligent Vehicle Communication System

Vehicle communication systems are becoming an integral part of future autonomous vehicles. The latest developments in the field of information technology, including internet of things (IoT), cloud computing, and edge AI, will have a significant impact on future motor control systems [34]. For instance, the use of these emerging concepts can lead to new intelligent control solutions for real-time motor monitoring, autonomous driving, and vehicle-to-everything (V2X) communications.

VIII. Conclusion

The growing interest in electric transportation has led to an increasing number of research studies addressing the powertrain design, energy storage, and motor control systems. BLDC motors have become one of the most widely used motor drives due to their high efficiency, reliability, and compact size. Nonetheless, the control system should be advanced to achieve the desired speed response, torque characteristics, and power efficiency in various operating conditions. The review above provides a comprehensive summary of the latest developments in this field, including conventional approaches like PI/PID regulators and PWM modulation, as well as emerging approaches like sensorless control, artificial intelligence, and digital twins.

References

[1]. R. Krishnan, Permanent Magnet Synchronous And Brushless Dc Motor Drives. Boca Raton, Fl, Usa: Crc Press, 2010.

[2]. C. L. Xia, Permanent Magnet Brushless Dc Motor Drives And Controls. Hoboken, Nj, Usa: Wiley, 2012.

[3]. J. F. Gieras And M. Wing, Permanent Magnet Motor Technology: Design And Applications, 3rd Ed. Boca Raton, Fl, Usa: Crc Press, 2010.

[4]. M. Ehsani, Y. Gao, S. E. Gay, And A. Emadi, Modern Electric, Hybrid Electric, And Fuel Cell Vehicles. Boca Raton, Fl, Usa: Crc Press, 2018.

[5]. K. J. Åström And T. Hägglund, Advanced Pid Control. Research Triangle Park, Nc, Usa: Isa, 2006.

[6]. B. K. Bose, Modern Power Electronics And Ac Drives. Upper Saddle River, Nj, Usa: Prentice Hall, 2002.

[7]. J. Shao, D. Nolan, M. Teissier, And D. Swanson, "A Novel Microcontroller-Based Sensorless Brushless Dc Motor Drive For Automotive Fuel Pumps," Ieee Transactions On Industry Applications, Vol. 39, No. 6, Pp. 1734–1740, 2003.

[8]. P. P. Acarnley And J. F. Watson, "Review Of Position-Sensorless Operation Of Brushless Permanent-Magnet Machines," Ieee Transactions On Industrial Electronics, Vol. 53, No. 2, Pp. 352–362, 2006.

[9]. C. C. Lee, "Fuzzy Logic In Control Systems: Fuzzy Logic Controller—Part I," Ieee Transactions On Systems, Man, And Cybernetics, Vol. 20, No. 2, Pp. 404–418, 1990.

[10]. K. J. Åström And B. Wittenmark, Adaptive Control, 2nd Ed. Boston, Ma, Usa: Addison-Wesley, 1995.

[11]. V. Utkin, J. Guldner, And J. Shi, Sliding Mode Control In Electromechanical Systems. Boca Raton, Fl, Usa: Crc Press, 2009.

[12]. J. Rodriguez And P. Cortes, Predictive Control Of Power Converters And Electrical Drives. Chichester, U.K.: Wiley, 2012.

[13]. J. Rodriguez Et Al., "State Of The Art Of Finite Control Set Model Predictive Control In Power Electronics," Ieee Transactions On Industrial Informatics, Vol. 9, No. 2, Pp. 1003–1016, 2013.

[14]. S. Haykin, Neural Networks And Learning Machines, 3rd Ed. Pearson, 2009.

[15]. J. Kennedy And R. Eberhart, "Particle Swarm Optimization," In Proc. Ieee International Conference On Neural Networks, 1995, Pp. 1942–1948.

[16]. J. H. Song And I. Choy, "Commutation Torque Ripple Reduction In Brushless Dc Motor Drives Using A Single Dc Current Sensor," Ieee Transactions On Power Electronics, Vol. 19, No. 2, Pp. 312–319, 2004.

[17]. M. A. Hannan Et Al., "Review Of Energy Storage Systems For Electric Vehicle Applications," Renewable And Sustainable Energy Reviews, Vol. 69, Pp. 771–789, 2017.

[18]. R. Krishnan, Electric Motor Drives: Modeling, Analysis, And Control. Upper Saddle River, Nj, Usa: Prentice Hall, 2001.

[19]. R. S. Sutton And A. G. Barto, Reinforcement Learning: An Introduction, 2nd Ed. Mit Press, 2018.

[20]. F. Tao, H. Zhang, A. Liu, And A. Y. C. Nee, "Digital Twin In Industry: State-Of-The-Art," Ieee Transactions On Industrial Informatics, Vol. 15, No. 4, Pp. 2405–2415, 2019.

[21]. B. J. Baliga, Fundamentals Of Power Semiconductor Devices. Springer, 2008.

[22]. L. D. Xu, W. He, And S. Li, "Internet Of Things In Industries: A Survey," Ieee Transactions On Industrial Informatics, Vol. 10, No. 4, Pp. 2233–2243, 2014.