Comparative Analysis of Field Oriented Control and Trapezoidal Commutation for BLDC Motors in Light Electric Vehicles

***Abstract*—This paper compares Field-Oriented Control (FOC) and Trapezoidal commutation (Six-Step control) for BLDC motors in light electric vehicles. Both methods are compared and evaluated in terms of torque ripple, energy efficiency, implementation complexity, and dynamic response. Results show that FOC delivers smoother torque and higher efficiency, while Six-Step control offers simplicity, robustness, and lower hardware cost. The choice of control strategy depends on design priorities: high performance favors FOC, whereas cost-sensitive applications benefit from Trapezoidal commutation.**

***Index Terms*—brushless DC motors, six-step control, trapezoidal commutation, field-oriented control**

I. Introduction

Light electric vehicles (e-bikes, scooters) increasingly rely on brushless DC (BLDC) motors for their high efficiency, reliability, and low maintenance requirements [1], [2]. The choice of control strategy between Trapezoidal commutation (Six-Step) and Field-Oriented Control (FOC) is critical to balance performance, efficiency, simplicity, and cost, especially in low-tech oriented applications. This study provides a comparative analysis of these two control methods, focusing on objective technical criteria relevant to light electric vehicle propulsion. This paper aims to synthesize existing comparative studies by focusing on design trade-offs relevant to low-cost and low-tech light electric vehicle applications.

II. Modeling of BLDC Motor

The electromechanical model of a BLDC motor is foundational for understanding its behavior under different control schemes. BLDC motors are categorized by their back-electromotive force (back-EMF) waveform: trapezoidal or sinusoidal. This distinction is crucial, as the trapezoidal shape inherently leads to torque ripple when the supplied phase currents are not perfectly aligned, directly influencing the choice and effectiveness of the control strategy [3]. For a BLDC motor with trapezoidal back-EMF, the electromagnetic torque is given by:

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_m}$$

where e_x is the back-EMF and i_x is the phase current [4]. The classical d-q reference frame model, ideal for sinusoidal machines, is less suitable for trapezoidal BLDC motors because it assumes sinusoidal flux distribution. Phase-variable modeling in the natural (abc) frame is therefore more appropriate, as it directly accounts for the non-sinusoidal, trapezoidal nature of the back-EMF and the associated harmonics [5].

III. Trapezoidal Commutation (Six-Step Control) for BLDC Motors

Trapezoidal commutation, or Six-Step control, uses bipolar conduction, with two motor phases conducting at any time and current commutation occurring every 120 electrical degrees [2]. As commutation depends on rotor position, Six-Step control requires either position sensors (e.g. Hall sensors, encoders, or resolvers) or sensorless estimation based on back-EMF detection or observers [2], [6]. This method is renowned for its simplicity of implementation and low hardware cost [1]. It enables effective torque control but introduces significant torque ripple during commutation events, especially under high load [7]. This ripple generates noise, increases mechanical stress, and reduces overall efficiency [5]. Although PWM techniques can mitigate this ripple, they do not completely eliminate it [4].

IV. Field-Oriented Control (FOC) for BLDC Motors

FOC is a vector control strategy that decouples the stator flux and torque components. It transforms three-phase currents into orthogonal I_d and I_q components, enabling precise torque control and significant ripple reduction [7]. FOC is particularly effective for BLDC motors with sinusoidal back-EMF but can also be applied to trapezoidal back-EMF motors, albeit with less impressive ripple suppression results [4]. It requires greater computational power and more precise position sensors (e.g. encoders). Comparative analysis shows that FOC yields a more stable stator current profile and significantly reduces torque variations compared to trapezoidal control [3].

V. Comparative Analysis: FOC vs. Trapezoidal for Light Electric Vehicles

A. Torque Ripple and User Comfort

Firstly, torque ripple can be reduced for both control methods by selecting appropriate motor parameters, such as the number of stator slots and rotor poles [6]. FOC substantially reduces torque ripple compared to Six-Step control, directly enhancing ride comfort and minimizing vibrations. Experimental results show a torque ripple of $18.38\,\%$ for FOC versus $35.67\,\%$ for Six-Step control at $500\,\mathrm{RPM}$ [7]. Commutation torque ripple (CTR), prominent in Six-Step control, can be specifically targeted and mitigated using advanced control techniques like Model Predictive Control (MPC) while retaining the fundamental simplicity of trapezoidal commutation [5].

B. Energy Efficiency

FOC optimizes torque per ampere (MTPA), improving efficiency at low loads. Six-Step control exhibits lower switching losses at high speeds [4].

C. Complexity, Cost, and Low-Tech Suitability

Six-Step control is inherently simpler, cheaper, and more robust, making it a prime candidate for low-tech applications. Research focused on reducing propulsion system costs proposes simplified hardware topologies, such as 4-switch inverters (instead of 6) coupled with direct current control strategies, maintaining acceptable performance while significantly lowering hardware costs [8]. FOC, while superior in performance, is more complex to implement and carries higher hardware costs (sensors, processing power).

D. Dynamic Response

FOC provides faster response times and better load disturbance rejection [7].

VI. Conclusion

For light electric vehicles where low-tech priorities prevail, trapezoidal commutation remains a relevant solution due to its simplicity, low cost, and robustness. Hardware optimizations (reduced inverter topologies) and software improvements (predictive controllers targeting ripple) can enhance its performance without sacrificing its low-cost essence [5], [8]. FOC, while technically superior in performance, comfort, and efficiency, is more complex and costly to implement. The final choice depends on the designer's priorities: high performance and refined control (FOC) versus simplicity, ruggedness, and cost minimization (optimized Six-Step). The evolution of low-cost microcontrollers may eventually make FOC more accessible, but trapezoidal control will retain a distinct advantage for applications where extreme simplicity and reliability are paramount.

References

[1] H. Bhatiya, D. Patil, S. Makune, S. Kadam, V. Mahajan, and H. Vaidya, "BLDC motor trapezoidal regulation using hall effect sensor," in *2024 International Conference on Intelligent Systems and Advanced Applications (ICISAA)*, Oct. 2024, pp. 1–6. DOI: 10.1109/ICISAA62385.2024.10829278. Accessed: Dec. 17, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/10829278/.

[2] J. F. Gieras and J.-X. Shen, *Modern permanent magnet electric machines: theory and control*, First edition. Boca Raton: CRC Press, 2023, ISBN: 978-0-367-61058-6. DOI: 10.1201/9781003103073.

[3] H. Patil, S. Argade, A. Mulla, S. Bharambe, H. Barve, and R. Suryawanshi, "Analysis of FOC & trapezoidal method of PMSM motor for variable speed application," in *2025 6th International Conference for Emerging Technology (INCET)*, BELGAUM, India: IEEE, May 23, 2025, pp. 1–9, ISBN: 979-8-3315-1873-8 979-8-3315-3103-4. DOI: 10.1109/INCET64471.2025.11140901. Accessed: Dec. 27, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/11140901/.

[4] F. Li, W. Yao, and K. Lee, "Quantitative characteristic comparison between sensorless six step and field oriented control methods for permanent magnet brushless DC motors," in *2019 IEEE Energy Conversion Congress and Exposition (ECCE)*, ISSN: 2329-3748, Sep. 2019, pp. 1881–1885. DOI: 10.1109/ECCE.2019.8912478. Accessed: Dec. 17, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/8912478/.

[5] S. Mohammd Taher, A. Halvaei Niasar, and S. Abbas Taher, "A new MPC-based approach for torque ripple reduction in BLDC motor drive," in *2021 12th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)*, Tabriz, Iran: IEEE, Feb. 2, 2021, pp. 1–6, ISBN: 978-1-6654-0366-5. DOI: 10.1109/PEDSTC52094.2021.9405871. Accessed: Dec. 27, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/9405871/.

[6] L. Gasc, "Conception d'un actionneur à aimants permanents à faibles ondulations de couple pour assistance de direction automobile," Issue: 2004INPT043H, Theses, Institut National Polytechnique (Toulouse), Nov. 2004. Accessed: Jan. 2, 2026. [Online]. Available: https://hal.science/tel-04297384.

[7] J. Jomsa-Nga, P. Teesakul, W. Tanjaroen, and U. Supatti, "Torque ripple mitigation using field oriented control for BLDC in small electric vehicles," in *2024 IEEE International Smart Cities Conference (ISC2)*, ISSN: 2687-8860, Oct. 2024, pp. 1–6. DOI: 10.1109/ISC260477.2024.11004292. Accessed: Dec. 17, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/11004292/.

[8] B. Lee and M. Ehsani, "Advanced BLDC motor drive for low cost and high performance propulsion system in electric and hybrid vehicles," in *IEMDC 2001. IEEE International Electric Machines and Drives Conference (Cat. No.01EX485)*, Cambridge, MA, USA: IEEE, 2001, pp. 246–251, ISBN: 978-0-7803-7091-3. DOI: 10.1109/IEMDC.2001.939307. Accessed: Dec. 27, 2025. [Online]. Available: http://ieeexplore.ieee.org/document/939307/.