STM JOURNALS

International Journal of
Electrical Machine Analysis and Design

Volume 3, Issue 2, 2025
July–December
DOI (Journal): 10.37591/IJEMAD

https://journals.stmjournals.com/ijemad

Review IJEMAD

Torque Ripple Reduction Techniques in Switched Reluctance Motors: A Review

Vaibhav Godase[1],*, Swapnil Takale[1], Rahul Ghodake[1]

Abstract

Switched reluctance motors (SRMs) have emerged as a promising alternative to conventional motor technologies due to their rugged structure, low manufacturing cost, high-temperature capability, and suitability for harsh environments. Despite these advantages, the widespread adoption of SRMs in applications such as electric vehicles, household appliances, industrial drives, and aerospace systems is significantly restricted by the issue of torque ripple. Torque ripple manifests as periodic fluctuations in the developed electromagnetic torque, primarily arising from the motor's doubly salient geometry, non-linear magnetic characteristics, and discrete phase commutation. These fluctuations not only reduce the mechanical performance of the drive system but also increase acoustic noise, vibration, and component wear, thereby compromising overall system efficiency and user comfort. This review paper provides a comprehensive examination of the major torque ripple reduction techniques proposed in recent literature. The discussion covers structural design improvements, advanced control strategies, current profiling methods, converter-based enhancements, and emerging hybrid intelligent approaches. Each category is analyzed with respect to its operating principle, effectiveness, practical limitations, and applicability to modern SRM systems. The review highlights that while design-based solutions offer inherent improvements, control-oriented and intelligent techniques provide greater adaptability and superior dynamic performance. However, no single method offers a universal solution, underscoring the need for integrated approaches that combine machine design optimization, intelligent torque control, and advanced power electronics. The paper concludes by identifying key research challenges and outlining future directions aimed at enabling SRMs to achieve smoother torque production suitable for next-generation high-performance applications.

Keywords: Switched reluctance motor, torque ripple, acoustic noise, current profiling, torque-sharing function

INTRODUCTION

Switched reluctance motors (SRMs) have gained renewed global interest, as industries increasingly seek reliable, cost-effective, and energy-efficient motor solutions for modern applications. Characterized by a simple and rugged construction, absence of permanent magnets, and capability to operate under extreme temperature variations, SRMs offer several advantages over conventional motor types, such as induction motors and permanent magnet synchronous machines [1–5]. These attributes have positioned SRMs as a preferred choice in sectors such as electric mobility, household appliances, renewable energy systems, industrial automation, and aerospace actuation. Their fault-tolerant capabilities and reduced dependency on rare-earth materials further enhance their relevance in the context of global sustainability and supply chain constraints.

***Author for Correspondence**
Vaibhav Godase
E-mail: vaibbhavgodse@gmail.com

[1]Assistant Professor, Department of Electronics and Telecommunication Engineering SKN Sinhgad College of Engineering, Pandharpur, Solapur, Maharashtra, India

Received Date: December 02, 2025
Accepted Date: December 06, 2025
Published Date: December 31, 2025

Citation: Vaibhav Godase, Swapnil Takale, Rahul Ghodake. Torque Ripple Reduction Techniques in Switched Reluctance Motors: A Review. International Journal of Electrical Machine Analysis and Design. 2025; 3(2): 45-50p.

Despite these merits, the commercial adoption of SRMs faces a significant barrier in terms of torque ripple. Torque ripple refers to the periodic variation in the electromagnetic torque during motor operation, primarily resulting from the doubly salient structure of the SRM, non-linear magnetic saturation, and discrete phase commutation. These variations lead to undesirable consequences, such as acoustic noise, mechanical vibration, increased wear of components, and reduced drive smoothness. For instance, in electric vehicle applications, excessive torque ripples can degrade ride quality and user experience, whereas in industrial drives, they may limit precision and efficiency. Consequently, torque ripple reduction remains a central research challenge in the development of high-performance SRM drives [6–12].

Over the past two decades, researchers have proposed various strategies to address this challenge. These include geometric modifications aimed at smoothing the inductance profile, sophisticated control strategies such as torque-sharing functions and model predictive control, current profiling techniques that tailor the excitation waveform, and converter-based improvements for finer current regulation. More recently, machine-learning-based methods and hybrid optimization approaches have shown promise in achieving adaptive and real-time torque ripple suppression [13–20].

Given the breadth of research and rapid advancements in control and power electronics, there is a strong need for a consolidated, up-to-date review of torque ripple reduction techniques. This paper aims to fill this gap by critically examining the major approaches reported in contemporary literature and analyzing their operating principles, strengths, limitations, and practical applicability. By synthesizing these findings, this study provides a comprehensive understanding of existing solutions and highlights potential avenues for developing next-generation SRM drives capable of achieving smoother, quieter, and more efficient operation.

LITERATURE REVIEW

Over the past two decades, research on SRMs has increasingly focused on addressing the torque ripple, which remains the most critical barrier preventing their widespread industrial adoption. Early foundational studies emphasized the structural origins of the torque ripple, highlighting how the doubly salient geometry of the stator and rotor, combined with non-linear magnetic behavior, produces abrupt variations in inductance as the rotor moves between aligned and unaligned positions. This discovery motivated initial research efforts toward machine design-based solutions intended to alter inherent torque production characteristics [21–24].

Machine design modifications have been extensively explored as a means of achieving smoother inductance profiles and reducing abrupt torque transitions inherent in SRMs. One of the earliest strategies involved reshaping rotor and stator poles through chamfering, notching, and tapering. These geometric alterations aim to linearize the inductance curve and reduce the sharp rise and fall of magnetic attraction forces. Studies have demonstrated that such modifications can significantly lower the torque ripple without increasing control complexity. Moreover, the introduction of asymmetric air gaps and high-permeability magnetic materials has been shown to mitigate the magnetic saturation and provide a more uniform torque output. Although these structural approaches offer inherent and permanent benefits, they often require extensive redesign and incur increased manufacturing costs.

Parallel to structural efforts, control-based torque ripple reduction methods have emerged as the most widely adopted and practically flexible solution. Torque-sharing functions (TSFs) have become central to modern SRM control, enabling smoother transitions of torque contribution between the outgoing and incoming phases during commutation. Numerous variations of TSFs, including linear, exponential, cosine-shaped, and adaptive forms, have been proposed to distribute torque more evenly across phases. Additionally, advanced strategies, such as direct instantaneous torque control and model predictive control, have further refined torque regulation by incorporating real-time torque estimation and predictive adjustment of phase currents. These methods have demonstrated improved performance under dynamic conditions, although their effectiveness tends to be sensitive to modeling accuracy and computational resources [25–28].

Current profiling represents another important research direction, in which the phase-current waveform is shaped to align with the motor's torque–inductance relationship. By departing from conventional rectangular excitation pulses, the shaped or overlapped current profiles significantly enhance torque continuity. However, these approaches may increase the current demand at certain rotor positions, which can affect efficiency and thermal performance [29, 30].

In recent years, converter-based techniques have gained attention owing to advancements in power electronics. Asymmetric half-bridge converters, multilevel inverters, and soft-switching schemes have improved the precision of the current control and reduced switching-induced torque disturbances. Coupled with this, intelligent techniques, such as fuzzy logic control, neural networks, genetic algorithms, and digital twin assisted optimization, represent the latest wave of research. These methods enable adaptive torque ripple minimization under varying load, speed, and temperature conditions.

SYSTEM OVERVIEW OF SRM TORQUE PRODUCTION

Torque production in an SRM is governed by the principle of variable reluctance, where energized stator phases draw the rotor toward positions of minimum magnetic reluctance. The sequential excitation of the phases generates torque in discrete steps, inherently introducing a torque ripple. The nonsinusoidal inductance profile of the SRM, combined with magnetic saturation, leads to an uneven torque output. Moreover, the torque ripple becomes most significant during the commutation interval when one phase hands over torque production to the next, and mismatches in the current overlap cause abrupt torque transitions. To support the understanding of the operating fundamentals of the machine, a conceptual diagram of a typical SRM is presented below. Figure 1 illustrates the stator poles, rotor poles, and phase arrangement responsible for the distinct torque production mechanism.

These structural characteristics contribute to the robustness of the machine but also amplify the torque ripple. As the operating speed increases, the current regulation time decreases, worsening the commutation overlap and complicating the ripple mitigation. Therefore, addressing the torque ripple requires a combination of machine design refinement and advanced current/torque control techniques.

METHODOLOGY

The methodology adopted in this review is designed to systematically evaluate the breadth of research related to torque ripple reduction in SRMs. To ensure comprehensive coverage, this study utilized a structured multistage approach. The first stage involved an extensive search of reputable scientific databases, including Scopus, IEEE Xplore, ScienceDirect, and the IET Digital Library, focusing on articles published between 2014 and 2024. This period was selected to capture contemporary developments in machine design, control strategies, power electronics, and artificial intelligence

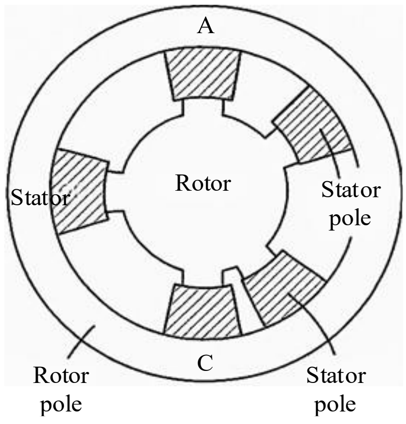

Figure 1. Basic structure of a switched reluctance motor.

techniques relevant to SRM torque ripple mitigation. Only peer-reviewed journal articles and conference papers that specifically addressed torque ripple, torque smoothing, and commutation-related challenges in SRMs were considered for inclusion.

Following the initial screening, the selected literature was evaluated based on relevance, clarity of methodology, and presence of experimentally validated or simulation-supported results. The shortlisted studies were then examined in detail to identify the underlying principles, implementation methodologies, performance characteristics, and limitations of each proposed technique. To facilitate structured understanding, the reviewed techniques were organized into five major categories: machine design enhancements, control-oriented approaches, current profiling techniques, converter-based improvements, and hybrid intelligent solutions. Each category was analyzed to determine the extent to which it contributes to torque ripple reduction and its suitability for real-world SRM applications. In addition to classification, the methodology involved a comparative assessment of the techniques using key performance indicators, such as torque ripple reduction percentage, computational complexity, hardware requirements, and applicability across different operating conditions. Studies that presented innovative concepts or demonstrated significant improvements in dynamic environments were closely examined to understand their potential for future SRM development.

Through this systematic and analytical process, this review provides a coherent synthesis of existing research, enabling the identification of dominant trends and persistent challenges. Methodological rigor ensures that the findings are comprehensive, unbiased, and reflective of the current advancements in SRM torque ripple reduction.

COMPARATIVE DISCUSSION

A comparison of existing torque ripple reduction techniques reveals that each category offers distinct strengths. Machine design strategies produce permanent improvements by smoothing magnetic flux transitions and reducing saturation effects, but these require modifications to the motor geometry and cannot be easily applied to pre-existing systems. Control-based techniques, such as advanced TSFs and predictive controllers, offer greater adaptability and can be implemented through software, making them suitable for a wide range of applications. However, their performance diminishes at high speeds, and current regulation becomes challenging.

Current profiling approaches create smoother torque output by shaping the current waveform, although this sometimes increases the current demand and reduces efficiency (Figure 2). Converter-based improvements provide enhanced current regulation and reduced switching distortion but increase hardware costs and complexity owing to additional power electronic components. Hybrid intelligent methods that combine AI, optimization algorithms, and adaptive control deliver the most significant reduction in torque ripple and the best performance under dynamic load and speed conditions. However, their computational demands and reliance on data present practical challenges. To visualize the relationship between these methods, the following Figure 1 provides a conceptual comparison of the relative effectiveness, complexity, and adaptability of the different classes of ripple reduction techniques.

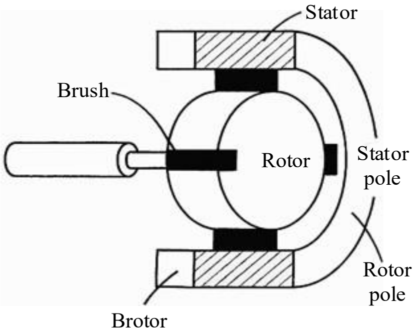

Figure 2. Comparative illustration of torque ripple reduction approaches.

CONCLUSION

This paper provides a comprehensive review of torque ripple reduction techniques in SRMs. No single approach provides a universal solution. Machine design improvements offer permanent structural benefits but lack flexibility. Control-oriented techniques, such as TSFs and model predictive control, show promising performance, especially when combined with current profiling. Emerging approaches, such as artificial intelligence, digital twins, and adaptive controllers, provide the most significant improvements under dynamic conditions. For future research, integrating AI-driven torque control**,** advanced magnetic materials**,** and low-noise converter topologies represents a crucial direction for developing next-generation high-performance SRMs that are suitable for electric vehicles and industrial applications.

REFERENCES

1. Godase V, Pawar P, Nagane S, Kumbhar S. Automatic railway horn system using NodeMCU. J Control Instrum. 2024;15(1):11–19.
2. Godase V, Godase J. Diet prediction and feature importance of gut microbiome using machine learning. Evol Electr Electron Eng. 2024;5(2):214–219.
3. Jamadade VK, Ghodke MG, Katakdhond SS, Godase V. A comprehensive review on scalable Arduino radar platform for real-time object detection and mapping. SSRN Electron J. 2025. doi:10.2139/ssrn.5383814.
4. Godase VV. A comprehensive study of revolutionizing EV charging with solar-powered wireless solutions. Adv Res Power Electron Devices. 2025 Jan–Apr;2(1):23–37.
5. Sharada AK, Kathiravan A, Mannam P, Akila D, Kumar BS, Godase VV. Advanced neural network models for optimal energy management in microgrids with integrated electric vehicles. 2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM), Kanyakumari, India. 2025. p. 1869–1874. doi:10.1109/ICTMIM65579.2025.10988248.
6. Velmurugan G, Bozhko S, Yang T. A review of torque ripple minimization techniques in switched reluctance machine. 2018 IEEE International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & International Transportation Electrification Conference (ESARS-ITEC), Nottingham, UK. 2018. p. 1–6. doi:10.1109/ESARS-ITEC.2018.8607614.
7. Shahgholian G, Sahafi AR, Faiz J. Torque ripple reduction in switched reluctance motors—A review. J Electromotion. 2015;22:35–56.
8. Wallace RS, Taylor DG. A balanced commutator for switched reluctance motors to reduce torque ripple. IEEE Trans Power Electron. 1992;7(4):617–626. doi:10.1109/63.163641.
9. Choi YK, Yoon HS, Koh CS. Pole-shape optimization of a switched-reluctance motor for torque ripple reduction. IEEE Trans Magn. 2007;43(4):1797–1800. doi:10.1109/TMAG.2006.892292.
10. Saleh AL, Al-Amyal F, Számel L. Control techniques of switched reluctance motors in electric vehicle applications: A review on torque ripple reduction strategies. AIMS Electron Electr Eng. 2024;8:104–145. doi:10.3934/electreng.2024005.
11. Ma C, Qu L, Mitra R, Pramod P, Islam R. Vibration and torque ripple reduction of switched reluctance motors through current profile optimization. 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA. 2016. p. 3279–3285. doi:10.1109/APEC.2016.7468336.
12. Kimpara MLM, Reis RRC, da Silva LEB, Pinto JOP, Fahimi B. A two-step control approach for torque ripple and vibration reduction in switched reluctance motor drives. IEEE Access. 2022;10:82106–82118. doi:10.1109/ACCESS.2022.3195493.
13. Abdel-Aziz A, Elgenedy M, Williams B. Review of switched reluctance motor converters and torque ripple minimisation techniques for electric vehicle applications. Energies. 2024;17(13):3263. doi:10.3390/en17133263.
14. Cai H, Wang H, Li M, Shen S, Feng Y, Zheng J. Torque ripple reduction for switched reluctance motor with optimized PWM control strategy. Energies. 2018;11(11):3215. doi:10.3390/en11113215.

15. Suryadevara R, Fernandes BG. Control techniques for torque ripple minimization in switched reluctance motor: An overview. 2013 IEEE 8th International Conference on Industrial and Information Systems, Peradeniya, Sri Lanka. 2013. p. 24–29. doi:10.1109/ICIInfS.2013.6731949.
16. Seshadri A, Lenin NC. Review based on losses, torque ripple, vibration and noise in switched reluctance motor. IET Electr Power Appl. 2020;14(8):1311–1326. doi:10.1049/iet-epa.2019.0251.
17. Rana AK, Teja AVR. A mathematical torque ripple minimization technique based on a nonlinear modulating factor for switched reluctance motor drives. IEEE Trans Ind Electron. 2022;69:1356–1366. doi:10.1109/TIE.2021.3063871.
18. Inanc N, Ozbulur V. Torque ripple minimization of a switched reluctance motor by using continuous sliding mode control technique. Electr Power Syst Res. 2003;66(3):241–251. doi:10.1016/S0378-7796(03)00093-2.
19. Sun X, Xiong Y, Yang J, Tian X. Torque ripple reduction for a 12/8 switched reluctance motor based on a novel sliding mode control strategy. IEEE Trans Transp Electr. 2023;9:359–369. doi:10.1109/TTE.2022.3161078.
20. Mikail R, Husain I, Sozer Y, Islam MS, Sebastian T. Torque-ripple minimization of switched reluctance machines through current profiling. IEEE Trans Ind Appl. 2013;49(3):1258–1267. doi:10.1109/TIA.2013.2252592.
21. Tariq I, Muzzammel R, Alqasmi U, Raza A. Artificial neural network-based control of switched reluctance motor for torque ripple reduction. Math Probl Eng. 2020;2020:9812715. doi:10.1155/2020/9812715.
22. Stankovic AM, Tadmor G, Coric ZJ, Agirman I. On torque ripple reduction in current-fed switched reluctance motors. IEEE Trans Ind Electron. 1999;46(1):177–183. doi:10.1109/41.744409.
23. Reddy PK, Ronanki D, Perumal P. Efficiency improvement and torque ripple minimisation of four-phase switched reluctance motor drive using new direct torque control strategy. IET Electr Power Appl. 2020;14(1):52–61. doi:10.1049/iet-epa.2019.0432.
24. Yang F, Chen H, Pires V, Martins J, Gorbounov Y, Li X, Orabi M. Improved direct torque control strategy for reducing torque ripple in switched reluctance motors. J Power Electron. 2022;22(4):603–613. doi:10.1007/s43236-021-00380-z.
25. Zhang X, Yang Q, Ma M, Lin Z, Yang S. A switched reluctance motor torque ripple reduction strategy with deadbeat current control and active thermal management. IEEE Trans Veh Technol. 2020;69(1):317–327. doi:10.1109/TVT.2019.2955218.
26. Hajatipour M, Farrokhi M. Adaptive intelligent speed control of switched reluctance motors with torque ripple reduction. Energy Convers Manag. 2008;49(5):1028–1038. doi:10.1016/j.enconman.2007.09.019.
27. Maksoud HA. Torque ripple minimization of a switched reluctance motor using a torque sharing function based on the overlap control technique. Eng Technol Appl Sci Res. 2020;10(2):5371–5376. doi:10.48084/etasr.3389.
28. Siadatan A, Roohisankestani M, Farhangian S. Design and simulation of a new switched reluctance motor with changes in the shape of stator and rotor to reduce torque ripple and comparison with the conventional motor. 2018 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Amalfi, Italy. 2018. p. 353–358. doi:10.1109/SPEEDAM.2018.8445245.
29. Jing B, Dang X, Liu Z, Ji J. Torque ripple suppression of switched reluctance motor with reference torque online correction. Machines. 2023;11(2):179. doi:10.3390/machines11020179.
30. Cheok AD, Fukuda Y. A new torque and flux control method for switched reluctance motor drives. IEEE Trans Power Electron. 2002;17(4):543–557. doi:10.1109/TPEL.2002.800968.