A Comprehensive Review of Control Techniques for Torque Ripple Reduction in Switched Reluctance Motor Drives for Evs

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Abstract : Electric Vehicles continue to advance, optimizing the performance and efficiency of their propulsion systems remains a critical focus. Switched Reluctance Motors have emerged as a promising candidate for EV applications due to their simple construction, magnet-free operation, robustness, and cost-effectiveness. However, SRMs face inherent challenges, particularly torque ripple and audible noise, which arise from their nonlinear characteristics and adversely affect overall performance and efficiency. Addressing torque ripple reduction is essential to improving SRM drive systems and making them more competitive with other motor technologies. This paper presents a comprehensive review of torque ripple minimization techniques in SRM-driven EV applications, categorizing and evaluating various mitigation strategies with a strong emphasis on control-oriented approaches. The review explores different torque control methods, assessing their effectiveness in suppressing torque ripple while analyzing fundamental SRM operations and excitation angle techniques. Furthermore, a comparative analysis of torque control strategies is conducted, highlighting their key features, torque ripple performance, and associated limitations.

Keywords: Switched Reluctance Motor; SRM Drive System; Torque Ripple Reduction Strategies; Electric Vehicle

1. INTRODUCTION

In response to growing concerns about environmental sustainability and the urgent need for energy-efficient transportation, Electric Vehicles (EVs) have emerged as a transformative solution to reduce the adverse effects of fossil fuel consumption [1]. The global automotive industry is continuously exploring innovative technologies to enhance efficiency, reduce emissions, and improve overall energy economy. Within an EV system, the electric motor plays a pivotal role, making the selection of an appropriate motor crucial to meeting the specific demands of EV applications. While permanent magnet synchronous motors have gained prominence due to their high efficiency and power density, their dependence on rare-earth materials poses significant challenges [2]. These challenges include the high cost of extraction and processing, limited global supply, environmental concerns, and the sensitivity of magnets to high temperatures, which can negatively impact motor performance under demanding automotive conditions.

To address these issues, there is a growing need to develop electric motors that eliminate reliance on rare-earth elements while maintaining high performance and efficiency for EV applications [3]. In this context, Switched Reluctance Motors (SRMs) have emerged as a viable alternative to conventional electric motors, offering a rare-earth-free solution. SRMs are characterized by their simple double-salient structure, low manufacturing and maintenance costs, and a rotor composed of laminated electrical steel [4]. Additionally, their independent concentrated windings provide inherent fault tolerance, enhancing reliability in demanding operational environments. Furthermore, SRMs exhibit exceptional versatility, operating efficiently across a wide range of speeds and temperatures, making them well-suited for variable-speed applications and harsh conditions [6].

However, despite these advantages, SRM performance is limited by inherent drawbacks such as high torque ripple and nonlinear magnetic characteristics, which arise from their double-salient structure and current switching mechanism. These factors reduce the motor's reliability and hinder its widespread adoption [7]. Moreover, achieving precise control using conventional methods remains challenging due to the influence of machine characteristics, converter configurations, and feedback variables.

To overcome these limitations, researchers have proposed various advanced control strategies aimed at improving SRM performance by minimizing torque ripple and acoustic noise, thereby enhancing efficiency and reliability in EV applications [8]. This paper provides a comprehensive review and evaluation of advanced control strategies for SRMs, with a primary focus on torque ripple mitigation techniques. The study categorizes and analyzes different control approaches, discussing their effectiveness, advantages, and limitations. The paper is organized as follows: Section 1 presents an overview of the SRM drive system, covering SRM fundamentals and its nonlinear modeling. Section 2 explores various control strategies employed in SRM drive systems. Section 3 introduces key torque ripple reduction techniques. Finally, Section 4 concludes the study, summarizing key findings and future research directions.

a. Modeling of SRM drive

An SRM exhibits highly nonlinear characteristics due to its doubly salient structure and switching current excitation. This inherent nonlinearity necessitates a nonlinear modeling approach to accurately predict its dynamic performance and analyze its magnetization characteristics. The mathematical model of an SRM is essential for evaluating these attributes. The voltage and flux linkage equations are given below:

$$V = I R + \frac{d\lambda\,(i,\theta)}{dt} \qquad \text{--------} \quad (1)$$

$$\lambda\,(I, \theta) = \int (V - I R)\ dt \qquad \text{--------} \quad (2)$$

Where, V is phase voltage , I is phase current, θ is rotor position , λ is flux linkage, R is winding resistance per phase

$$(I, \theta) = I * L\,(I, \theta) \qquad \text{--------} \quad (3)$$

The torque is calculated by replacing the flux linkage expression from Eq. 3 with Eq. 1, where phase inductance L. This results in:

$$T = \frac{1}{2} I^2 d\,L(I, \theta) / dt \qquad \text{--------} \quad (4)$$

The Simulink model for a single phase of an 8/6 SRM was developed using finite element methods (FEM) based on its magnetic flux linkage characteristics. Figure 2 illustrates the magnetic flux linkage, inductance, and torque characteristic curves at the aligned (0°) and unaligned (30°) rotor positions.

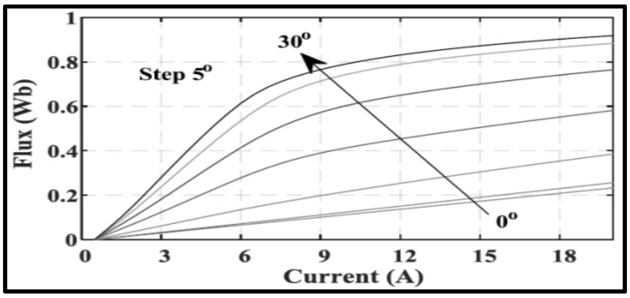

Fig.1 (a) The flux-position characteristics λ(i,θ

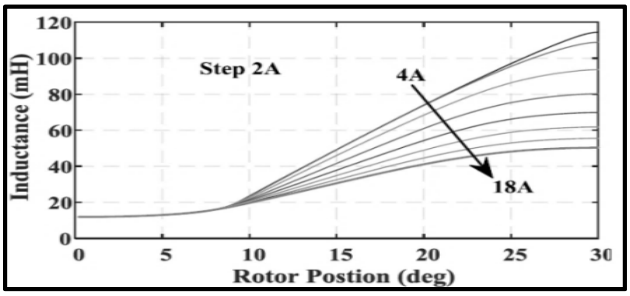

Fig.1(b) The inductance-position curves L(i,θ)

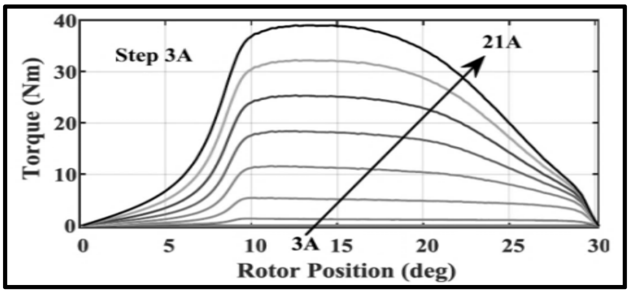

Fig1.(c) The torque-position characteristics T(i,θ)

b. Switching angles approaches

The excitation angles (θon, θoff) play a crucial role in SRM torque production by synchronizing excitation with the rotor position. These angles directly influence the current profile, torque generation, and overall SRM performance across different operating speeds. The excitation process typically involves three key parameters: the switch-on angle (θon), the switch-off angle (θoff), and the reference current (Iref) over a wide speed range [19]. To maximize SRM performance, the switching angles (θon, θoff) should be selected such that excitation occurs in the increasing inductance region (dL/dθ > 0) and de-energization takes place before entering the negative inductance region (dL/dθ < 0), thereby preventing negative torque generation, as illustrated in Figure 2. Consequently, these switching angles are critical parameters in SRM control [20]. However, due to the highly nonlinear nature of SRMs, optimizing these angles is challenging. Extensive research has been conducted to determine the optimal switching angles for improving SRM performance.

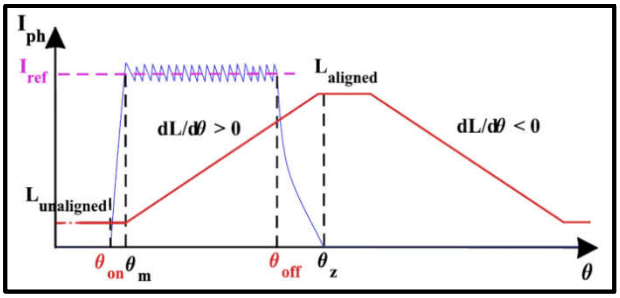

Fig. 2. Current waveform with Ideal inductance profile.

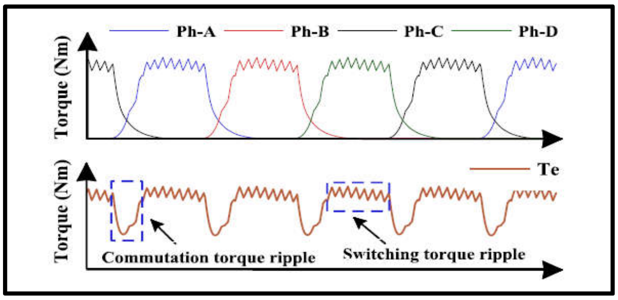

Fig.3. The torque ripple in phase torque and total torque waveforms.

2. TORQUE RIPPLE REDUCTION TECHNOLOGIES

Torque ripple is the primary limitation affecting the reliability of SRM drives in high-performance applications such as electric vehicles (EVs). It arises due to the doubly salient structure of the motor, which leads to highly nonlinear magnetic characteristics and discontinuous current commutation, as illustrated in Figure 3. These factors not only increase torque ripple but also complicate the control of SRM drives. Torque ripple mitigation can be achieved through two main approaches:

improving the machine's geometric design or implementing advanced control techniques. The optimal performance of an SRM drive system depends on multiple factors, including machine characteristics, control strategies, converter configurations, and feedback variables. However, the SRM drive system requires extensive feedback, necessitating at least one current sensor to measure motor current and a position sensor for rotor angle detection. Since torque generation is highly dependent on rotor position and switching current angles, these parameters can be stored in look-up tables to simplify control processing. In this context, we present a comprehensive categorization of control strategies aimed at mitigating torque ripple and enhancing the overall performance of SRM drives.

A. Indirect Torque Control (ITC)

1.Open loop current sharing

The open-loop current control technique is used to directly obtain the average torque from the phase current of the SRM. The fundamental principle involves computing the phase current profile offline to achieve zero torque ripple, relying on the system's ability to accurately track the predefined current waveform, as illustrated in Figure 4. This approach utilizes pre computed current values stored in a lookup table, I= f (T, θ) which are determined based on the rising and falling characteristics of the current for each operating condition. One of the key advantages of this method is its ability to minimize torque ripple, with its effectiveness primarily constrained by the switching frequency. Additionally, this technique enhances motor efficiency by optimizing current control. However, it also has notable drawbacks, particularly its sensitivity to variations in motor parameters, which can impact performance and stability.

In 2015, Mikail et al. [1] introduced a method for minimizing torque ripple by profiling phase currents while considering mutual coupling effects between conducting phases. This approach also accounted for sensor errors and manufacturing build variations, leading to improved performance in practical applications.

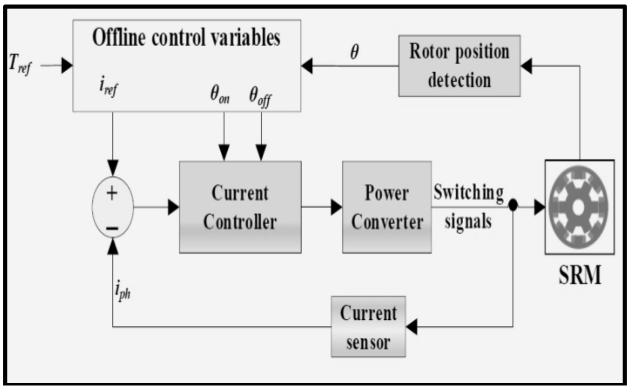

Fig.4. Open loop current sharing.

Building on this, in 2016, Ma et al. [2] proposed a differential evolution optimization-based current profiling technique, which effectively reduced torque ripple and vibration while offering lower computational costs compared to conventional finite element analysis-based methods. By 2017, Dúbravka et al. [3] developed a new current profiling method that demonstrated torque ripple minimization in both normal and open-phase fault conditions, making SRMs more resilient to faults compared to standard control methods. The focus on expanding the operating range continued in 2018, when Mehta et al. [4] introduced a current profiling algorithm designed for high-speed applications, enabling a wider speed range for low-ripple torque control. In the same year, Cai et al. [5] proposed an optimized PWM control strategy that significantly reduced torque ripple and copper loss while improving current tracing performance, all without increasing switching frequency or altering the hysteresis band. Advancements in acoustic noise and vibration reduction gained traction in 2019 when Kawa et al. [6] presented a novel current profiling method that minimized acoustic noise and vibration in hybrid electric vehicles without compromising efficiency, and in some cases, even enhancing it. Further developments in 2020 were made by Kusumi et al. [7], who introduced a phase-current waveform strategy that successfully reduced input current and torque ripples, improving the efficiency of low-power electric vehicle propulsion systems. More recent research has focused on refining torque ripple minimization techniques using enhanced torque distribution functions. In 2022, Ling et al. [8] proposed an improved torque distribution function method, which effectively suppressed torque ripple, reducing maximum torque fluctuation and keeping average error within 1% compared to traditional direct torque control (DTC) methods. Lastly, Agrawal et al. [9] advanced torque ripple minimization efforts by developing a current profiling-based control strategy specifically designed for generating mode in SRM drives. Their approach not only reduced torque ripple but also maximized average torque and enhanced regenerative braking benefits, making it highly beneficial for electric vehicle applications.

2.Torque sharing function (TSF)

The Torque Sharing Function (TSF) is one of the most effective and widely used indirect control strategies for mitigating torque ripple in SRM drive systems. This approach utilizes the motor's static characteristics to distribute the total torque among the motor phases, as illustrated in Figure 5. The TSF generates a reference torque for each phase, which is then converted into a reference phase current using the inverse torque model (i−T−θ)of the SRM. A current controller, employing either hysteresis or PWM control, ensures that the feedback current accurately follows the reference current. To maintain a stable torque output from each phase, TSF regulates turn-on, turn-off, and overlap angles based on the rotor position, independently generating reference torque signals for each phase The TSF can be implemented using either a linear or nonlinear function. However, due to the inherently nonlinear characteristics of SRMs, the linear TSF approach is often less effective, as torque ripple remains highly sensitive to rotor position variations.

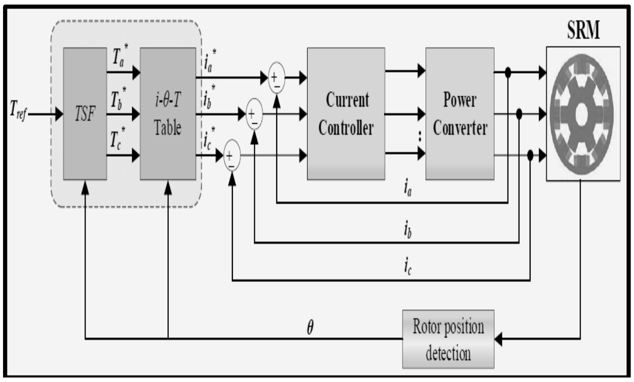

Fig.5. Ttorque control strategy based on TSF.

In 2015, Ye et al. [10] introduced an offline torque sharing function that effectively reduced torque ripple without increasing copper loss over a wide speed range. Later that year, Ye et al. [11] extended this work by developing an enhanced TSF, which not only minimized torque ripples but also increased the maximum torque-ripple-free speed, surpassing conventional TSF techniques. By 2019, Li et al. [12] proposed an offline TSF approach, which significantly improved torque ripple suppression while maintaining minimal copper losses. This method presented a viable alternative to conduction angle control at higher speeds, addressing a critical limitation of traditional SRM control strategies. Meanwhile, Hu et al. [13] introduced a novel TSF method that integrated predictive control, further refining torque ripple minimization and enhancing motor performance. In 2020, research on torque control strategies progressed further. Hamoudaa et al. [14] proposed an improved indirect instantaneous torque control strategy, specifically designed for electric vehicles (EVs), which not only reduced torque ripple but also improved efficiency and extended the operating speed range. Around the same time, Al-Amyal et al. [16] applied genetic algorithms to TSF, optimizing the function to minimize torque ripple and increase average torque, thereby reducing copper loss and improving system efficiency. By 2021, Xia et al. [17] refined TSF techniques further, presenting a new method that effectively reduced both torque ripple and copper losses, achieving lower current tracking error and improved torque-speed performance. Additionally, Li et al. [18] developed a high-performance indirect torque control strategy, which not only minimized torque ripple but also enhanced system efficiency and anti-disturbance capabilities, making it highly suitable for SRM-based electric vehicle applications. More advanced hybrid techniques emerged in 2022, when Al-Amyal et al. [19] introduced a hybrid TSF approach, which adapted to real-time operating conditions, utilizing a higher tracking capability during the magnetization period to effectively suppress torque ripples. The latest advancements in 2024 focus on combining TSF with indirect instantaneous torque control (ITC). Al Quraan et al. [20] proposed an improved TSF-ITC strategy, which effectively reduces torque ripple at medium and high speeds while enhancing efficiency and the torque-to-current ratio, making it a promising technique for high-performance SRM applications.

3.Average torque control (ATC)

Average Torque Control (ATC) is one of the most fundamental traditional torque control methods for SRM drive systems. Its primary advantage lies in maintaining a fixed reference phase current throughout the excitation cycle, allowing it to operate across a wide speed range while requiring only a constant reference torque and discrete rotor position However, ATC has notable drawbacks, particularly at low speeds, where it induces significant speed oscillations and fluctuations due to torque ripple during phase commutation. To achieve a constant average torque, this method retrieves phase torque values from a torque-sharing look-up table based on the reference current (iref), switch-on angle (θon), and switch-off angle (θoff), as illustrated in Figure 6. In this approach, the commanded torque is distributed across phases according to the reference current (iref) and motor speed (ωm), ensuring that current ripple is minimized to generate output torque with reduced ripple. Furthermore, for precise operation, key control parameters including reference current, turn-on angle, and turn-off angle can be optimized to enhance performance.

In 2015, Cheng et al. [21] introduced three novel control methods to optimize average torque control for electric vehicles, focusing on enhancing torque precision, process smoothness, and driving efficiency. These methods laid the foundation for further improvements in ATC-based SRM control strategies. By 2017, Jamil et al. [22] proposed an online average torque control algorithm that effectively stabilized system dynamics and achieved the desired average torque output by dynamically adjusting reference current and switching angles. This technique proved to be highly effective in light electric vehicle applications, ensuring better performance under varying load conditions. In 2018, Hamouda et al. [23] introduced a simplified structure ATC method, specifically designed to reduce torque ripple and improve efficiency in electric vehicles. This control strategy emphasized structural simplicity while maintaining robust torque performance, making it a practical approach for commercial SRM-based EVs. Further advancements were made in 2020, when Hamouda et al. [24] proposed an enhanced ATC-based control method that significantly reduced torque ripple while maintaining high efficiency and a superior torque-to-current ratio. This method also ensured fast dynamic response, making it well-suited for electric vehicle applications requiring rapid torque adjustments.

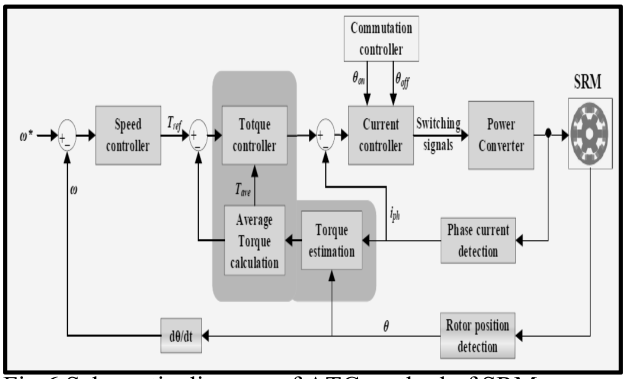

Fig.6. Schematic diagram of ATC method of SRM.

4.Vector control (field-oriented control)

The vector control strategy is extensively used in AC machines to enhance torque control performance, leveraging Park's transformation. Unfortunately, in the early development of SRM control techniques, no equivalent transformation was available to decouple position from flux-linkage and torque, even under linear conditions, as illustrated in Figure 7. However, in recent decades, field-oriented control (FOC) has been developed for SRMs based on the average value of the first-order inductance. A relationship between the qqq-axis current and torque has been derived, but only for unsaturated SRMs. In the vector control method for SRMs, a sinusoidal current with a DC offset is applied to each phase, creating a unipolar excitation current. This excitation comprises both DC and AC components, generating a virtual rotor flux and a rotating stator field, allowing SRMs to operate similarly to traditional AC machines. Notably, continuous current excitation in vector control has been shown to reduce vibration and acoustic noise in SRMs. However, the practical application of vector control in high-speed SRM operations remains limited due to uncertainties related to bus voltage, switching frequency, and inverter specifications required for implementing vector control in high-speed drives.

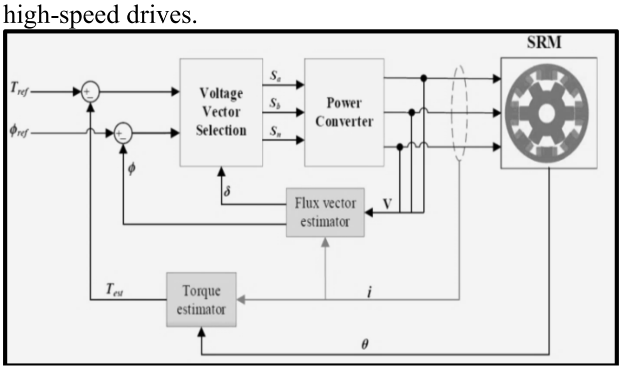

Fig.7. Vector control method of SRM.

In 2019, Ma et al. [25] introduced a 12-voltage vector control strategy for SRMs using a T-type three-level converter. This approach not only reduced torque ripple but also simplified the connection between the converter and the motor, improving overall drive performance. Around the same time, Kuai et al. [26] proposed an advanced current control method for SRMs, which effectively suppressed torque ripple and improved operational performance. However, the study noted a potential efficiency reduction when incorporating third harmonic current injection, highlighting a trade-off between torque ripple suppression and energy efficiency. By 2020, new strategies emerged focusing on rotor-stator design modifications. Dmitry S. et al. [27] presented a method for optimizing rotor-stator teeth ratios to achieve sinusoidal current flow in SRMs. This innovation enabled vector control of the electromagnetic moment, resulting in a more sinusoidal torque ripple profile, which significantly improved torque smoothness compared to traditional SRM configurations.

.B. Direct torque control

1. Direct Instantaneous Torque Control (DITC)

Recent advancements in instantaneous torque control (ITC) algorithms have significantly enhanced their effectiveness, making ITC a widely adopted solution for addressing the limitations of indirect torque control approaches. The key advantage of ITC lies in its direct consideration of instantaneous torque as a control variable, eliminating the need for torque-to-current conversion and closed-loop current control. Additionally, ITC offers rapid error elimination with excellent dynamic response while effectively minimizing torque ripple. The ITC scheme can be categorized into three main approaches: indirect ITC (IITC) based on the torque sharing function (TSF), direct torque-flux control (DTFC), and direct ITC (DITC). Figure 8 illustrates the schematic diagram of the DITC approach for the SRM drive system. In this method, the instantaneous torque is estimated online, and the torque error (ΔT) is directly used as the control input without a current loop, generating the appropriate switching signals for the SRM drive.

In 2017, Gao et al. [28] introduced a double-index synchronous optimization policy that effectively reduced torque ripple and enhanced electric efficiency in SRMs for EVs. In 2018, S. Yao et al. [29] proposed a simple identification strategy for SRM DITC parameters, improving flux linkage estimation and advance angle adjustments across different operating conditions. Xu et al. [30] further demonstrated that DTC achieved better torque ripple reduction in SRMs than DITC, offering improved control performance. By 2019, Liu et al. [32] proposed a DITC strategy based on a fractional-order PID controller, significantly improving dynamic response and torque ripple suppression. Weiss et al. [33] explored the mutual coupling effects between SRM phases, integrating them into the DITC model to minimize torque ripple and harmonic distortions. Reddy et al. [34-35] developed an enhanced DTC method with an innovative switching sequence, reducing power loss and torque ripple in four-phase SRMs. Meanwhile, Abdel-Fadi et al. [36] introduced fuzzy logic-based DTC, which outperformed conventional DTC methods in torque ripple suppression and motor efficiency enhancement. In 2020, Wang et al. [41] proposed a PWM-based DITC strategy, significantly reducing shaft stress and torque ripple, improving SRM starter/generator reliability. Chen et al. [42] combined DITC with excitation angle control, ensuring smooth torque production and high efficiency without preliminary tuning. Sun et al. [43] introduced an optimized DITC scheme, dynamically adjusting commutation instants to improve efficiency and torque stability. From 2021 to 2022, researchers focused on real-time torque optimization and adaptive control mechanisms. Yin et al. [47] developed a terminal sliding mode control scheme, which enhanced torque suppression, speed tracking, and anti-interference capability. Al-Amyal et al. [48-49] introduced an improved DITC controller with adaptive turn-on and turn-off angle adjustments, leading to higher torque efficiency and ripple minimization. By 2023, Cai et al. [50] proposed a multilevel converter-based DITC system, significantly reducing torque ripple and enhancing efficiency in EV applications.

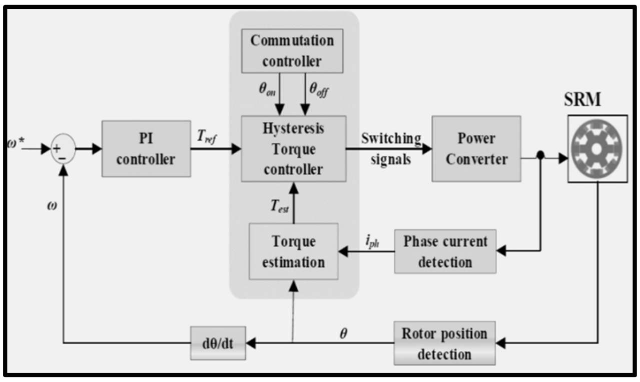

Fig.8. Direct instantaneous torque methods.

2. Model predictive torque control (MPC)

Model Predictive Control (MPC) has been widely employed in industrial control applications and, more recently, in industrial power electronic systems. In electric motor drives, the primary objective of MPC is to determine the optimal switching state of the converter at each switching instant. This is achieved by leveraging a predictive model of the system to satisfy specific constraints and meet predefined performance objectives. In the case of Switched Reluctance Motors (SRMs), MPC has been utilized to predict key operating variables such as torque, current, and flux, as illustrated in Figure 9.

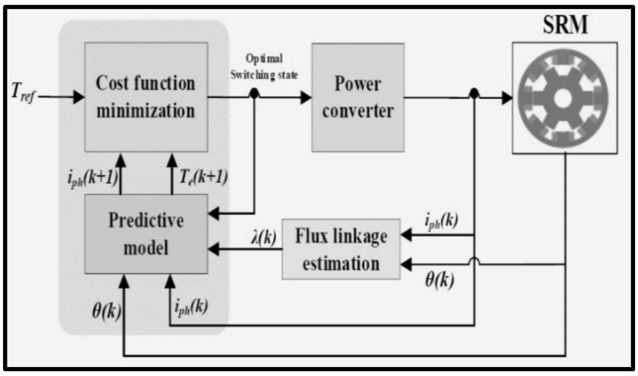

Fig.9. Model predictive torque control (MPC) for SRM.

This control strategy is particularly well-suited for SRMs due to its ability to effectively manage the nonlinear magnetic characteristics and complex switching rules associated with these motors. By defining a cost function, MPC selects the optimal voltage vector from a set of candidate voltage vectors, thereby minimizing torque ripple and reducing copper losses.

In 2018, Abdel-Fadil et al. [51] demonstrated that MPC significantly reduced SRM current and torque ripples, offering superior performance compared to traditional current control methods. By 2019, Xu et al. [52] combined DTC with Model Predictive Flux Control (MPFC), achieving improved torque ripple suppression. In 2020, Abdel-Fadil et al. [53] refined MPC-based SRM control, reducing torque ripples, stator copper losses, and switching frequency, making it more efficient than conventional DTC techniques. By 2022, Fang et al. [54] developed an MPC-based torque control scheme, reducing computational burden by 25%, optimizing torque control performance, and saving storage space compared to traditional LUT-based methods. Most recently, in 2023, Sheng et al. [55] introduced a direct predictive torque control approach, effectively minimizing torque ripple and copper loss, further enhancing torque control performance in SRM drives.

C. Intelligent control

1. Iterative learning control (ILC)

Iterative Learning Control (ILC) is a powerful technique for improving output tracking performance in uncertain nonlinear systems, particularly in applications requiring high-precision control. Unlike conventional control methods, ILC does not require explicit system parameter identification, making it highly effective for complex and dynamically varying systems. The fundamental principle of ILC involves repeatedly applying a simple algorithm to the system or plant, refining the control input with each iteration to achieve near-perfect tracking, as illustrated in Figure 10. This iterative process systematically adjusts the input to minimize tracking errors, ensuring that the system output closely follows the desired reference trajectory over successive learning cycles.

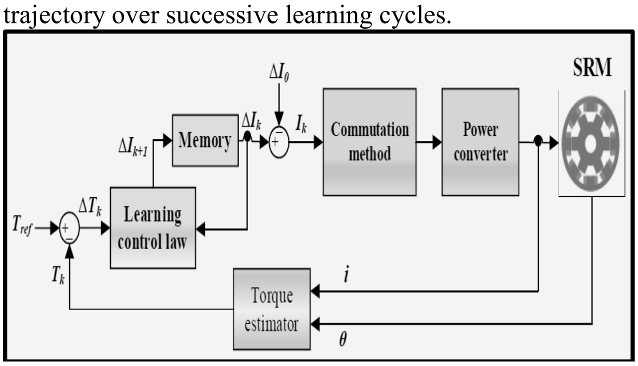

Fig.10. Schematic diagram of iterative learning control.

In the late 1990s, researchers began exploring iterative learning-based methods to minimize torque ripple. Sahoo, N. C. et al. (1998) [57] proposed an iterative learning approach that required minimal prior knowledge of the motor's magnetic characteristics, making it a practical solution for real-world applications. This concept was further extended by Sahoo, N. C. et al. (2001) [58], who introduced an efficient control algorithm for constant torque control, further reducing the need for detailed motor modeling. By the early 2000s, Direct Instantaneous Torque Control (DITC) emerged as a promising technique for torque ripple minimization. Sahoo, S. K. et al. (2004) [56, 59] developed a DITC scheme that significantly minimized torque ripples in high-speed SRM applications while eliminating the need for an accurate plant model. These studies demonstrated that DITC could effectively enhance performance under varying operating conditions. Advancements in adaptive control methods continued into the mid-2000s. Wang, S.-C. et al. (2007) [60] introduced an adaptive iterative learning control (ILC) strategy, which tuned commutation angles and duty ratios dynamically, further improving torque ripple suppression and reducing electromagnetic energy conversion losses.

2.Fuzzy logic control (FLC)

Fuzzy Logic Control (FLC) is a widely used intelligent control method, particularly effective for nonlinear and complex systems where conventional control techniques struggle to achieve optimal performance. FLC offers strong stability and flexibility, making it well-suited for applications such as torque control in Switched Reluctance Motors (SRMs). One of the key advantages of FLC is that it does not require an exact mathematical model of the system, allowing for easier implementation and adaptability to varying operating conditions. Figure 11 illustrates a fuzzy logic controller (FLC) designed to regulate the torque of an SRM, demonstrating its capability to handle uncertainties and nonlinearities in the control process.

In 2015, E. V. C. Sekhara Rao et al. [61] introduced Fuzzy Logic Control to effectively minimize torque ripples in SRMs. Their study highlighted that FLC improved smooth control and significantly reduced acoustic noise and vibrations compared to conventional controllers, making SRMs more suitable for high-performance applications. Building on this, Ming-Shyan Wang et al. [62] in 2016 proposed an enhanced approach by combining FLC with Pulse Width Modulation (PWM) techniques and turn-off angle adjustments. This integration further improved torque ripple suppression and enhanced the dynamic response of SRMs, optimizing their overall performance. In the same year, M. Divandari et al. [63] developed a Fuzzy Logic Current Compensator, which effectively reduced radial force and torque ripple while maintaining maximum torque and minimizing acoustic noise, leading to a smoother operation of SRMs. A significant advancement was made in 2019 when R. Abdel-Fadil et al. [64] implemented Direct Torque Control (DTC) using FLC. Their study demonstrated that FLC-based DTC substantially improved motor performance and torque ripple reduction, particularly in electric vehicle applications. Furthermore, Feng Ling et al. [65] proposed an adaptive fuzzy control method incorporating segmented harmonic current injection. This technique provided a flexible and adaptable solution for minimizing torque ripple over a wide range of operating conditions, further enhancing SRM efficiency. In 2020, Hafeezul Haq et al. [66] introduced the FLC-DTC method, specifically designed for 8/6 SRM drives. This method effectively minimized torque ripple and controlled speed, offering improved performance in various applications, including electric vehicles and industrial drives. Recent advancements in 2022 by Ashok Kumar Kolluru et al. [67] showcased the effectiveness of a fuzzy logic-based DTC technique tailored for SRMs in electric vehicles. Their study demonstrated superior torque ripple reduction and enhanced performance under both steady-state and transient conditions compared to traditional vector control methods. The latest development in 2024 by D. N. Padmavathi et al. [68] focused on a Fuzzy-based PID controller for SRM drives. Their work emphasized the capability of the proposed controller to minimize torque ripples in both dynamic and steady states, significantly improving efficiency in electric vehicle applications and robotics.

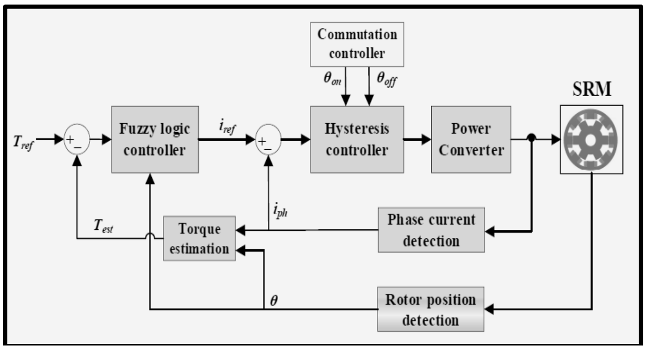

Fig.11. Fuzzy logic control for torque control of SRM.

3.Artificial neural network (ANN)

Artificial Neural Network (ANN) Control is inspired by the human brain's neural structure, offering advantages such as self-learning capability, fault tolerance, and adaptive data processing. ANN-based control has been widely explored for torque ripple minimization in Switched Reluctance Motors (SRMs) due to its ability to predict and optimize system performance in real time. In this approach, ANN is employed to predict stator current and flux, thereby enhancing current and speed response while significantly reducing torque ripple across a broad speed range. Additionally, an improved Torque Sharing Function (TSF) technique integrated with ANN has been developed for four-quadrant operation of the SRM, further mitigating torque ripple and improving overall drive performance. Figure 12 illustrates this ANN-based TSF control scheme for SRM drives.

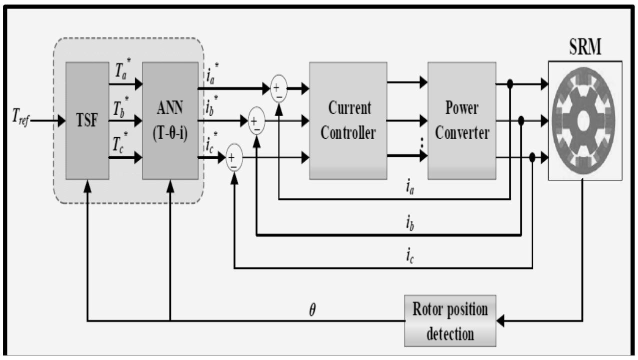

Fig.12.TSF based on ANN control for torque control of SRM

In 2016, Phuoc Hoa Truonga et al. [69] demonstrated that artificial neural networks (ANNs) could effectively reduce torque ripple in non-sinusoidal synchronous reluctance motors, minimizing ohmic losses and enhancing overall performance. In the same year, Pushparajesh V et al. [70] proposed a neural network-based direct torque control (DTC) technique for four-phase SRMs, which improved torque ripple suppression and settling time, performing comparably to classical DTC methods. In 2020, Iqra Tariq et al. [71] further validated the effectiveness of ANNs in minimizing torque ripples, leading to reduced noise and vibration in SRMs. Meanwhile, Xuanju Dang et al. [72] introduced a learning error pre-processing-based time-frequency recurrent neural network with adaptive integral control (TFRNNAIC), which outperformed existing control strategies in reducing torque ripple. By 2022, ANN-based techniques had evolved to enhance motor efficiency further. Kalagotla Chenchireddy et al. [73] proposed an ANN-based SRM control method that minimized torque ripple and noise while reducing starting torque and current consumption. Junxin Xu et al. [74] introduced a BP (Backpropagation) neural network-based torque ripple control strategy, effectively improving SRM performance across various working conditions. Recent advancements in 2023 and 2024 have focused on reinforcement learning and direct torque control applications. In 2023, Hamad Alharkan et al. [75] developed a reinforcement learning-based neural network approach that significantly minimized torque ripple, enhanced tracking performance, and optimized energy consumption. Finally, in 2024, Ganesh D et al. [76] introduced a neural network-based DTC method for a 6/4 SRM used in electric vehicles, achieving torque ripple minimization and reduced charging time, marking a step forward in efficient EV motor control.

4.Neuro-fuzzy inference system (ANFIS)

The neuro-fuzzy inference system (ANFIS) incorporates the merits of both approaches, artificial neural networks and fuzzy logic systems . Adaptive Neuro-Fuzzy Inference System (ANFIS) Control combines the strengths of artificial neural networks (ANNs) and fuzzy logic systems, leveraging their advantages in learning, adaptability, and rule-based decision-making. The schematic diagram of the ANFIS controller for torque control is similar to Figure 11 or Figure 12, with the control unit replaced based on the specific implementation approach. To further reduce torque ripple in SRM drives, a hybrid ANFIS-based control strategy is developed. In this method, the optimal switch-off angle is determined using ANFIS, while the switch-on angle is analytically computed. The effectiveness of the proposed ANFIS approach is then compared with analytical methods and traditional fuzzy logic control, demonstrating ANFIS's superior ability to minimize torque ripple and enhance SRM drive performance.In 2018, Megha Chaple et al. [77] proposed an ANFACO-based control method that significantly minimized torque ripples in SRMs. This method outperformed existing optimization techniques, such as the ant lion optimization and NSGA-II, demonstrating superior performance in reducing torque fluctuations.

5.Machine learning

Machine learning represents a next-generation intelligent control system characterized by high adaptability, automatic learning capability, and a simplified structure, making it well-suited for industrial-scale applications. In this approach, a machine learning-based control strategy is developed using two pre-trained artificial neural network (ANN) models to minimize torque ripple across a wide speed range in SRM drives. The first ANN model is employed to predict the actual torque based on the motor's current and position, while the second ANN model computes the optimal reference currents for each phase, ensuring effective torque ripple mitigation. Building on these advancements, Mohamed Omar et al. [78] (2017) proposed an advanced optimization method utilizing a supervised learning algorithm for SRMs. Their approach not only improved average torque by 2% but also achieved a 24% reduction in torque ripple while minimizing computational overhead Furthermore, Srinivasan Kandhasamy et al. [79] introduced a novel control algorithm aimed at reducing torque ripple across base, medium, and high-speed motor operations, enhancing the adaptability of control strategies in varying operating conditions.

D. Other torque control strategies

This section covers various strategies for reducing torque ripple in motors. Feedback linearization (FBL) is a technique that linearizes a nonlinear system, but has limitations like high current requirements and measurement of state variables. An adaptive feedback linearization approach is used to overcome these. Nonlinear control methods like internal model control (IMC) and variable structure control methods like sliding mode control are also used to mitigate torque ripple. These methods offer fast response, robustness, and are not dependent on parameters or disturbances.

In 2015, Mohammad Masoud Namazi et al. [81] introduced an EM-MOPSO-based controller to reduce torque ripple in SRM drives, significantly improving speed control accuracy. Around the same time, Nutan Saha et al. [101] (2016) developed a Hybrid MOLGSA algorithm, which proved superior to the Gravitational Search Algorithm in reducing torque ripple and improving speed control. That same year, Phuoc Hoa Truonga et al. [69] and Pushparajesh V et al. [70] explored artificial neural networks (ANNs) for torque ripple minimization, demonstrating effective ripple reduction while improving motor performance and settling time. Additionally, Renata Rezende et al. [103] (2017) utilized genetic algorithms to optimize commutation angles, reducing torque ripple by over 50% and lowering acoustic noise. From 2018 onward, optimization techniques evolved further. Mahdi Debouza et al. [102] (2018) employed the Grey Wolf Optimizer to reduce torque ripple without requiring physical modifications to the motor. Megha Chaple et al. [77] proposed an ANFACO-based control method that outperformed optimization techniques like NSGA-II and ant lion optimization. Meanwhile, Aide Xu et al. [99] (2019) combined direct torque control with model predictive flux control, further improving ripple suppression. Ganesh D et al. [76] (2024) proposed a neural network-based DTC controller for a 6/4 SRM, improving torque ripple reduction and lowering charging time in electric cars. In 2019 and 2020, sliding mode control (SMC) methods gained prominence. R. Abdel-Fadil et al. [64] (2019) showed that fuzzy logic-based direct torque control (DTC) significantly improved performance in electric vehicles. Fatma Ben Salem et al. [83] (2020) developed a second-order sliding mode control approach to reduce current distortions and torque ripple while mitigating chattering phenomena. Xiaodong Sun et al. [85] proposed an improved DTC with an observer and sliding mode controller, enhancing industrial SRM applications. Similarly, Xiaodong Sun et al. [98] introduced an adaptive terminal sliding mode control for direct instantaneous torque control (DITC), which improved speed and torque response, robustness, and anti-interference capabilities. The introduction of predictive and reinforcement learning-based strategies marked another leap forward. Qianni Li et al. [80] (2021) and [90] (2020) proposed a non-linear deadbeat direct torque and flux control (N-DB-DTFC) method, achieving lower torque ripple than traditional deadbeat controls. Yonghua Yin et al. [86] (2022) developed an advanced terminal sliding mode control (TSMC) speed controller, enhancing dynamic performance and reducing torque ripple in SRMs. Hossam Kotb et al. [88] (2022) applied SHO-based cascaded PID control using LUS and SHO algorithms, effectively reducing torque ripple and improving speed response. Recent research has focused on hybrid and adaptive techniques. Vo Quang Vinh et al. [87] (2023) introduced an SMC-DTC approach, making the SRM drive more resistant to parameter variations while improving efficiency in electric vehicles. Laith Al Quraan et al. [96] (2023) improved torque ripple suppression using adaptive turn-on angle techniques in DITC for electric vehicles. Linhao Sheng et al. [95] (2023) employed direct predictive torque control, reducing both copper losses and torque ripple. The most recent advancements in 2024 and 2025 have further refined these control strategies. Jackson Oloo et al. [89] (2025) leveraged Radial Basis Functions (RBFs) and Harris Hawks Optimization (HHO) to optimize switching angles in an 8/6 SRM, achieving minimal torque ripple across all operating speeds. Meanwhile, Hongyao Wang et al. [104] (2025) introduced a DITC strategy that effectively suppresses torque ripple during commutation while reducing peak current in vehicle-mounted SRMs.

TABLE I

TORQUE RIPPLE ANALYSIS OF DIFFERENT TORQUE RIPPLE CONTROL TECHNIQUE

Author Citation []	**Control Technique**	**Torque Ripple Analysis**
Rajib Mikail et al. [1] 2015	Four quadrant mode-Current Profiling	3-phase, 12/8 SRM, • The torque ripple was found to go down from 4% to 2% after adjusting the current sensor gains and offset.
Cong Ma et al. [2] 2016	DE optimization-FEA	1-kW,12/8 SRM, At same reference torque **,** Conduction angle of 240° • Torque ripple is 8.11% and Radial forces is 70.92%. • Torque ripple is 8.78% , Radial forces is reduced to 45.66% with the optimal current profile
Peter Dúbravka et al. [3] 2017	Current profile computation - FEM for static parameter analysis.	At Speed 100 rpm and different conditions Condition / Standard control,% / Current profiling,% Healthy SRM / Trp = 39 / Trp = 18 Open Phase / Trp = 185 / Trp = 152
Siddharth Mehta et al. [4] 2018	Slew rate analysis for predictive controller's bandwidth on current profile tracking	3-phase, 12-slot /8 pole SRM • The torque ripple is 7.5% with the proposed profiling method at 1000 rpm. • The same profile is applied at 1500 rpm the torque ripple is limited to 12%. • The current tracking error reduction is almost 60%.
Hui Cai et al. [5] 2018	Optimized pulse width modulation (PWM) control strategy	• The torque ripple and copper loss are reduced by about 70% and 12%, respectively.
Masachika Kawa et al. [6] 2019	Novel current profiling	18/12 pole SRM, • It is also found that there is no coefficients combination to satisfy the conditions of less than 10% torque ripple and less than 6.0-N radial force ripple simultaneously.
Takayuki Kusumi et al. [7] 2020	Proposed phase-current waveform.	At 500 rpm / Proposed Method / square waveforms Torque ripple ratios / 11% / 28% Input-current ripple ratios / 197% / 1943%

		At 5000 rpm Proposed Method square waveforms Torque ripple ratios 11% 41% Input-current ripple ratios 58% 442%
Xiao Ling et al. [8] 2022	CMAC- PWM based on the PID	• The maximum torque ripple is reduced from 15% to 3%, which proves the effectiveness of the proposed method
Aniruddha Agrawal et al. [9] 2024	Current Profiling Control –GA Optimization	At 400 rpm, 20Nm, ATC Linear TSF Cubic TSF RMS torque ripple 10.03Nm 7.96Nm 8Nm At 800 rpm, 10Nm, ATC Linear TSF Cubic TSF RMS torque ripple 4.79Nm 4.62Nm 4.77Nm • The proposed current profiling-based control provides the lowest RMS torque ripple of 3.11Nm • The proposed current profiling-based control provides the lowest RMS torque ripple of 2.21Nm.
Jin Ye et al. [10] 2015	Offline Torque Sharing Function	**Case i**:at 3000 r/min Tref = 1.5 Nm , Ts= 5 μs, Method linear TSF Cubic TSF Exponential TSF Offline TSF Torque ripples 67% 73% 67% 43% **Case ii**: Proposed offline TSF at 1800 r/min Tref = 3 Nm Ts= 5 μs, Method linear TSF Cubic TSF Exponential TSF offline TSF Torque ripple 53% 57% 63% 37%,
Jin Ye, et al. [11] 2015	TSF- ARCFL Technique	2.3 kW, three-phase 12/8 SRM At 6000rpm ,Tref=1.5Nm At 4000rpm ,Tref=3Nm] Method Ts=0.1μs Ts= 5 μs Ts=0.1μs Ts= 5μs Linear TSF 67% 100% 67% 67% Cubic TSF 74% 93% 88% 90% Exponential TSF 80% 80% 67% 88% Online TSF 20% 40% 13% 41%
Haoding Li, et al. [12] 2019	Current shaping TSF- Genetic Algorithm	At 8/6, four phase 5.2 kW SRM with a base speed of 6000 RPM • Improved tracking performance and the reduction of 0.5 Nm RMS of torque ripple.
Hongyan Hu et al. [13] 2019	TSF-Predictive control	At 12/8 structure SRM. Switching Angle Conventional TSF Proposed TSF (θon=3) (θov=1) 24.7% 24.2 % (θon=4) (θov=2) 28.0 % 27.8 %
Mahmoud Hamoudaa et al. [14] 2020	Analytical formulation for efficient turn-on angle determination-Modified TSF	At 8/6 SRM Speed 500 1000 1500 2000 2500 Conventional 7% 10% 12% 17% 30% Proposed IITC 5% 8% 9% 15% 28%
Oğuz Üstün et al. [15] 2020	TSF- Genetic algorithm (GA)	Method Type III Type IV weight parameter is m=10 55 % 37% when weight parameter is m=0 26 % 23% • The optimal improved sinusoidal TSF shows slightly lower torque ripple.
Fahad Al-Amyal et al. [16] 2020	Torque sharing function (TSF)- Multistage ant colony optimization (MSACO)	At 4 kW, 1500 rpm, four-phase 8/6 SRM. Steady State performances Torque ripple Avarage Torque at 1000 r/min speed, 24 Nm 21% 23.83 Nm at 2100 r/min speed, 16 Nm 18% 15.13 Nm
Zekun Xia et al. [17] 2021	TSF with Lower Current Tracking Error	At3-Phase, 12/8 SRM, Speed = 1000 r/min, Tref = 20 Nm Method TRrms Tcoe Conduction angle control 8.29 Nm 59.20% Proposed TSF 2.48 Nm 28.36 % TSF in [29] 4.47 Nm 66.06 % Cubic TSF 2.67 Nm 92.22 %
Cunhe Li et al. [18] 2021	Novel TSF with Robust current controller is derived through the Lyapunov stability theory	Sinusoidal TSF Proposed TSF Speed 100 r/min 1500 r/min 100 r/min 1500 r/min Trf 0.2519 0.4839 0.2506 0.4390 Hysteresis current controller Robust current controller Speed 100 r/min 1500 r/min 100 r/min 1500 r/min IRMSE 0.1554 0.8076 0.1410 0.7745 Trf 0.3762 0.5484 0.2503 0.3995

Fahad Al-Amyal et al. [19] 2022	Hybrid torque sharing function	Speed Linear TSF Sin TSF Hybrid TSF 500 15% 12% 10% 1000 17% 15% 12% 1500 20% 17% 8% 2000 28% 18% 15% 2500 45% 40% 20%
Laith Al Quraan et al. [20] 2024	TSF- Finite Element Analysis.	Method Speed Tref(Nm) Torque tripple Proposed 750,2250 22,15 9%,17% Traditional 750,2250 22 ,15 10%,31%
He Cheng et al. [21] 2015	ATC- GA optimisation-CCC-APC hybrid crossover control	12/8 Rated torque 25 Nm Rated speed 1300 r/min (θon, θoff) Torque Ripple Efficiency (−2.87°, 21.55°) 3.22 83.02% (5.00°, 15.37°) 0.57 92.81% (−1.97°,21.46°) 3.19 86.61% (0.68°,21.65°) 3.12 87.82%
Muhammad Usman Jamil et al. [22] 2017	Average Torque Algorithm	3kW, 6/4 SRM • Online average torque control (ATC) of a switched reluctance motor for light electric vehicle applications stabilizes the system dynamics by estimating the average torque at every time instant and adjusting reference current and switching angles to obtain the desired average torque at the operating speed.
Mahmoud Hamouda et al. [23] 2018	ATC-FEM Technique	4kW four phases 8/6 SRM • The torque ripples are very low at low speed of 500 r/min which mean lower oscillations and noise of vehicle. • The copper losses with proposed ATC are higher than that with conventional approach especially at low speeds. • The proposed ATC has a reduced torque ripples and high dynamic performance
Mahmoud Hamouda et al. [24] 2020	Direct Average Torque Control (DATC)-Aearching Algorithm.	At 627 r/min At 806 r/min Conventional Proposed Conventional Proposed Tav (N.m) 6.459 6.388 4.834 4.827 IRMS (A) 5.488 4.585 4.706 4.097 Tr (%) 68.763 30.822 72.821 36.254
Mingyao Ma et al. [25] 2019	Vector Control Strategy of a T-type Three-level Converter	• The results of the conventional control strategy based on six voltage vectors with a 117% torque ripple. • The results based on the proposed 12 voltage vectors with a 20% torque ripple. • The total torque continues to be straight line, and the torque ripple is 13%.
Songyan Kuai1 et al. [26] 2019	Unipolar sinusoidal excited with Voltage Space Vector	Control strategies Proposed TSF DITC Torque ripple 0.76 0.65 0.49 Torque Response Very Fast Fast Very Fast Commutation angle control No Yes Yes Torque Estimation No Yes Yes
Dmitry S. et al. [27] 2020	Vector Control-Pattern Synthesis.	• The machine can operate without torque ripples under proposed control strategy without consideration of the saturation effect in the SRM.
XudongGaoet al. [28]2017	Novel double-index synchronous optimization	Speed (rpm) 300 500 700 900 1100 1500 Torque Ripple(N-m) 0.75 0.77 0.85 0.91 0.94 0.99
S. Yao de et al[29] 2018	Rotating Flux detection method And CCC algorithm	T_L = 20Nm , N = 1000 rpm Proposed method =Torque ripple=35% , FEA-based method =Torque ripple=40% • The real torque ripple proposed method is smaller than FEA-based method
Aide Xuet al. [30] 2018	DTC and DITC Technique	DTC : An applied torque command step from 5 N-m to 10 N-m , Torque Ripple 15.3%. DITC: An applied torque command step from 5 N-m to 10 N-m ,Torque Ripple 7%.
Hao Chen et al. [31] 2018	Taguchi-CSO Technique	• The torque ripple in Taguchi-CSO techniqueis smaller than Conventional method, at torque ripple factor β_0 is (Optimize Value

		) = 1.55.
Lijun Liu et al. [32] 2019	DITC based on a fractional-order PID Controller	3 phase , 6/4 SRM , N= 600 r/min, T_L= 1.5 N-m Integer-order controller (λ= 1) - Synthesis of T/N-m = 2.4 Fractional-order controller (λ= 0.8) - Synthesis of T/N-m = 2.1
Claude Pascal Weiss1 et al. [33] 2019	LUT based SRM Predictive PWM-based DITC	4 Phase , 16/12 SRM , N = 400 rpm , T_L= 4.9 N-m Without Coupling = Torque ripple > 6% , With Coupling = Torque ripple < 3 %
Pittam Krishna Reddy et al. [34] 2019	DTFC Strategy	4 Phase , 8/6 SRM Speed (r/min) N= 100 N=2500 N=5000 Torque Ripple(N-m) 25.1 28.1 31.1
Pittam Krishna Reddy et al.[35] 2019	DTC + Innovative Switching Sequence Scheme	Speed (r/min) 300 400 500 600 700 800 Torque Ripple (N-m) 0.91 10.01 13.01 13.33 13.61 13.61
R. Abdel-Fadi et al.[36] 2019	DITC Using Fuzzy Logic Control	Case i): Speed =1000 rpm Case ii): Load torque 10 nm Load torque 10 nm 20 Nm Motor Speed 800rpm 1220 rpm Torque Ripple 6.9% 5.85% Torque Ripple 20.7% 12.5%
Pittam Krishna Reddy et al.[37] 2019	New DITC strategy	Reference Torque 15 N-m (8/6 srm) Speed (r/min) N= 250 N= 500 N=750 Torque Ripple (%) 10.66 13.66 14.02
Jiangyong Liu et al.[38] 2019	DITC + Improved Firefly Algorithm	Load Torque 4 N-m Speed (r/min) N= 100 N= 500 N=1000 Torque Ripple (%) 8.44 5.59 8.51
Pittam Krishna Reddy et al.[39] 2019	DTFC strategy	4 k-W, 8/6 pole ,Speed =500 rpm Reference Torque 5 N-m 10 N-m 15 N-m Torque Ripple 33.07 % 19.01 % 18.53 %
Gaoliang Fang et al.[40] 2020	DITC + PSO Algorithm	• Reduced torque rippleby 9% compared with the fixed switching scheme in the low-speed region.
Shauanghongwangetc al [41] 2020	PWM+ DITC with fixed switching frequency	Load torque = 200 N-m, 12/8 SRM , Fixed switching Frequency = 20 kHz Speed (rpm) N=500 N=1000 N=2000 Torque Ripple 7.27% 8.05% 20.01%
Yue Chen et al[42] 2020	DITC + Adaptive Excitation Angle	At 12/8 SRM, Speed = 900 rpm Load Torque Torque Ripple 10 Nm 14.2 % 30 Nm 14.5 %
Qingguo Sun et al[43] 2021	DITC+ Adaptive Dynamic Commutation strategy	3 phase , 12/8 pole , T_L = 2 N-m Speed (rpm) N=300 N=600 N=1000 N= 1500 Torque Ripple 10.6% 15.4% 36% 43%
Yong Cheng et al[44] 2021	Modified Hysteresis and PWM in DITC	3 phase, 6/4 SRM, Torque Ripple In DITC = 0.82 , Torque Ripple In MP-DITC = 0.63
Mahmoud Hamouda et al [45] 2021	DITC strategy	Case -1: At Low Speed , Torque Ripple = Low Case -2: At High Speed , Torque Ripple = Medium
Ping Renet al [46] 2022	DITC Strategy based on adaptive turn – on angle TSF	12/8 SRM , Speed = 300 rpm , Load Torque= 5 N-m • Torque Ripple coefficient reduced by 64 %
Yonghua Yin et al[47] 2022	DITC+ Advanced SMO with (GWOA+COA)	• Torque ripple range of proposed TSMC can be reduced by 38% and 21% compared with PI and SMC under variable load condition .
Fahad Al-Amyal et al [48] 2022	DITC+ Adaptive Commutation Strategy	3 phase , 12/8 pole , T_L = 1.5 N-m Speed (rpm) N=400 N=700 N=1000 Torque Ripple (%) 32.6 % 35.4 % 38 %
Fahad Al-Amyal et al [49] 2022	DITC + Ant Colony Optimization Technique	3 phase, 750 W , 12/8 SRM Speed(rpm) TL(N-m) Torque Ripple (%) 400 2.5 N-m 19 % 800 2.0 N-m 20 % 1200 1.5 N-m 27 %
Yan Cai et al [50] 2023	DITC+ Torque Hysteresis Control	At 12/8 SRM , Load Torque = 2 N-m Speed (rpm) N=500 N= 1000 N= 1750

	Strategy with the Novel Multilevel Converter with Search Algorithm	Torque Ripple 23.2% 25.1% 26.2 %
Reyad Abdel-Fadil et al. [51] 2018	HCC -MPC	Load Torque =10Nm Load Torque = 20Nm HCC MPC HCC MPC During Phases Conduction 27 % 6% 22% 5% Average Torque 42 % 21 46% 27.5%
Aide Xu et al. [52] 2019	DITC- Model Predictive Flux control (MPFC).	Method Speed= 450rpm, 10Nm Speed= 1200rpm,20 Nm DTC Trc= 3.34 Trc= 3.31 DITC Trc= 2.90 Trc= 2.79 Proposed Trc= 1.77 Trc= 1.91
Reyad Abdel-Fadil et al. [53] 2020	PDITC Technique	Torque (Nm) Speed (rpm) Torque Ripple (%) DITC PDITC 10 800 13.5 8.48 10 1200 14.8 8.76 20 800 9.7 6.75 20 1200 11.4 9.4
Gaoliang Fang et al. [54] 2022	Linear MPC Technique	Speed(rpm) TorqueConvetional (Trp) Improved(Trp)Linear MPC(Trp 100 8Nm 0.9301 0.9017 0.8774 1000 8Nm 0.6620 0.7076 0.6511 5000 4Nm 1.6691 0.9732 0.8325
Linhao Sheng et al. [55] 2023	DPTC Technique	Speed (rpm) DITC FCS-MPTC PWM-DITC DPTC 200 39.1% 38.2% 19.2% 17.9% 400 42.9% 41.8% 33.5% 29.4% 800 58.4% 53.2% 39.3% 38.6%
Sahoo, S. K. et al. [56]2004	DITC-ILC Technique	• ILC is effective in minimizing torque ripples during steady state operations
Sahoo, N. C et al. [57] 1998	Iterative Learning Ontrol	• This paper explores using iterative learning to minimize torque ripple in switched reluctance motors, requiring less prior knowledge of the motor's magnetic characteristics.
Sahoo, N. C et al. [58]2001	ILC Technique	• This paper presents a simple and efficient control algorithm for constant torque control of switched reluctance motors using iterative learning, requiring less knowledge of the motor's magnetic characteristics.
Sahoo, S. K. et al. [59]2004	DITC-ILC Technique	• The proposed DITC scheme effectively minimizes torque ripples in switched reluctance motors, improving performance in high-speed applications without requiring an accurate plant model.
Wang, S.-C.,et al. [60]2007	Adaptive Iterative Learning Control Method	• The adaptive iterative learning control method effectively minimizes torque ripple and electromagnetic energy conversion losses in switched reluctance motors by tuning commutation angles and duty ratio.
E. V. C. Sekhara Rao et al. [61] 2015	FLC-PID Technique	8/6 SRM 4 phase Controller used Without controller With PID With PI With FLC-PI With FLC-PID TorqueRipple (%) 77.69 56.06 45.45 32.15 21.25
Ming-Shyan Wang et al. [62] 2016	Fuzzy logic control - PWM Technique	• The proposed scheme is found to outperform its traditional counterpart at rise time and less damping.
M. Divandari et al. [63] 2016	FLCC Technique	6/4 pole SRM for ω = 1500 rpm • It can be observed that the maximum radial force, the maximum torque, and the torque ripple are 2 × 106 N, 3.5 N m, and (ΔT = Tmax−Tmin = 0.7 N m), respectively.
R. Abdel-Fadil et al. [64] 2019	DITC- PD-FLC Technique	Speed =1000 rpm Torque = 10 Nm Load Torque 10 Nm 20 Nm 800 rpm 1200 rpm Fuzzy Logic DITC 6.9% 5.8% 20.7% 12.5% Conventional DITC 12.3% 8.85% 30.65% 17.8%
Feng Ling et al. [65] 2019	Adaptive Fuzzy Logic Control	Case i : Indicators Without Harmonic Injection Speed(Rpm) At (%) Peak Value Of Phase Current(A) 400 69 83 1200 58 85 Case ii: Indicators With Harmonic Injection Speed(Rpm) At (%) Peak Value Of Phase Current(A) 400 10 95

		1200 27 90 Case iii: Indicators Without Harmonic Injection Load Torque(N*M) At (%) Peak Value Of Phase Current(A) 10 76 53 70 48 133 Case iv: Indicators With Harmonic Injection Load Toque(N*M) At (%) Peak Value Of Phase Current(A) 10 10 60 70 15 150
Hafeezul Haq et al. [66] 2020	FLC-DTC Method	• Fuzzy logic controller is used with direct torque control method to control the ripples in torque and also to control the speed of the motor.
Ashok Kumar Kolluru et al. [67] 2022	FLC Based DTC Technique	At 6/4 poles Load torque =25 N-m , Torque ripple at 1.2 sec vector control + ANN = 1.4 N-m DTC + fuzzy = 0.4 N-m
D N Padmavathi et al. [68] 2024	Non-Linear Dynamic Characteristics of Fuzzy-Based SRM	• It was found that the torque ripples are minimized upto the minimum level by using Fuzzy based SRM Drive.
Phuoc Hoa Truonga et al. [69] 2016	Artificial Neural Networks	At Refer-ence speed 1000 rpm, Desired torque Tref= 2 N.m • It can be noticed that the torque ripple obtained with proposed method is not sig-nificant (only 2% of the desired torque) and the convergence of thisstrategy takes approximately one electrical cycle (about 25 ms).
Pushparajesh V et al. [70] 2016	DTC-ANN Technique	Classical DTC Proposed DTC Speed % Torque ripple in % Torque ripple in % 100 5.2 3.5 50 6.47 4.4 10 7.4 5.6
Iqra Tariq et al. [71] 2020	ANN by regulating its speed and current	Case Torque ripple Torque improvement (%) Simplified model 12.61 — ANN-based speed and current simple 9.73 22 ANN-based current and speed simple 8.53 31.9 ANN-based speed with noise and current simple 9.66 23.4 ANN-based current with noise and speed simple 8.469 32 Improved model 7.49 40.6
Xuanju Dang et al. [72] 2020	Torque–Flux Linkage Recurrent Neural Network Adaptive Inversion Control (TFRNNAIC)	6/4-pole SRM Comparison of torque ripple coefficients for same structure neural network Control strategy Tmax Nm Tmin Nm Tav Nm Kt % Parallel RBF structure 8.1365 7.9179 8.0004 2.73 Series–parallel RBF 8.0965 7.8938 7.9996 2.53 Proposed TFRNNAI 8.0667 7.9117 7.9999 1.94
Kalagotla Chenchireddy et al. [73] 2022	HCC - ANN	8/6 pole SRM Motor specifications HCC ANN Steady-state position 0.2 sec 1 sec Speed (RPM) 1500 RPM 3000 RPM Torque (N*M) to running toque 8 Times High Staring toque equal Current starting condition 4 times high 1.3 times high Current at running condition 15A 15A Flux in starting motor condition 5 times High 2time high
Junxin Xu et al. [74] 2022	DITC based on BP neural network	• The torque ripple of the conventional DITC varies greatly under different loads, which are 70.5% and 21.75% respectively. • The torque ripple is 23.5% and 12% respectively under different loads, which significantly reduces the torque ripple compared with the conventional DITC. • The total torque is stable, the total torque is between 2.4 N·m and 1.7N·m, and the torque ripple is 14%.
Hamad Alharkan et al. [75] 2023	Neural Network	• The parameters of the second NN approach to their ideal values after 10 epochs to minimize the torque ripples and achieve excellent performance for the motor. • After the weights of NNs settle to their optimal number, the controller successfully minimize the torque ripples.

Ganesh D et al. [76] 2024	Neural Network based Direct Torque Controller	• The neural network-based direct torque controller effectively drives a 6/4 Switched Reluctance Motor (SRM) in an electric car, minimizing torque ripples and reducing charging time.
Megha Chaple1 et al. [77] 2018	NSGA-II , CMFG-RNN , ANFACO	Controller NSGA-II CMFG-RNN ANFACO Kp 9.096 8.264 7.3254 Ki 0.8107 0.7616 0.6541 Θon 0.2012 0.184 0.1251 θoff 0.7264 0.687 0.615
Mohamed Omar et al. [78] 2017	Back-Propagation Neural Network (BPNN)	• This proposed method showcases an improvement of 1.8% in the motor average torque and a remarkable reduction of 23.8% in torque ripples compared to the baseline design.
Srinivasan Kandhasamy et al. [79] 2020	TSF-ANN Technique	At 1.25 kW, 12/8, 3 Phase motor. Speed(rpm) Torque (Nm) Algorithm Torqur Ripple % 1000 12 Normal TSF 17.5% 1000 12 ANN Based 4.2% 1000 4 Normal TSF 17.3% 1000 4 ANN Based 2.2% • Torque ripple is considerably minimized from 17.3% to 2.2% at base speed. It is observed that the torque ripple is more than 10% at higher speeds, which needs further optimization of the control.
Qianni Li et al. [80] 2021	N-DB-DTFC Technique	12/8-poles SRM, Dynamic response comparison at Speed = 1200 rpm **At t=0.1 sec** **At t=0.2sec** DB-FC, Trc= 1.14Nm Trc= 1.20Nm DB-DTFC Trc= 0.97Nm Trc= 1.08Nm N-DB-DTFC Trc= 0.75 Nm Trc= 0.83Nm
Mohammad Masoud Namazi et al. [81] 2015	Adaptive Sliding mode Control and Particle Swarm Optimization	• The target was to reduce the ripple of torque and speed at the same with consideration of ISE-speed and ISE-torque. • The desired rotor speed is set to 200rpm and the external load torque is suddenly changed at t = 0.2s from 4 to 8N.m.
Gurmeet Singh et al. [82] 2019	PI control - SMC Technique	• SMC technique shows better performance than a PI control. SMC starts tracking at 0.33s., while the PI control starts tracking after 0.6s. • Thus SMC technique has a better response with respect to the PI control technique.
Fatma Ben Salem et al. [83] 2020	Straightforward Second-Order Sliding Mode Control (SMC)	8/6 SRM, 4 phases Torque ripples (experimental results). Speed TRIP, 1 (%) TRIP, 2 (%) TRIP,1 (%) (rpm) SM1 SM2 SM1 SM2 SM1 SM2 500 6.12 5.38 8.28 7.28 34.95 29.96 1000 7.97 4.87 9.97 6.40 34.28 24.64 1500 14.84 10.06 17.62 12.30 53.43 36.82
Marcelo Vin´ıcius de Paula et al. [84]2020	MTRPT Technique	The MTRPT reduced the torque ripple by 14:6% in low speeds (ECE-R15) and by 10:1% at high speeds .
Xiaodong Sun et al. [85]2020	SMSC-ADSMO	At 16/10 SRM, 4 pahese , PI Tr= 4.0 , SMSC-ADSMO Tr= 3.0
Yonghua Yin et al. [86] 2022	PI - SMC – TSMC Technique	Condition PI SMC TSMC Constant load torque 0.4Nm 0.36Nm 0.3Nm Load torque disturbance 0.6Nm 0.47Nm 0.37Nm
Vo Quang Vinh et al. [87] 2023	DTC based on the Sliding Mode Control (SMC)	• The increased torque response of the PI control method is 23%, and the setting time is slower than that of the SMC controller.
Hossam Kotb et al. [88]2022	LUS-PID and SHO-PID	Optimal fitness function using different controllers CASE 1 CASE 2. CASE 3 Controller No-load torque T = 100 N.m load torque GA-FOPID [23] 0.0199 0.4528 0.7443 PSO-FOPID [24] 0.0081 0.4334 0.1997 Ant-Lion-FOPID [26] 0.0081 0.4352 0.7249 LUS-PID (proposed) 0.0099 0.0165 0.0201 SHO-PID (proposed) 0.0075 0.0161 0.0183
Jackson Oloo et al. [89] 2025	Harris Hawks Optimization (HHO) and Radial	Loading Speed (r/min) Torque Ripple Average Torque PSO 50% 2500 54% 9.142 Nm Proposed Method 50% 2500 44% 8.86 Nm

	Basis Functions (RBFs)	PSO 100% 2500 19% 18.24 Nm Proposed Method 100% 2500 46% 17.28 Nm
Qianni Li et al. [90] 2020	DB-DTFC and N-DB-DTF	Method ω = 500 rpm, TL = 10 N·m ω = 1200 rpm, TL = 25 N·m DB-FC TRC = 2.69, Imax = 12.0 TRC = 2.94, Imax = 18.5 DB-DTFC TRC = 2.18, Imax = 12.3 TRC = 2.31, Imax = 18.7 N-DB-DTF TRC = 1.94, Imax = 10.3 TRC = 2.04, Imax = 16.2
Mahmoud Hamouda et al. [91] 2022	ATC - DITC - UTC Technique	Low Speed High Speed ATC DITC UTC ATC DITC UTC Average torque High High High High Low High Torque ripple High Low Very Low Low High Low Tav/IRMS Medium Low High High Low High Switching frequency Low Low Low Low Low Low Efficiency Medium High High High Medium High
Deepak A. Shahakar et al [92] 2022	DITC+ PF-HHO algorithm	Case -1 : Non Uniform Load Torque (15 nm to 75 Nm) , Torque Ripple = 1.05 (KTSR-0.80017) Case -2: Uniform Load Torque (75 Nm), Torque Ripple = 1.77 (KTSR-0.8412)
Ping Renet al [93] 2022	DITC Strategy based on adaptive turn – on angle TSF	12/8 SRM , Speed = 300 rpm , Load Torque= 5 N-m , Torque Ripple coefficient reduced by 64 %
MaohmoudHaomudaet al [94] 2022	DITC+ UTC with Search Algorithm	Case -1: Low Speed, Torque Ripple = Very Low Case -2: High Speed, Torque Ripple = Low
Linhao Sheng et al [95] 2023	DPTC Algorithm	phase ,12/8 SRM, Load Torque = 5 Nm Speed (rpm) N= 200 N= 400 N= 800 Torque Ripple 17.9% 29.4% 38.6%
Laith Al Quraan et al [96] 2023	DITC + Adaptive Turn on technique	4 phase , 8/6 SRM , T_L = 10 N-m Speed (rpm) N=800 N=1600 N=2400 N=2600 Torque Ripple 10% 13 % 40% 68%
Z. Hao et al [97]2020	Improved control method based on DTC and DFC	Torque ripple reduced by 66.7%. Torque/ampere ration increased by 200% Switching times reduced by 47.3%
XiaodongSun et al.[98] 2020	Improved DITC based ATSMC	16/10 SRM , Constant Load Torque Control Method SMC TSMC ATSMC Torque ripple (%) 66.8 % 66.5 % 46.2 %
Aide Xu et al. [99] 2019	DTC-DITC-MPFC strategy	Reference Flux= 0.33 Wb 12/8 SRM , T_L=15N-m , N= 800r/min Torque Ripple analysis - DTC = 15.51 N-m , Proposed Method = 15.30 N-m , Optimize DITC =15.08 N-m
NingYan et al. [100] 2019	DTC + Removal Hysteresis- loop control of flux	• T/A is 0.335N•m/A in conventional DTC method, whereas 0.454 N•m/A in proposed DTC method. • The torque ripple can be decreased by 52.37% when using proposed DTC method
Nutan Saha et al.[101]2016	Hybrid Many Optimizing Liaison Gravitational Search technique	60 KW, 3-phase 6/8 SRM • It is noticed that the torque ripple coefficient, ISE of speed & current are reduced by 12.81%, 38.60%, 16.74% respectively by Hybrid MOLGSA algorithm compared to Gravitational Search Algorithm (GSA) algorithm. • It is also observed that the settling times for the controller using the parameter values for obtaining best values of torque ripple, Integral square error of speed and current are reduced by 51.25%, 58.04% and 59.375% by proposed Hybrid MOLGSA algorithm compared to the GSA algorithm.
Mahdi Debouza et al.[102]2018	Response surface method (RSM), Grey wolf optimizer (GWO)	• The first combination is 50^0 and 90^0 and the second combination is 42.1623^0 and 85^0 which is the one obtained from the optimization. • It can be clearly seen that the torque ripples in first combination are higher that those obtained from the second firing angles combination .

		• The optimal value of the objective function found by GWO is 0.98167.
Renata Rezende et al.[103]2017	Genetic Algorithm-Based Commutation Angle	2 kW 8/6 SRM Speed Parameter Conventional Optimized 160rpm Tavg 0.167 Nm 0.167 Nm 200 rpm Tavg 0.18 Nm 0.17Nm 360rpm Tavg 0.334 Nm 0.331 Nm 600 rpm Tavg 0.75 Nm 0.71 Nm
Hongyao Wang et al.[104]2025	DITC-PSO-ABC Optimization	Speed DITC Improved DITC 300 r/min 9.34% 8.35% 600 r/min 10.92% 8.71% 1000 r/min 12.89% 10.35%

Table 2. Comparison of the SRM torque control strategies with merits, demerits and complexity .

Control Method	Adopted Technique	Merits	Drawbacks	Implementation& Computational Complexity	Ref.
Current Profiling	Intelligent current profiling online	Minimize torque ripple during commutation by determining the optimal current profile offline.	It requires a large memory space to store current profile data and is highly sensitive to variations in the actual operating parameters of the SRM.	Complex/ Low	[1-9]
Torque Sharing Current	A modified offline TSF	Highly powerful and efficient, with well-defined torque waveforms, smooth torque delivery across a wide speed range, and improved current tracking performance.	Requires i-T-θ characteristics and an offline-designed torque waveform; demands a high-bandwidth current regulator but cannot achieve high torque commands.	Complex/ High	[10-20]
Average Torque Control	online average torque estimator with optimized switching angles offline	Offers a high torque-per-ampere ratio, with a fixed reference phase current throughout excitation, ensuring easy implementation and lower cost.	The torque ripple is high at low speed	Simple/low	[21-24]
Vector Control (FOC)	Improved FOC based on a non-sinusoidal d-q transform	Eliminates the need for an excitation angle controller, resulting in reduced torque ripple.	Vector control has not been implemented at high speeds and involves a complex d-q transformation.	Complex/ Medium	[25-27]
DITC	Improved DTC based on adaptive commutation strategy	Reduces torque ripple with directly controlled instantaneous torque.	Prerequisite knowledge of machine parameters is required.	Medium/ Low	[27-50]
Model Predictive Control	Online adaptive PWM-MPC method	Torque ripple is minimized, and theoretical delays are reduced; optimized current profiles are not necessary.	Accurate information about the machine's characteristics is required.	Simple/ high	[51-55]
Iterative Learning control	Adaptive iterative learning control	Effective torque tracking and reduced torque ripple do not require an accurate plant model.	Need of Complex learning control is finite-time limited.	Complex\ High	[56-60]
Intelligent control	(ANN, FLC, ANFIS)	Strong self-learning and adaptive capability; does not require model parameters;	Involves a complex computational process.	Complex/ High	[61-79]

		ensures low torque ripple.			
Feedback linearization control	Feedback linearization control with PID controller	A feedback loop with no nonlinear variables provides the necessary decoupling between currents.	Requires very high flux variations; an accurate motor model is necessary; poses difficulties in practical implementation.	Complex/ Medium	
Sliding Mode Controller (SMC)	Adaptive control, fuzzy logic, or neural networks	High robustness to system uncertainties and external disturbances. - Fast dynamic response and accurate tracking performance. - Suitable for nonlinear systems like SRMs. - Insensitive to parameter variations.	Chattering effect due to high-frequency switching. - Requires precise system modeling. - Implementation complexity increases with higher-order systems.	Complex/ Medium	[80-104]
Variable Structure Control	Sliding mode variable structure	Low sensitivity to plant uncertainties, fast response, and easy implementation.	Chattering; challenging to build an accurate nonlinear model.	Complex/ High	

4. CONCLUSIONS

EVs are increasingly focused on reducing fossil fuel consumption and carbon dioxide emissions. SRMs are gaining interest for these vehicles due to their simple and robust structures, high reliability, and lack of rare-earth materials. However, the inherent SRM structure causes acoustic noise, limiting their development.The paper presents an overview of the most widely used SRM torque ripple minimization approaches. The main focus is on control strategy improvement. From the previous research , it is evident that much effort has been devoted to optimizing motor structure through new stator and rotor designs. However, this effort results in structural complexity and increased production costs. Improving control strategies is a more cost-effective and flexible approach to addressing the SRM torque ripple problem. The methods, advantages, limitations and torque ripple analysis of these approaches were summarized and compared. It was concluded that DITC is the most efficient and mature torque ripple minimization approach. The authors propose a 4φ SRM drive for EV applications, driven by a passive boost and a shared phase converter, controlled using DITC. This 4φ SRM is chosen for its even-phase converter and compact converter with minimal switching losses, balancing converter cost, complexity, and losses. DITC is the most efficient control approach, with the SRM drive sensing rotor position and handling error signals.

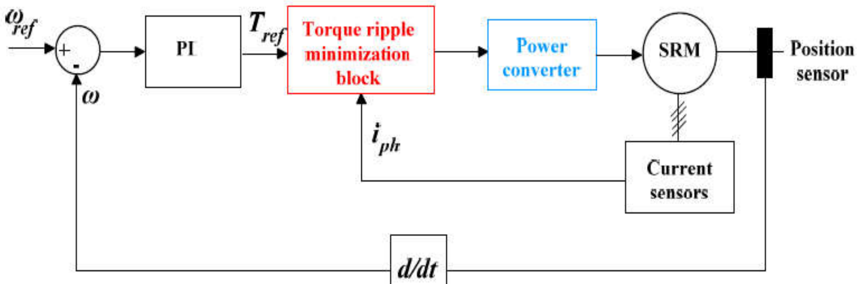

Figure 13. Suggested SRM drive for EV applications

Future research and forecasted research hotspots include:

1. Developing control schemes to reduce torque ripple over a wide speed range
2. Investigating the performance of SRM power converters using SiC and GaN semiconductor devices.
3. Investigating and developing torque ripple reduction techniques for converter fault conditions, including open and short circuit faults, using fewer additional power switches

REFERENCES

[1] R. Mikail, I. Husain, M. S. Islam, Y. Sozer, and T. Sebastian, 'Four-Quadrant Torque Ripple Minimization of Switched Reluctance Machine Through Current Profiling With Mitigation of Rotor Eccentricity Problem and Sensor Errors', IEEE Trans. Ind. Appl., vol. 51, no. 3, pp. 2097–2104, 2015, doi: 10.1109/TIA.2014.2365715.

[2] C. Ma, L. Qu, R. Mitra, P. Pramod, and R. Islam, 'Vibration and torque ripple reduction of switched reluctance motors through current profile optimization', Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, vol. 2016-May, pp. 3279–3285, 2016, doi: 10.1109/APEC.2016.7468336.

[3] P. Dúbravka, P. Rafajdus, P. Makyš, and L. Szabó, 'Control of switched reluctance motor by current profiling under normal and open phase operating condition', IET Electr. Power Appl., vol. 11, no. 4, pp. 548–556, 2017,

doi: 10.1049/iet-epa.2016.0543.

[4] S. Mehta, M. A. Kabir, and I. Husain, 'Extended Speed Current Profiling Algorithm for Low Torque Ripple SRM Using Model Predictive Control', 2018 IEEE Energy Convers. Congr. Expo. ECCE 2018, pp. 4558–4563, 2018, doi: 10.1109/ECCE.2018.8558169.

[5] H. Cai, H. Wang, M. Li, S. Shen, Y. Feng, and J. Zheng, 'Torque ripple reduction for switched reluctance motor with optimized PWM control strategy', Energies, vol. 11, no. 11, 2018, doi: 10.3390/en11113215.

[6] M. Kawa, K. Kiyota, J. Furqani, and A. Chiba, 'Acoustic Noise Reduction of a High-Efficiency Switched Reluctance Motor for Hybrid Electric Vehicles with Novel Current Waveform', IEEE Trans. Ind. Appl., vol. 55, no. 3, pp. 2519–2528, 2019, doi: 10.1109/TIA.2018.2888847.

[7] T. Kusumi, T. Hara, K. Umetani, and E. Hiraki, 'Phase-current waveform for switched reluctance motors to eliminate input-current ripple and torque ripple in low-power propulsion below magnetic saturation', IET Power Electron., vol. 13, no. 15, pp. 3351–3359, 2020, doi: 10.1049/iet-pel.2019.1207.

[8] Ling, X., Zhou, C., Yang, L., & Zhang, J. (2022). Torque Ripple Suppression Method of Switched Reluctance Motor Based on an Improved Torque Distribution Function. In Electronics (Vol. 11, Issue 10, p. 1552). MDPI AG. https://doi.org/10.3390/electronics11101552

[9] A. Agrawal, B. Bilgin, and A. K. Haridas, 'Current Profiling Control for Torque Ripple Reduction in the Generating Mode of Operation of a Switched Reluctance Motor Drive', Symmetry (Basel)., vol. 16, no. 10, 2024, doi: 10.3390/sym16101278.

[10] J. Ye, B. Bilgin, and A. Emadi, 'An Offline Torque Sharing Function for Torque Ripple Reduction in Switched Reluctance Motor Drives', IEEE Trans. Energy Convers., vol. 30, no. 2, pp. 726–735, 2015, doi: 10.1109/TEC.2014.2383991.

[11] J. Ye, B. Bilgin, and A. Emadi, 'An extended-speed low-ripple torque control of switched reluctance motor drives', IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1457–1470, 2015, doi: 10.1109/TPEL.2014.2316272.

[12] H. Li, B. Bilgin, and A. Emadi, 'An Improved Torque Sharing Function for Torque Ripple Reduction in Switched Reluctance Machines', IEEE Trans. Power Electron., vol. 34, no. 2, pp. 1635–1644, 2019, doi: 10.1109/TPEL.2018.2835773.

[13] H. Hu, X. Cao, N. Yan, and Z. Deng, 'A New Predictive Torque Control Based Torque Sharing Function for Switched Reluctance Motors', 2019 22nd Int. Conf. Electr. Mach. Syst. ICEMS 2019, pp. 1–5, 2019, doi: 10.1109/ICEMS.2019.8922297.

[14] M. Hamouda, A. A. Menaem, H. Rezk, M. N. Ibrahim, and L. Számel, 'An improved indirect instantaneous torque control strategy of switched reluctance motor drives for light electric vehicles', Energy Reports, vol. 6, pp. 709–715, 2020, doi: 10.1016/j.egyr.2020.11.142.

[15] O. Üstün and M. Önder, 'An Improved Torque Sharing Function to Minimize Torque Ripple and Increase Average Torque for Switched Reluctance Motor Drives', Electr. Power Components Syst., vol. 48, no. 6–7, pp. 667–681, 2020, doi: 10.1080/15325008.2020.1797939.

[16] F. Al-Amyal, L. Al Quraan, and L. Szamel, 'Torque Sharing Function Optimization for Extended Speed Range Control in Switched Reluctance Motor Drive', CANDO-EPE 2020 - Proceedings, IEEE 3rd Int. Conf. Work. Obuda Electr. Power Eng., pp. 119–124, 2020, doi: 10.1109/CANDO-EPE51100.2020.9337792.

[17] Z. Xia, B. Bilgin, S. Nalakath, and A. Emadi, 'A New Torque Sharing Function Method for Switched Reluctance Machines with Lower Current Tracking Error', IEEE Trans. Ind. Electron., vol. 68, no. 11, pp. 10612–10622, 2021, doi: 10.1109/TIE.2020.3037987.

[18] C. Li, C. Zhang, J. Liu, and D. Bian, 'A High-Performance Indirect Torque Control Strategy for Switched Reluctance Motor Drives', Math. Probl. Eng., vol. 2021, 2021, doi: 10.1155/2021/6618539.

[19] F. Al-Amyal and L. Szamel, 'Research on Novel Hybrid Torque Sharing Function for Switched Reluctance Motors', IEEE Access, vol. 10, no. July, pp. 91306–91315, 2022, doi: 10.1109/ACCESS.2022.3202296.

[20] L. Al Quraan, A. L. Saleh, and L. Szamel, 'Indirect Instantaneous Torque Control for Switched Reluctance Motor Based on Improved Torque Sharing Function', IEEE Access, vol. 12, pp. 11810–11821, 2024, doi: 10.1109/ACCESS.2024.3355389.

[21] H. Cheng, H. Chen, and Z. Yang, 'Average torque control of switched reluctance machine drives for electric vehicles', IET Electr. Power Appl., vol. 9, no. 7, pp. 459–468, 2015, doi: 10.1049/iet-epa.2014.0424.

[22] M. Usman Jamil, W. Kongprawechnon, and N. Chayopitak, 'Average Torque Control of a Switched Reluctance Motor Drive for Light Electric Vehicle Applications', IFAC-PapersOnLine, vol. 50, no. 1, pp. 11535–11540, 2017, doi: 10.1016/j.ifacol.2017.08.1628.

[23] M. Hamouda and L. Szamel, 'Reduced torque ripple based on a simplified structure average torque control of switched reluctance motor for electric vehicles', CANDO-EPE 2018 - Proc. IEEE Int. Conf. Work. Obuda Electr. Power Eng., pp. 109–113, 2018, doi: 10.1109/CANDO-EPE.2018.8601133.

[24] M. Hamouda, A. A. Menaem, H. Rezk, M. N. Ibrahim, and L. Számel, 'Numerical estimation of switched reluctance motor excitation parameters based on a simplified structure average torque control strategy for electric vehicles', Mathematics, vol. 8, no. 8, 2020, doi: 10.3390/MATH8081213.

[25] M. Ma, Z. Wang, Q. Yang, S. Yang, and X. Zhang, 'Vector control strategy of a T-type three-level converter driving a switched reluctance motor', Chinese J. Electr. Eng., vol. 5, no. 4, pp. 15–21, 2019, doi: 10.23919/CJEE.2019.000023.

[26] S. Kuai, H. Zhang, X. Xia, and K. Li, 'Unipolar sinusoidal excited switched reluctance motor control based on voltage space vector', IET Electr. Power Appl., vol. 13, no. 5, pp. 670–675, 2019, doi: 10.1049/iet-

epa.2018.5636.

[27] D. S. Veretin, V. F. Samoseiko, A. V. Saushev, and E. V. Shiryaev, ‘Vector Control of a Switched Reluctance Motor’, 2020 27th Int. Work. Electr. Drives MPEI Dep. Electr. Drives 90th Anniv. IWED 2020 - Proc., no. 1, pp. 1–5, 2020, doi: 10.1109/IWED48848.2020.9069551.

[28] X. Gao, R. Na, C. Jia, X. Wang, and Y. Zhou, ‘Multi- objective optimization of switched reluctance motor drive in electric vehicles’, Comput. Electr. Eng., vol. 70, pp. 914–930, 2018, doi: 10.1016/j.compeleceng.2017.12.016.

[29] S. Yao and W. Zhang, ‘A Simple Strategy for Parameters Identification of SRM Direct Instantaneous Torque Control’, IEEE Trans. Power Electron., vol. 33, no. 4, pp. 3622–3630, 2018, doi: 10.1109/TPEL.2017.2710137.

[30] A. Xu, W. Zhang, and P. Ren, ‘Comparison of torque ripple reduction for switched reluctance motor based on DTC and DITC’, Proc. 13th IEEE Conf. Ind. Electron. Appl. ICIEA 2018, pp. 1727–1732, 2018, doi: 10.1109/ICIEA.2018.8397988.

[31] H. Chen, W. Yan, J. J. Gu, and M. Sun, ‘Multiobjective Optimization Design of a Switched Reluctance Motor for Low-Speed Electric Vehicles with a Taguchi-CSO Algorithm’, IEEE/ASME Trans. Mechatronics, vol. 23, no. 4, pp. 1762–1774, 2018, doi: 10.1109/TMECH.2018.2839619.

[32] L. Liu, M. Zhao, X. Yuan, and Y. Ruan, ‘Direct instantaneous torque control system for switched reluctance motor in electric vehicles’, J. Eng., vol. 2019, no. 16, pp. 1847–1852, 2019, doi: 10.1049/joe.2018.8726.

[33] C. P. Weiss, S. Schoeler, and R. W. De Doncker, ‘Direct instantaneous torque control for switched reluctance machines considering mutual coupling’, J. Eng., vol. 2019, no. 17, pp. 3701–3704, 2019, doi: 10.1049/joe.2018.8136.

[34] K. R. Pittam, D. Ronanki, P. Perumal, and S. S. Williamson, ‘New direct torque and flux control with improved torque per ampere for switched reluctance motor’, 2019 IEEE Int. Electr. Mach. Drives Conf. IEMDC 2019, pp. 1792–1797, 2019, doi: 10.1109/IEMDC.2019.8785327.

[35] K. R. Pittam, D. Ronanki, P. Perumal, A. R. Beig, and S. S. Williamson, ‘Torque Ripple Minimization of Four-phase Switched Reluctance Motor using Direct Torque Control with an Innovative Switching Sequence Scheme’, 2019 IEEE Energy Convers. Congr. Expo. ECCE 2019, pp. 1810–1815, 2019, doi: 10.1109/ECCE.2019.8912508.

[36] R. M. Abdel-Fadil and L. Számel, ‘Direct Instantaneous Torque Control of the Switched Reluctance Motor for Electric Vehicles Applications Using Fuzzy Logic Control’, Acta Tech. Jaurinensis, vol. 12, no. 2, pp. 101–116, 2019, doi: 10.14513/actatechjaur.v12.n2.496.

[37] P. K. Reddy, D. Ronanki, and P. Perumal, ‘Efficiency improvement and torque ripple minimisation of four-phase switched reluctance motor drive using new direct torque control strategy’, IET Electr. Power Appl., vol. 14, no. 1, pp. 52–61, 2020, doi: 10.1049/iet-epa.2019.0432.

[38] J. Liu, L. Wang, L. Yi, G. Zhu, and X. Yin, ‘Optimization of SRM Direct Instantaneous Torque Control Strategy based on Improved Firefly Algorithm’, 2019 3rd IEEE Conf. Energy Internet Energy Syst. Integr. Ubiquitous Energy Netw. Connect. Everything, EI2 2019, no. 2, pp. 364–368, 2019, doi: 10.1109/EI247390.2019.9062228.

[39] Pittam, K. R., Ronanki, D., Perumal, P., & Williamson, S. S. (2019). New Direct Torque and Flux Control with Improved Torque Per Ampere for Switched Reluctance Motor. In 2019 IEEE International Electric Machines & Drives Conference (IEMDC) (pp. 1792–1797). 2019 IEEE International Electric Machines & Drives Conference (IEMDC). IEEE. https://doi.org/10.1109/iemdc.2019.8785327

[40] G. Fang and J. Bauman, ‘Optimized switching angle-based torque control of switched reluctance machines for electric vehicles’, 2020 IEEE Transp. Electrif. Conf. Expo, ITEC 2020, vol. 2, no. c, pp. 186–191, 2020, doi: 10.1109/ITEC48692.2020.9161705.

[41] S. Wang, Z. Hu, and X. Cui, ‘Research on Novel Direct Instantaneous Torque Control Strategy for Switched Reluctance Motor’, IEEE Access, vol. 8, pp. 66910–66916, 2020, doi: 10.1109/ACCESS.2020.2986393.

[42] Y. Chen, Q. Jiang, L. Zhai, F. Liang, and W. Yao, ‘Direct Instantaneous Torque Control of Switched Reluctance Motor Using Adaptive Excitation Angle’, Proc. 15th IEEE Conf. Ind. Electron. Appl. ICIEA 2020, no. 2, pp. 1359–1364, 2020, doi: 10.1109/ICIEA48937.2020.9248263.

[43] Q. Sun, J. Wu, and C. Gan, ‘Optimized Direct Instantaneous Torque Control for SRMs with Efficiency Improvement’, IEEE Trans. Ind. Electron., vol. 68, no. 3, pp. 2072–2082, 2021, doi: 10.1109/TIE.2020.2975481.

[44] Y. Cheng, ‘Modified PWM Direct Instantaneous Torque Control System for SRM’, Math. Probl. Eng., vol. 2021, 2021, doi: 10.1155/2021/1158360.

[45] M. Hamouda, A. A. Menaem, H. Rezk, M. N. Ibrahim, and L. Számel, ‘Comparative evaluation for an improved direct instantaneous torque control strategy of switched reluctance motor drives for electric vehicles’, Mathematics, vol. 9, no. 4, pp. 1–17, 2021, doi: 10.3390/math9040302.

[46] P. Ren, J. Zhu, Z. Jing, Z. Guo, and A. Xu, ‘Improved DITC strategy of switched reluctance motor based on adaptive turn-on angle TSF’, Energy Reports, vol. 8, pp. 1336–1343, 2022, doi: 10.1016/j.egyr.2022.08.076.

[47] Y. Yin, ‘Optimal Direct Instantaneous Torque Control for SRMs Using Advanced Sliding Mode Controller’, Appl. Sci., vol. 12, no. 23, 2022, doi: 10.3390/app122312177.

[48] F. Al-Amyal, M. Hamouda, and L. Számel, ‘Performance improvement based on adaptive commutation strategy for switched reluctance motors using direct torque control’, Alexandria Eng. J., vol. 61, no. 11, pp. 9219–9233, 2022, doi: 10.1016/j.aej.2022.02.039.

[49] F. Al-Amyal, L. Számel, and M. Hamouda, 'An enhanced direct instantaneous torque control of switched reluctance motor drives using ant colony optimization', Ain Shams Eng. J., vol. 14, no. 5, p. 101967, 2023, doi: 10.1016/j.asej.2022.101967.

[50] Y. Cai, Z. Dong, H. Liu, Y. Liu, and Y. Wu, 'Direct Instantaneous Torque Control of SRM Based on a Novel Multilevel Converter for Low Torque Ripple', World Electr. Veh. J., vol. 14, no. 6, 2023, doi: 10.3390/wevj14060140.

[51] R. Abdel-Fadil and L. Szamel, 'Enhancement of the switched reluctance motor performance for electric vehicles applications using predictive current control', CANDO-EPE 2018 - Proc. IEEE Int. Conf. Work. Obuda Electr. Power Eng., pp. 195–199, 2018, doi: 10.1109/CANDO-EPE.2018.8601168.

[52] A. Xu, C. Shang, J. Chen, J. Zhu, and L. Han, 'A New Control Method Based on DTC and MPC to Reduce Torque Ripple in SRM', IEEE Access, vol. 7, pp. 68584–68593, 2019, doi: 10.1109/ACCESS.2019.2917317.

[53] R. Abdel-Fadil and L. Számel, 'Predictive direct torque control of switched reluctance motor for electric vehicles drives', Period. Polytech. Electr. Eng. Comput. Sci., vol. 64, no. 3, pp. 264–273, 2020, doi: 10.3311/PPee.15496.

[54] G. Fang, J. Ye, D. Xiao, Z. Xia, and A. Emadi, 'Computational-Efficient Model Predictive Torque Control for Switched Reluctance Machines with Linear-Model-Based Equivalent Transformations', IEEE Trans. Ind. Electron., vol. 69, no. 6, pp. 5465–5477, 2022, doi: 10.1109/TIE.2021.3091918.

[55] L. Sheng, G. Wang, Y. Fan, J. Liu, D. Liu, and D. Mu, 'An Improved Direct Predictive Torque Control for Torque Ripple and Copper Loss Reduction in SRM Drive', Appl. Sci., vol. 13, no. 9, 2023, doi: 10.3390/app13095319.

[56] Sahoo, S. K., Panda, S. K., & Xu, J. X. (n.d.). Iterative learning control based direct instantaneous torque control of switched reluctance motors. In 2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No.04CH37551) (pp. 4832–4837). 2004 IEEE 35th Annual Power Electronics Specialists Conference. IEEE. https://doi.org/10.1109/pesc.2004.1354854

[57] Sahoo, N. C., Xu, J. X., & Panda, S. K. (1998). An Iterative Learning Approach to Torque Ripple Minimization in Switched Reluctance Motors. In IFAC Proceedings Volumes (Vol. 31, Issue 27, pp. 303–308). Elsevier BV. https://doi.org/10.1016/s1474-6670(17)40045-0

[58] Sahoo, N. C., Xu, J. X., & Panda, S. K. (2001). Low torque ripple control of switched reluctance motors using iterative learning. In IEEE Transactions on Energy Conversion (Vol. 16, Issue 4, pp. 318–326). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/60.969470

[59] Sahoo, S. K., Panda, S. K., & Xu, J. X. (n.d.). Iterative learning control based direct instantaneous torque control of switched reluctance motors. In 2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No.04CH37551) (pp. 4832–4837). 2004 IEEE 35th Annual Power Electronics Specialists Conference. IEEE. https://doi.org/10.1109/pesc.2004.1354854

[60] Wang, S.-C., Liu, Y.-H., Wang, S.-J., Chen, Y.-C., & Lin, S.-Z. (2007). Adaptive Iterative Learning Control of Switched Reluctance Motors for Minimizing Energy Conversion Loss and Torque Ripple. In 2007 IEEE Power Electronics Specialists Conference (pp. 1796–1802). 2007 IEEE Power Electronics Specialists Conference. IEEE. https://doi.org/10.1109/pesc.2007.4342273

[61] E. Sekhara Rao, 'Torque Ripple Minimization of a Switched Reluctance Motor using Fuzzy Logic Control', Int. J. Recent Innov. Trends Comput. Commun., vol. 3, no. 7, 2015.

[62] M. S. Wang, S. C. Chen, W. C. Fang, and P. H. Chuang, 'Torque ripple reduction of switched reluctance motor using fuzzy control', Eng. Comput. (Swansea, Wales), vol. 33, no. 6, pp. 1668–1679, 2016, doi: 10.1108/EC-08-2015-0220.

[63] Divandari, M., & Rezaie, B. (2016). Fuzzy Logic Control of Switched Reluctance Motor Drives. In New Applications of Artificial Intelligence. InTech. https://doi.org/10.5772/63642

[64] Abdel-Fadil, R. M., & Számel, L. (2019). Direct Instantaneous Torque Control of the Switched Reluctance Motor for Electric Vehicles Applications Using Fuzzy Logic Control. In Acta Technica Jaurinensis (Vol. 12, Issue 2, pp. 101–116). Szechenyi Istvan University. https://doi.org/10.14513/actatechjaur.v12.n2.496

[65] M. Ma, F. Ling, F. Li, and F. Liu, 'Torque ripple suppression of switched reluctance motor by segmented harmonic currents injection based on adaptive fuzzy logic control', IET Electr. Power Appl., vol. 14, no. 2, pp. 325–335, 2020, doi: 10.1049/iet-epa.2019.0027.

[66] H. Haq and H. I. Okumus, 'Flc-Dtc Method for Torque Ripples Minimization of 8/6 Switched Reluctance Motors Drive', JAREE (Journal Adv. Res. Electr. Eng., vol. 4, no. 1, pp. 51–55, 2020, doi: 10.12962/j25796216.v4.i1.114.

[67] A. K. Kolluru and K. K. Malligunta, 'Fuzzy Controller Based DTC of SRM Drive Fed by Common High Side Asymmetric Switch Converter', Int. J. Electr. Comput. Eng. Syst., vol. 13, no. 8, pp. 701–708, 2022, doi: 10.32985/ijeces.13.8.10.

[68] N. Padmavathi, R. Suresh, N. P. Ponnuviji, S. R. Balaji, G. Yamini, and K. R. Chairma Lakshmi, 'Analysis of Non-Linear Dynamic Characteristics of Fuzzy-Based SRM Drive for Electric Vehicle Applications', Commun. Appl. Nonlinear Anal., vol. 31, no. 2s, pp. 163–172, 2024, doi: 10.52783/cana.v31.618.

[69] P. H. Truong, D. Flieller, N. K. Nguyen, J. Mercklé, and G. Sturtzer, 'Torque ripple minimization in non-sinusoidal synchronous reluctance motors based on artificial neural networks', Electr. Power Syst. Res., vol. 140, pp. 37–45, 2016, doi: 10.1016/j.epsr.2016.06.045.

[70] V. Pushparajesh, M. Balamurugan, and N. Ramaiah, 'A RTIFICIAL N EURAL N ETWORK BASED D

IRECT T ORQUE C ONTROL OF F OUR P HASE S WITCHED R ELUCTANCE M OTOR', pp. 1–8.

[71] I. Tariq, R. Muzzammel, U. Alqasmi, and A. Raza, 'Artificial Neural Network-Based Control of Switched Reluctance Motor for Torque Ripple Reduction', Math. Probl. Eng., vol. 2020, 2020, doi: 10.1155/2020/9812715.

[72] X. Dang, Y. Shi, and H. Peng, 'Torque–flux linkage recurrent neural network adaptive inversion control of torque for switched reluctance motor', IET Electr. Power Appl., vol. 14, no. 9, pp. 1612–1623, 2020, doi: 10.1049/iet-epa.2020.0105.

[73] K. Chenchireddy, V. Kumar, G. Eswaraiah, K. R. Sreejyothi, S. A. Sydu, and L. B. Ganesh, 'Torque Ripple Minimization in Switched Reluctance Motor by Using Artificial Neural Network', 2022 IEEE 2nd Int. Conf. Sustain. Energy Futur. Electr. Transp. SeFeT 2022, no. October, 2022, doi: 10.1109/SeFeT55524.2022.9909305.

[74] J. Xu, C. Huang, W. Cao, and Y. Wu, 'Torque Ripple Control Strategy of Switched Reluctance Motor Based on BP Neural Network', J. Phys. Conf. Ser., vol. 2242, no. 1, 2022, doi: 10.1088/1742-6596/2242/1/012036.

[75] H. Alharkan, 'Torque Ripple Minimization of Variable Reluctance Motor Using Reinforcement Dual NNs Learning Architecture', Energies, vol. 16, no. 13, 2023, doi: 10.3390/en16134839.

[76] D, G., Saxena, V., Singh, D. P., & Faujdar, P. K. (2024). Neural Network based Direct Torque Controller of SRM for EV Application. In S. G. Malla, B. Pragathi, U. R. Muduli, & H. Awad (Eds.), E3S Web of Conferences (Vol. 540, p. 02003). EDP Sciences. https://doi.org/10.1051/e3sconf/202454002003

[77] M. Chaple, S. Bodkhe, and P. Daigavane, 'Torque ripple minimization in Switch reluctance motor drives: An ANFACO based control', Int. J. Intell. Eng. Syst., vol. 11, no. 4, pp. 264–274, 2018, doi: 10.22266/ijies2018.0831.26.

[78] M. Omar, M. H. Bakr, and A. Emadi, 'Advanced Design Optimization of Switched Reluctance Motors for Torque Improvement Using Supervised Learning Algorithm', IEEE Access, vol. 11, pp. 122057–122068, 2023, doi: 10.1109/ACCESS.2023.3328143.

[79] S. Kandhasamy, 'Machine learning based SRM control using FPGAs for torque ripple minimization', 2020 Int. Conf. Artif. Intell. Inf. Commun. ICAIIC 2020, pp. 675–680, 2020, doi: 10.1109/ICAIIC48513.2020.9065241.

[80] Q. Li, A. Xu, C. Shang, J. Zhu, and L. Zhou, 'Non-linear deadbeat direct torque and flux control for switched reluctance motor', IET Power Electron., vol. 13, no. 18, pp. 4176–4182, 2020, doi: 10.1049/iet-pel.2020.0244.

[81] M. M. Namazi, M. M. Borujeni, A. Rashidi, S. M. S. Nejad, and J. W. Ahn, 'Torque ripple reduction of switched reluctance motor drive with adaptive sliding mode control and Particle Swarm Optimization', IEEE/ASME Int. Conf. Adv. Intell. Mechatronics, AIM, vol. 2015-Augus, pp. 371–376, 2015, doi: 10.1109/AIM.2015.7222560.

[82] G. Singh and B. Singh, 'Design and Implementation of Sliding Mode Control of Light Electric Vehicle Employing Switched Reluctance Motor', IECON Proc. (Industrial Electron. Conf., vol. 2019-Octob, pp. 2646–2651, 2019, doi: 10.1109/IECON.2019.8926922.

[83] F. Ben Salem, I. Bahri, H. Maamri, and N. Derbel, 'A Second-Order Sliding Mode Control of Switched Reluctance Motor', Electr. Power Components Syst., vol. 48, no. 6–7, pp. 640–651, 2020, doi: 10.1080/15325008.2020.1797937.

[84] M. V. De Paula and T. A. D. S. Barros, 'A sliding mode ditc cruise control for srm with steepest descent minimum torque ripple point tracking', IEEE Trans. Ind. Electron., vol. 69, no. 1, pp. 151–159, 2022, doi: 10.1109/TIE.2021.3050349.

[85] X. Sun, J. Wu, G. Lei, Y. Guo, and J. Zhu, 'Torque Ripple Reduction of SRM Drive Using Improved Direct Torque Control with Sliding Mode Controller and Observer', IEEE Trans. Ind. Electron., vol. 68, no. 10, pp. 9334–9345, 2021, doi: 10.1109/TIE.2020.3020026.

[86] Yin, Y. (2022). Optimal Direct Instantaneous Torque Control for SRMs Using Advanced Sliding Mode Controller. In Applied Sciences (Vol. 12, Issue 23, p. 12177). MDPI AG. https://doi.org/10.3390/app122312177

[87] V. Q. Vinh and V. T. Ha, 'Improved Torque Ripple of Switched Reluctance Motors using Sliding Mode Control for Electric Vehicles', Eng. Technol. Appl. Sci. Res., vol. 13, no. 1, pp. 10140–10144, 2023, doi: 10.48084/etasr.5559.

[88] H. Kotb, A. H. Yakout, M. A. Attia, R. A. Turky, and K. M. AboRas, 'Speed control and torque ripple minimization of SRM using local unimodal sampling and spotted hyena algorithms based cascaded PID controller', Ain Shams Eng. J., vol. 13, no. 4, p. 101719, 2022, doi: 10.1016/j.asej.2022.101719.

[89] J. Oloo and S. Laszlo, 'Torque Ripple Minimization for Switched Reluctance Motor Drives Based on Harris Hawks–Radial Basis Function Approximation', Energies, vol. 18, no. 4, pp. 1–26, 2025, doi: 10.3390/en18041006.

[90] Li, Q., Xu, A., Shang, C., Zhu, J., & Zhou, L. (2020). Non-linear deadbeat direct torque and flux control for switched reluctance motor. In IET Power Electronics (Vol. 13, Issue 18, pp. 4176–4182). Institution of Engineering and Technology (IET). https://doi.org/10.1049/iet-pel.2020.0244

[91] Hamouda, M., Al-Amyal, F., Odinaev, I., Ibrahim, M. N., & Számel, L. (2022). A Novel Universal Torque Control of Switched Reluctance Motors for Electric Vehicles. In Mathematics (Vol. 10, Issue 20, p. 3833). MDPI AG. https://doi.org/10.3390/math10203833

[92] Shahakar, D. A., & Warkad, S. B. (2022). An optimal angle control strategy for switched reluctance motor drive in EV applications. In Journal of Control and Decision (Vol. 11, Issue 2, pp. 271–282). Informa UK Limited. https://doi.org/10.1080/23307706.2022.2150329

[93] Ren, P., Zhu, J., Jing, Z., Guo, Z., & Xu, A. (2022). Improved DITC strategy of switched reluctance motor based on adaptive turn-on angle TSF. In Energy Reports (Vol. 8, pp. 1336–1343). Elsevier BV. https://doi.org/10.1016/j.egyr.2022.08.076

[94] Hamouda, M., Al-Amyal, F., Odinaev, I., Ibrahim, M. N., & Számel, L. (2022). A Novel Universal Torque Control of Switched Reluctance Motors for Electric Vehicles. In Mathematics (Vol. 10, Issue 20, p. 3833). MDPI AG. https://doi.org/10.3390/math10203833

[95] Sheng, L., Wang, G., Fan, Y., Liu, J., Liu, D., & Mu, D. (2023). An Improved Direct Predictive Torque Control for Torque Ripple and Copper Loss Reduction in SRM Drive. In Applied Sciences (Vol. 13, Issue 9, p. 5319). MDPI AG. https://doi.org/10.3390/app13095319

[96] Al Quraan, L., & Szamel, L. (2023). Torque ripple reduction of switched reluctance motor using direct instantaneous torque control and adaptive turn-on technique for electric vehicle applications. In IET Electric Power Applications (Vol. 17, Issue 12, pp. 1502–1514). Institution of Engineering and Technology (IET). https://doi.org/10.1049/elp2.12358

[97] Hao, Z., Yu, Q., Cao, X., Deng, X., & Shen, X. (2020). An Improved Direct Torque Control for a Single-Winding Bearingless Switched Reluctance Motor. In IEEE Transactions on Energy Conversion (Vol. 35, Issue 3, pp. 1381–1393). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/tec.2020.2988549

[98] Sun, X., Feng, L., Diao, K., & Yang, Z. (2021). An Improved Direct Instantaneous Torque Control Based on Adaptive Terminal Sliding Mode for a Segmented-Rotor SRM. In IEEE Transactions on Industrial Electronics (Vol. 68, Issue 11, pp. 10569–10579). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/tie.2020.3029463

[99] Xu, A., Shang, C., Chen, J., Zhu, J., & Han, L. (2019). A New Control Method Based on DTC and MPC to Reduce Torque Ripple in SRM. In IEEE Access (Vol. 7, pp. 68584–68593). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/access.2019.2917317

[100] Yan, N., Cao, X., & Deng, Z. (2019). Direct Torque Control for Switched Reluctance Motor to Obtain High Torque–Ampere Ratio. In IEEE Transactions on Industrial Electronics (Vol. 66, Issue 7, pp. 5144–5152). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/tie.2018.2870355

[101] Saha, N., & Panda, S. (2017). Speed control with torque ripple reduction of switched reluctance motor by Hybrid Many Optimizing Liaison Gravitational Search technique. In Engineering Science and Technology, an International Journal (Vol. 20, Issue 3, pp. 909–921). Elsevier BV. https://doi.org/10.1016/j.jestch.2016.11.018

[102] Debouza, M., Al-Durra, A., Hasanien, H. M., Leng, S., & Taha, W. (2018). Optimization of Switched Reluctance Motor Drive Firing Angles Using Grey Wolf Optimizer for Torque Ripples Minimization. In IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society (pp. 619–624). IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society. IEEE. https://doi.org/10.1109/iecon.2018.8591473

[103] Reis, R. R. C., Kimpara, M. L. M., Galotto, L., & Pinto, J. O. P. (2023). Genetic Algorithm-Based Commutation Angle Control for Torque Ripple Mitigation in Switched Reluctance Motor Drives. In IEEE Access (Vol. 11, pp. 97331–97339). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/access.2023.3313436

[104] Wang, H., Wu, J., Xie, C., & Guo, Z. (2025). Vehicle-Mounted SRM DITC Strategy Based on Optimal Switching Angle TSF. In World Electric Vehicle Journal (Vol. 16, Issue 1, p. 26). MDPI AG. https://doi.org/10.3390/wevj16010026