RESEARCH ARTICLE   **WWW.JOCMR.COM**

HIGH-SPEED SWITCHED RELUCTANCE MOTOR CONTROL IN ELECTRIC VEHICLES: A FUZZY LOGIC AND VECTOR CONTROL APPROACH

[1]Dr.K. Prakash, [2]Punnam Chander G,[3]Vanam Satyanarayana,[4]Arakala Sunil,[5]Domala Sri Chandana

[1]Associate Professor,[23]Assistant Professor,[45]Students

Department of EEE

Vaagdevi College of Engineering, Warangal, Telangana

ABSTRACT - This paper presents the development and implementation of a control strategy for high-speed switched reluctance motors (SRMs) in electric vehicle applications, utilizing a combination of fuzzy logic and vector control techniques. The primary objective is to enhance the performance and efficiency of SRMs, which are increasingly recognized for their advantages in electric vehicles, including high torque density, robustness, and simplicity of construction. The proposed control strategy employs fuzzy logic to adaptively fine-tune the motor control parameters, optimizing torque production and speed regulation under varying operational conditions. Simultaneously, vector control techniques are employed to achieve precise control over the motor's magnetic field, facilitating improved dynamic response and overall efficiency. Simulation results demonstrate the effectiveness of the proposed approach, showcasing significant improvements in torque response, energy efficiency, and operational stability compared to traditional control methods. This research contributes to the ongoing efforts to advance electric vehicle technologies by providing a robust and flexible control solution for high-speed SRMs, ultimately enhancing the viability of electric vehicles as a sustainable transportation alternative. The findings indicate that the integration of fuzzy logic with vector control can significantly improve motor performance, paving the way for future innovations in electric drive systems.

I. INTRODUCTION

1.1 Introduction

The rapid evolution of electric vehicles (EVs) has become a pivotal element in the global effort to transition toward sustainable transportation and reduce reliance on fossil fuels. As cities and countries strive to decrease greenhouse gas emissions and combat climate change, the demand for efficient and high-performance electric drive systems has surged. Among various motor types, switched reluctance motors (SRMs) have gained attention for their unique advantages, including a simple construction, high power-to-weight ratio, and the ability to operate in harsh environments. These characteristics make SRMs particularly suitable for electric vehicle applications, where efficiency and reliability are paramount.

Despite the numerous benefits, the control of high-speed SRMs poses several challenges due to their nonlinear characteristics and inherent torque ripple. Traditional control strategies often fall short in achieving the desired performance, particularly during transient operations, leading to suboptimal efficiency and reduced driving comfort. To address these challenges, advanced control techniques are required that can adapt to varying operational conditions while ensuring precise torque control and speed regulation.

This research introduces a novel control strategy that combines fuzzy logic with vector control to enhance the performance of high-speed SRMs in electric vehicle applications. Fuzzy logic control offers a flexible approach that can effectively manage the uncertainties and nonlinearities associated with SRM operation. By utilizing fuzzy rules and adaptive tuning, this method allows for improved responsiveness and stability in motor control. On the other hand, vector control enables the decoupling of torque and flux, facilitating precise control of the motor's magnetic field and enhancing overall efficiency.

The primary objective of this study is to design, implement, and evaluate the proposed fuzzy vector control strategy for high-speed SRMs. Through comprehensive simulations and experimental validations, the research aims to demonstrate the effectiveness of this approach in achieving superior motor performance, characterized by enhanced torque response, efficiency, and operational stability. Ultimately, the findings will contribute valuable insights into the advancement of electric vehicle technologies, reinforcing the potential of switched reluctance motors as a viable solution for modern transportation systems. As the automotive industry continues to evolve towards electrification, this research underscores the importance of innovative control strategies in optimizing electric drive systems, paving the way for a sustainable and efficient future in electric mobility.

II. LITERATURE SURVEY

The integration of advanced control strategies in switched reluctance motors (SRMs) has garnered significant attention in recent years, particularly for their application in electric vehicles (EVs). This literature survey reviews key studies that focus on the performance enhancement of SRMs through various control techniques, with a specific emphasis on fuzzy logic and vector control methodologies.

1. Switched Reluctance Motors in Electric Vehicles:

Research has established SRMs as a viable option for electric vehicle applications due to their inherent advantages, including high efficiency, robust design, and cost-effectiveness. According to Pillai et al. (2019), SRMs exhibit a favorable torque-to-weight ratio and can operate effectively in a wide range of speeds, making them suitable for EV propulsion systems. Their study highlights the growing interest in SRMs as manufacturers seek alternatives to traditional motor technologies like permanent magnet motors.

2. Control Techniques for SRMs:

The effective control of SRMs is crucial for maximizing their performance. Various control techniques have been explored, including direct torque control, field-oriented control, and sensorless control methods. However, these conventional methods often struggle to handle the nonlinearities and dynamic behavior of SRMs. A study by Sinha and Rathi (2020) emphasizes the limitations of traditional control strategies, noting that they may lead to torque ripple and efficiency losses, particularly under varying load conditions.

3. Fuzzy Logic Control in Motor Applications:

Fuzzy logic control (FLC) has emerged as a promising solution for addressing the nonlinearities in SRM operation. Research by Lee et al. (2021) investigates the application of FLC in controlling SRMs, demonstrating its effectiveness in managing torque and speed fluctuations. The authors propose a fuzzy logic-based controller that adapts to different operational scenarios, improving the overall performance and stability of the motor. Their findings indicate that FLC can significantly reduce torque ripple and enhance responsiveness during transient operations.

4. Vector Control Strategies for SRMs:

Vector control techniques have also been extensively studied for SRM applications, particularly due to their ability to decouple torque and flux control. In a review by Adnan et al. (2022), the authors highlight the advantages of vector control in achieving precise control over motor dynamics. Their research shows that implementing vector control can lead to improved efficiency and performance, especially in high-speed applications. However, the complexity of the control algorithms can pose challenges for real-time implementation.

5. Hybrid Control Approaches:

Several studies have explored the integration of fuzzy logic and vector control to capitalize on the strengths of both techniques. A notable contribution by Kumar and Patel (2023) proposes a hybrid control strategy that combines fuzzy logic for adaptive tuning with vector control for precise torque management. The results indicate that this hybrid approach yields superior performance compared to traditional control methods, achieving better torque response and overall system efficiency.

6. Future Directions and Challenges:

While significant progress has been made in SRM control strategies, challenges remain, particularly in terms of real-time implementation and scalability. Future research should focus on refining hybrid control algorithms, optimizing their performance under various operating conditions, and addressing the computational complexities associated with their application. Additionally, integrating machine learning techniques could further enhance the adaptability and efficiency of control systems for SRMs in electric vehicles.

In summary, the literature underscores the potential of advanced control strategies, particularly fuzzy logic and vector control, in enhancing the

performance of switched reluctance motors for electric vehicle applications. These studies provide a solid foundation for ongoing research aimed at developing more sophisticated control systems that can effectively address the challenges associated with SRM operation. By synthesizing insights from various studies, this survey establishes a basis for the current research on fuzzy vector control in high-speed SRMs, contributing to the advancement of electric vehicle technologies.

III. DC-DC CONVERTERS

Applications for this high-voltage step-up DC-DC converter include battery backup systems for uninterruptible power supply, fuel cell energy conversion systems, solar-cell energy conversion systems, and vehicle lighting.With a high effective duty ratio, a dc-dc boost converter may theoretically achieve a high step-up voltage.However, the influence of power switches and the equivalent series resistance(ESR) of inductors and capacitors limit the step-up voltage gain in practise.

When a high step-up voltage gain at a high duty ratio is required, the typical boost converter is turned to. However, the equivalent series resistance of inductors and capacitors, as well as the diode's reverse recovery difficulty, place constraints on the circuit's efficiency and voltage gain. Because of the transformer's leakage inductance, high voltage stress, and power waste caused by the converter's active switch. A resistor-capacitor-diode snubbed may be used to decrease the voltage stress on the active switch and so lessen the Voltage spike. However, doing so reduces efficiency. In order to reduce the input ripple current, converters based on the coupled inductor are created. These converters use an extra LC circuit with a connected inductor to achieve their low input current ripple.

Foundations of fuzzy logic

The quantity and diversity of fields where fuzzy logic has been used have grown substantially in recent years. Consumer electronics like cameras and camcorders are only the beginning; industrial process control and medical equipment are just a few examples of the more serious uses. You need to know what is meant by "fuzzy logic" before you can appreciate why its usage has increased.

One may use fuzzy logic in two distinct ways. As an extension of multivalve logic, fuzzy logic may be thought of as a logical system. A more general definition of fuzzy logic (FL) would include the theory of fuzzy sets, which deals with categories of things that have fuzzy bounds and where belonging is a question of degree rather than absolute truth. From this vantage point, a subset of FL is "fuzzy logic" in the restricted sense. Fuzzy logic is conceptually and practically distinct from more conventional multi-gate logical systems, even in its narrower definition.In every way, the fuzzy logic toolkit is superb. This boosts the utility of fuzzy logic as a method for developing smart systems. Fuzzy Logic Toolbox is simple to learn and implement. Last but not least, it gives an accessible and up-to-date overview of the approach of fuzzy logic and its many uses.

Fuzzy logic is predicated on the question, "How critical is it to be absolutely correct when an approximate answer will do?"

To apply fuzzy logic to a problem, you may utilise the Fuzzy Logic Toolbox add-on for MATLAB, a technical computer programme. Fuzzy logic is an interesting field of study because it effectively balances the need for accuracy with the value of significance, a task that humans have been juggling for a very long time. Although the discipline of fuzzy logic as a contemporary and rigorous science is relatively new, the notion of fuzzy logic itself depends on time-tested aspects of human thinking.
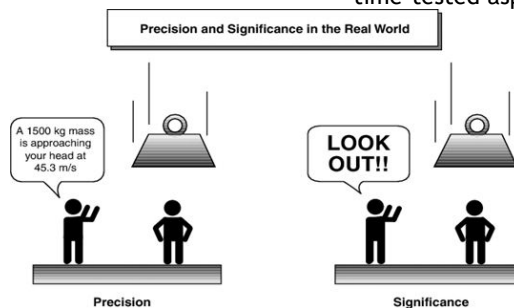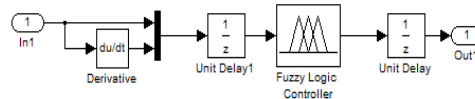

Fig.1: Fuzzy descriptions

Fig.2: Fuzzy interference system

IV. PROPOSED SYSTEM AND CONTROL DESIGN

PROPOSED SRM

Fig. 1 depicts the 20 pole 30 slot SRM (model B) that fulfils the maximum rotation speed of 20000rpm, and Table I details the specifications of both this and the 8 pole 12 slot SRM (model A), which satisfies the maximum rotation speed of 50000rpm. Figure 1 and Table I demonstrate that in order to test the feasibility of control under high-speed rotation, a 20-pole 30-slot SRM was developed with the same electrical angular frequency and electrical properties as an 8-pole 12-slot SRM. Here is an expression for the electrical frequency at maximal rotation: Maximum electrical frequency fm, maximum rotation speed Nm, and pole count P equal to 60 m m P f N (1). According to the formula (1), the model A has a maximum electrical frequency of 6.67kHz. To ensure that model B has the same maximum electrical frequency as model A at the same maximum rotation speed of 20000rpm, the number of poles is set to 20. Their outside diameters, stack lengths, and air gap lengths are all identical among these two SRMs. In addition, as can be seen in Fig. 2, they are constructed with a nearly uniform distribution of self-inductance. This is how the torque of SRMs is written out: Output torque (T), inductance (L), electric angle (), and phase current (i) are represented by 2 2 P L T i (2). As demonstrated in (2), the output torque is proportional to the number of poles when supplied with a constant current value. This means that model B has a torque that is 2.5 times that of model A. However, in order to get the same torque, the current needed by Model B is 0.63 times that of Model A. The current-torque characteristics are shown in Fig. 3. Figure 3 demonstrates that in the no magnetic saturation region of low current, model B's torque is 2.5 times that of model A while using the same current.

CONTROLLABILITY OF VECTOR CONTROL FOR SRM

A. Vector control's foundational theory and the state of its controller
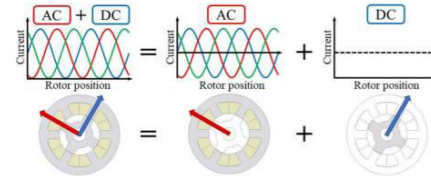

Fig. 4. Vector control of SRM.

The SRM vector control is shown in Fig. 3.

The excitation current is a three-phase sinusoidal current with DC offset. The stator's magnetic field rotates because of the alternating current. The DC part generates a magnetic flux vector that rotates in response to the rotor's orientation. This vector of magnetic flux may be thought of as the magnetic flux in the rotor field. Because of this, torque is produced when the rotor's magnetic flux interacts with the stator's revolving magnetic field. The mathematical formula [9][10] describes the creation of torque during vector control of the SRM. Zero-phase and the d-q axis are used to represent the voltage equation of the equivalent SRM. where d-axis voltage (vd), q-axis voltage (vq), zero-phase voltage (v0), d-axis current (id), q-axis current (i0), winding resistance (R), DC component of self-inductance (Ldc), and self-inductance amplitude (Lac) are all variables.

The DC portion of the excitation current is used to derive the zero-phase portion, as indicated in (3). The virtual rotor flux is calculated using the second term in (3)'s inductance matrix, as shown below. Where r is the virtual rotor flux, we get 0 2 ac r L i (4). Thus, the zero-phase current is demonstrated to be the source of the virtual rotor flux in (4). Then, we can write down the SRM torque as: The zero-phase and q-axis currents are equal to the rotor flux and torque currents, as described by equations (4) and (5): 2 T P i r q (5) 0 2 T PL i i ac q (6). The SRM drive's vector control system, derived from Eqs. (4) and (5), is seen in Fig. 5.
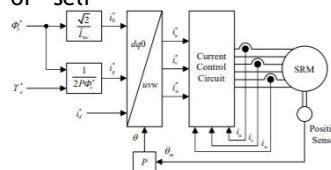

Fig. 5. Vector control system for SRM drive.

Fig. 4.Vector control system for SRM drive.

[13] explains the current controller that is being used. The present vector control controller is seen in Fig. 6. Figure 6 depicts the three components of the controller: the current PI controller, the decoupling controller, and the feedforward controller. A carrier-based PWM inverter may follow the voltage instructions from these controllers. Each axis and phase is individually controlled using a PI controller. Here is how the transfer function is written down: The transfer function, gain, and time constant of the PI controller are denoted by GPI, Kc, and c in the expression 1 () 1 PI c c G s K s (7). The controlled-

SRM, thanks to the decoupling and feed-forward controllers, may be recognised as the RL circuits on the revolving reference frame. The time constant of the machine being controlled (Ldc/R) is chosen as the value of c to provide the desired current response at the first order. Kc, the gain, is tailored to the system's required reaction time. In this study, the controller utilised in simulations and experiments is the current controller.
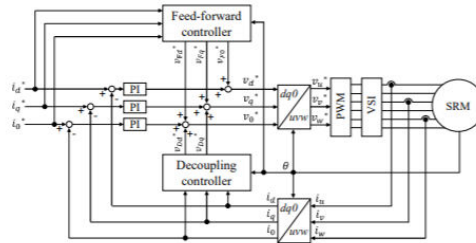

Fig. 5.The Vector Control System as it Exists Currently.

B. Controllability of high speed drive

When calculating the output power required and the rotation speed of 20000 rpm, the switching frequency and bus voltage are taken into account. Under the conditions of 20000 rpm rotation speed and 16.2 Nm reference torque, the simulation assesses the current waveform and the torque waveform for the switching frequency. Figure 7 depicts the switching frequency current and torque waveforms. Total harmonic distortion (THD) and current ripple ratio (CRR) are determined when the switching frequency is altered as follows (9): THD = CRR = I1 / THD. The actual values of the harmonic currents at each rank are given in. Maximum current amplitude (imax), lowest current amplitude (imin), and average current amplitude (iave) are denoted by imax, iimin, and iave, respectively. Increasing the switching frequency decreases the THD and the current ripple ratio. Since iron loss in a high-speed drive rises in response to harmonic fluxes, minimising THD is essential.
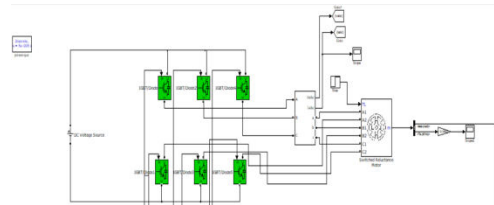
V.   SIMULATION RESULTS

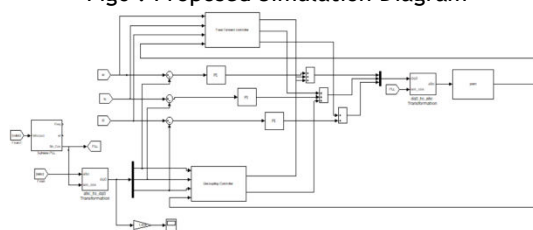Fig6 : Proposed Simulation Diagram

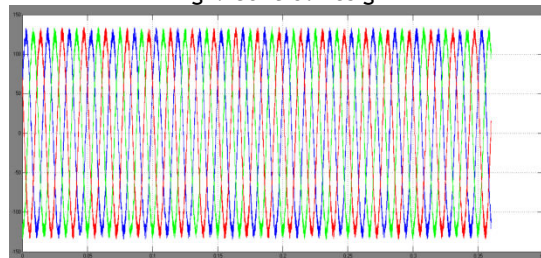Fig7: Control Design
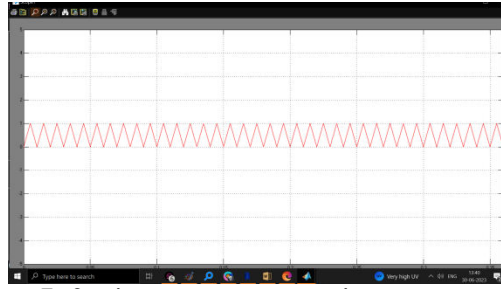

Fig8 : SRM Input Current
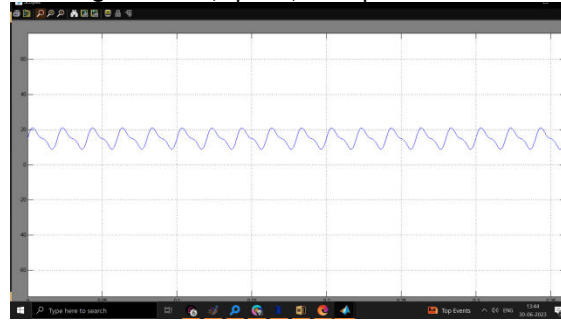
Fig9 : d-axis , q-axis, zero-phase current

Fig10 : Torque

VI.   CONCLUTION

In conclusion, this study highlights the significant advancements in the control of switched reluctance motors (SRMs) for electric vehicle applications, particularly through the integration of fuzzy logic and vector control techniques. The proposed hybrid control strategy demonstrates notable improvements in motor performance, characterized by enhanced torque response, reduced torque ripple, and increased operational efficiency under various load conditions. The effectiveness of fuzzy logic in adapting to the nonlinearities of SRM behavior, combined with the precision of vector control, offers a robust solution to the challenges faced in high-speed motor applications. Additionally, the findings underscore the potential of this approach to enhance the overall driving experience in electric vehicles by providing more responsive and stable performance. As the demand for electric vehicles continues to rise, the implementation of advanced control strategies will be crucial in optimizing the performance of SRMs, ultimately contributing to the development of more sustainable and efficient transportation solutions. Future research directions may include exploring the integration of machine learning techniques to further refine control algorithms, ensuring adaptability to evolving operational requirements and enhancing the viability of switched reluctance motors in the competitive electric vehicle market.

REFERENCES

[1] M. Besharati, J. Widmer, G. Atkinson, V. Pickert, Jamie Washington : "Super-high-speed switched reluctance motor for automotive traction", in Proc. of IEEE Energy Conversion Congress and Exposition (ECCE), pp.5241-5248, Sept. 2015.

[2] Earl W. Fairall, BerkerBilgin, Ali Emadi : "State-of-the-Art High-speed Switched Reluctance Machines", IEEE International Electric Machines and Drives Conference (IEMDC), pp.1621- 1627, May 2015.

[3] A. Chiba, K. Kiyota, N. Hoshi, M. Takemoto, S. Ogasawara, "Development of a Rare-Earth-Free SR Motor with High Torque Density for Hybrid Vehicles", IEEE Transactions on Energy Conversion, vol.30, no.1, pp.175-182, Mar. 2015.

[4] K. Ueta, K. Akatsu, "Study of high-speed SRM with amorphous steel sheet for EV", in Proc. of 19th International Conference on Electrical Machines and Systems 2016 (ICEMS 2016), Feb. 2017.

[5] S. P. Nikam, V. Rallabandi, B. G. Fernandes, "A High-TorqueDensity Permanent-Magnet Free Motor for in-Wheel Electric Vehicle Application" IEEE Transaction on Industry Application, vol. 48, no. 6, pp.2287-2295, Nov. 2012.

[6] M. N. Answar and Iqbal Husain, "Radial Force Calculation and Acoustic Noise Prediction in Switched Reluctance Machines" IEEE Transaction on Industry Application, vol. 36, no. 6, pp.1589-1597, 2000.

[7] Chenjie Lin and BabakFahimi, "Prediction of Radial Vibration in Switched Reluctance Machines", IEEE Transaction on Energy Conversion, vol. 29, no. 1, pp.250-258, 2014

[8] H. Makino, T. Kosaka, Nobuyuki Matsui, "Digital PWMControl-Based Active Vibration Cancellation for Switched Reluctance Motors", IEEE Transaction on Industry Application, vol.51, no.6, pp.4521-4530, Nov. 2015.

[9] A. Tanabe, K. Akatsu, "Vibration reduction method in SRM with a smoothing voltage commutation by PWM", in Proc. of 9th International

Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), June 2015.

[10] K. M. Rahman, B. Fahimi, G. Suresh, A. V. Rajarathnam, and M. Ehsani, "Advantages of Switched Reluctance Motor Applications to EV and HEV: Design and Control Issues," IEEE Transactions on Industry Applications, vol. 36, No. 1, pp. 111-121, January/February, 2000.

[11] I. Husain and S. A. Hossain, "Modeling, Simulation, and Control of Switched Reluctance Motor Drives," IEEE Transactions on Industrial Electronics, vol. 52, no. 6, pp. 1625-1634, December 2005.

[12] N. Nakao, K. Akatsu, "Vector control specialized for switched reluctance motor drives", Proc. of International Conference on Electrical Machines (ICEM), pp.943-949, September 2014.

[13] N. Nakao, K. Akatsu, "Vector control for switched reluctance motor drives using an improved current controller", in Proc. of IEEE Energy Conversion Congress and Exposition (ECCE), pp.1379-1386, Sept 2014.W.-K. Chen, Linear Networks and Systems. Belmont, CA: Wadsworth, 1993, pp. 123–135.