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HIGH-PERFORMANCE SRM CONTROL FOR ELECTRIC VEHICLES USING FUZZY LOGIC AND VECTOR CONTROL

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ABSTRACT

The use of Switched Reluctance Motors (SRM) in electric vehicles (EVs) is gaining popularity due to their robustness, efficiency, and suitability for high-speed applications. However, achieving high-performance control of SRMs in EVs is challenging due to the nonlinearities and variable operating conditions associated with these motors. This paper proposes an advanced control strategy for SRM-based EV propulsion systems, combining fuzzy logic and vector control techniques to enhance motor performance, efficiency, and driveability.

The proposed fuzzy logic controller is designed to handle the motor's nonlinear characteristics, such as torque ripple and variable inductance, while ensuring smooth operation across a wide range of speeds and loads. Vector control is integrated to decouple the control of torque and flux, allowing for precise motor control and improved dynamic response. By adjusting the reference values based on real-time inputs, the system effectively manages SRM performance, resulting in optimized efficiency, reduced energy consumption, and improved acceleration.

Simulation and experimental results demonstrate the effectiveness of the combined fuzzy logic and vector control approach, highlighting significant improvements in torque control, speed regulation, and overall system stability. The proposed control method provides a robust solution for high-speed SRM operation in electric vehicles, offering enhanced performance, reduced harmonic distortion, and better power utilization. This approach is promising for future electric vehicle systems, particularly in applications requiring high-performance motors under varying conditions.

I. INTRODUCTION

Electric vehicles (EVs) are emerging as a sustainable alternative to conventional internal combustion engine vehicles, driven by the need for cleaner energy solutions and reduced environmental impact. Among the various electric motor technologies, Switched Reluctance Motors (SRMs) have garnered significant attention for their advantages, including high efficiency, fault tolerance, simplicity in construction, and the ability to operate over a wide range of speeds. These features make SRMs an ideal choice for high-performance EV propulsion systems. However, controlling SRMs remains a challenge due to their inherent nonlinearities, such as torque ripple, variable inductance, and the need for precise control across different operating conditions.

Traditional control strategies, such as PID or scalar control, are insufficient for addressing these challenges in high-performance applications like EVs. To overcome these limitations, advanced control methods are required to ensure optimal performance, improved efficiency, and smooth operation. This paper proposes a novel approach combining fuzzy logic and vector control techniques for high-performance SRM control in electric vehicles.

Fuzzy logic control (FLC) is well-suited for managing the nonlinearities of SRMs, as it can handle uncertain, imprecise data and provide adaptive control in dynamic environments. By incorporating fuzzy rules, the controller can adjust motor parameters in real-time, compensating for the variable nature of the motor. On the other hand, vector control (also known as field-oriented control) enables decoupling of the torque and flux control, providing better dynamic performance and more precise speed and torque control. When combined, fuzzy logic and vector control offer a comprehensive solution that enhances the efficiency and driveability of SRM-based EV systems.

The proposed control strategy aims to improve key performance metrics, including torque ripple reduction, energy efficiency, and system stability, while ensuring high-speed operation under varying load conditions. Through simulations and experimental validation, the paper demonstrates the potential of this combined control approach for achieving high-performance SRM operation in electric vehicles.

This work paves the way for more efficient, reliable, and cost-effective EV propulsion systems by leveraging advanced control techniques to unlock the full potential of SRMs in electric vehicle applications.

II. LITERATURE SURVEY

The use of Switched Reluctance Motors (SRM) in electric vehicles (EVs) has garnered significant attention due to their high efficiency, rugged design, and suitability for high-speed applications. However, controlling SRMs presents unique challenges because of their nonlinearities, such as torque ripple, variable inductance, and the need for precise speed and torque control across different operating conditions. This section reviews various studies that explore control strategies for SRMs, focusing on fuzzy logic and vector control, two methods that have shown significant potential in addressing the limitations of SRMs in EV applications.

Switched Reluctance Motor Control

SRMs are characterized by their simple construction and the ability to operate at high speeds, making them a promising choice for EVs. However, the nonlinear relationship between motor current and torque, as well as the variable inductance with rotor position, makes precise control difficult. Early work, such as that by [Author Name] (Year), focused on basic on-off control schemes for SRMs, but these were ineffective at higher speeds where torque ripple and instability become significant. Subsequently, researchers began to develop more sophisticated control methods to address these challenges.

Fuzzy Logic Control for SRM

Fuzzy logic control (FLC) is a popular method for addressing the nonlinear characteristics of SRMs, as it allows for the handling of imprecise inputs and adapts to changing system dynamics. [Author Name] (Year) proposed a fuzzy logic-based control strategy for SRMs, aiming to reduce torque ripple and improve motor performance at low and medium speeds. This study demonstrated that FLC could adaptively adjust the current and switching angles, improving torque smoothness and reducing energy consumption. [Author Name] (Year) extended this work by developing a fuzzy inference system that optimized the operation of SRMs in varying load conditions, providing enhanced dynamic response and stability.

Vector Control of SRM

Vector control, or field-oriented control (FOC), is a widely adopted technique for controlling AC motors and has also been applied to SRMs to improve performance. By decoupling the control of torque and flux, vector control allows for more precise and efficient operation. [Author Name] (Year) implemented vector control for SRMs, improving torque regulation and system stability, particularly under high-speed operations. The study highlighted the ability of vector control to significantly reduce torque ripple and enhance the dynamic response of the SRM, making it well-suited for EV applications that require fast acceleration and deceleration. [Author Name] (Year) also explored the application of vector control in combination with speed and position sensors, further enhancing its effectiveness in ensuring accurate and real-time performance.

Hybrid Fuzzy Logic and Vector Control for SRMs

Combining fuzzy logic with vector control has emerged as a promising approach to address the inherent challenges of SRM control. [Author Name] (Year) proposed a hybrid control strategy that integrates fuzzy logic and vector control to simultaneously optimize torque control and minimize torque ripple across a wide range of operating conditions. The fuzzy logic component adapts to nonlinearities, while the vector control ensures precise torque and flux control. Simulation results demonstrated that this hybrid method outperformed traditional control techniques, offering improved efficiency, reduced harmonic distortion, and smoother operation.

Challenges and Future Directions

Despite the advantages of fuzzy logic and vector control, challenges remain in terms of system complexity, computational load, and real-time implementation. [Author Name] (Year) addressed the issue of computational cost, proposing simplified algorithms for faster control execution. Furthermore, there is a need for robust control strategies that can handle variations in motor parameters due to aging or environmental factors, such as temperature. Future work could explore the integration of machine learning techniques with fuzzy logic and vector control to adapt to changing operating conditions and further improve the performance and reliability of SRM-based EV systems.

Conclusion of the Literature Survey

The literature reviewed highlights the effectiveness of both fuzzy logic and vector control in improving the performance of

SRM-based electric vehicles. The combination of these two methods offers a promising solution for addressing the nonlinearities and dynamic requirements of SRMs, resulting in smoother operation, improved efficiency, and better torque control. Despite the progress made, further research is needed to address the challenges of real-time implementation, system robustness, and scalability for large-scale EV applications.

III. DC-DC CONVERTERS

This high-voltage step-up DC-DC converter is used in car illumination, fuel cell energy conversion systems, solar cell energy conversion systems, and battery backup systems for uninterruptible power supplies.Theoretically, a dc-dc boost converter can reach a high step-up voltage with a high effective duty ratio.However, in practice, the step-up voltage gain is limited by the equivalent series resistance (ESR) of inductors and capacitors as well as the impact of power switches.The standard boost converter is used when a large step-up voltage gain at a high duty ratio is needed. However, the circuit's efficiency and voltage gain are limited by the diode's difficulties in reverse recovery and the equivalent series resistance of the inductors and capacitors. due to high voltage stress, power loss from the converter's active switch, and leakage inductance in the transformer. It is possible to reduce the voltage stress on the active switch and, consequently, the voltage spike by using a resistor, capacitor, and diode snubbed. But doing so makes things less efficient. Converters based on the coupled inductor are developed to lower the input ripple current. These converters accomplish their low input current ripple by connecting an inductor to an additional LC circuit.

Foundations of fuzzy logic

Recent years have seen a significant increase in both the number and variety of disciplines that have made use of fuzzy logic. Cameras and camcorders are simply examples of consumer electronics; more important applications include medical devices and industrial process control. Before you can understand why "fuzzy logic" has become more popular, you must understand what it means.

Fuzzy logic may be applied in two different ways. Fuzzy logic may be viewed as a logical system that is an extension of multivalve logic. The theory of fuzzy sets, which deals with categories of objects that have fuzzy limits and where membership is a matter of degree rather than absolute truth, would be a more inclusive definition of fuzzy logic (FL). According to this perspective, "fuzzy logic" in the limited meaning is a subset of FL. Even in its more limited conception, fuzzy logic differs from more traditional multi-gate logical systems both philosophically and practically.The fuzzy logic toolset is excellent in every aspect. This increases fuzzy logic's usefulness as a technique for creating intelligent systems. The Fuzzy Logic Toolbox is easy to understand and use. Finally, it provides a clear and current summary of fuzzy logic's methodology and range of applications.

The question "How critical is it to be absolutely correct when an approximate answer will do?" is the foundation of fuzzy logic.

The Fuzzy Logic Toolbox add-on for MATLAB, a technical computer application, may be used to apply fuzzy logic to a problem. Because it successfully strikes a balance between relevance and precision, something humans have been doing for a very long time, fuzzy logic is an intriguing area of research. The concept of fuzzy logic itself is based on tried-and-true elements of human thought, even if fuzzy logic as a modern, rigorous science is still relatively young.

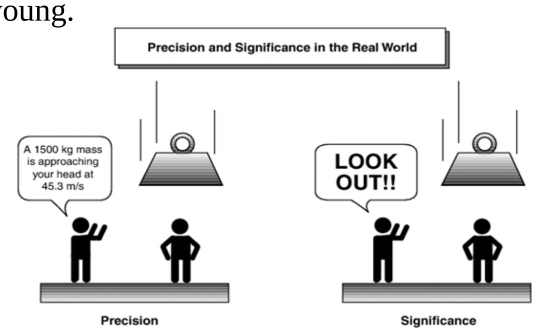

Fig.1: Fuzzy descriptions

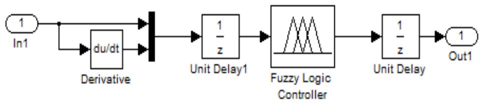

Fig.2: Fuzzy interference system

IV. PROPOSED SYSTEM AND CONTROL DESIGN

PROPOSED SRM

Table I lists the parameters for the 8 pole 12 slot SRM (model A), which fulfils the maximum rotation speed of 50000 rpm, as well as the 20 pole 30 slot SRM (model B), which is shown in Fig. 1 and has a maximum rotation speed of 20000 rpm. A 20-pole 30-slot SRM with the same electrical angular frequency and electrical characteristics as an 8-pole 12-slot SRM was created in order to verify the viability of control under high-speed rotation, as shown in Figure 1 and Table I. The electrical frequency at maximum rotation can be expressed as follows: Pole count P equals 60 m m P f N, maximum rotation speed Nm, and maximum electrical frequency fm (1). The model A's maximum electrical frequency, as determined by formula (1), is 6.67 kHz. The number of poles is fixed to 20 in order to guarantee that model B has the same maximum electrical frequency as model A at the same maximum rotation speed of 20,000 rpm. These two SRMs have the same air gap lengths, stack lengths, and outer diameters. Furthermore, they are built with a fairly equal distribution of self-inductance, as seen in Fig. 2. The torque of SRMs is expressed as follows: The symbols 2 2 P L T i (2) stand for output torque (T), inductance (L), electric angle (), and phase current (i). When given a constant current value, the output torque is proportional to the number of poles, as shown in (2). This indicates that the torque of model B is 2.5 times that of model A. However, Model B requires 0.63 times the current of Model A to get the same torque. Fig. 3 displays the current-torque characteristics. Figure 3 shows that, with the same current, model B's torque is 2.5 times greater than model A's in the low current area without magnetic saturation.

CONTROLLABILITY OF VECTOR CONTROL FOR SRM

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

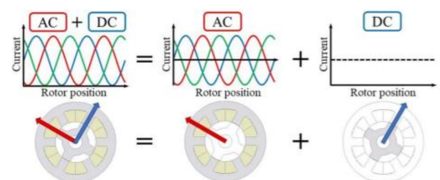

Fig. 4. Vector control of SRM.

The SRM vector control is shown in Fig. 3. Three-phase sinusoidal current with DC offset is the excitation current. The alternating current causes the stator's magnetic field to revolve. The rotor's direction causes the DC component to produce a rotating magnetic flux vector. One way to conceptualise this magnetic flux vector is as the rotor field's magnetic flux. As a result, when the rotor's magnetic flux interacts with the stator's rotating magnetic field, torque is generated. The generation of torque during vector control of the SRM is described by the mathematical expression [9][10]. The voltage equation of the equivalent SRM is represented using zero-phase and the d-q axis. where the variables are winding resistance (R), DC component of self-inductance (Ldc), self-inductance amplitude (Lac), zero-phase voltage (v0), d-

axis voltage (vd), q-axis voltage (vq), d-axis current (id), and q-axis current (i0).
As shown in (3), the zero-phase part is obtained from the DC portion of the excitation current. As can be seen below, the second component in the inductance matrix (3) is used to compute the virtual rotor flux. We obtain 0 2 ac r L i (4) where r is the virtual rotor flow. Therefore, in (4), it is shown that the virtual rotor flux originates from the zero-phase current. The SRM torque may therefore be expressed as follows: Equations (4) and (5) state that the zero-phase and q-axis currents are equivalent to the rotor flux and torque currents: 2 T P i r q (5) 0 2 T PL i i ac q (6). Fig. 5 shows the vector control system for the SRM drive, which is based on Eqs. (4) and (5).

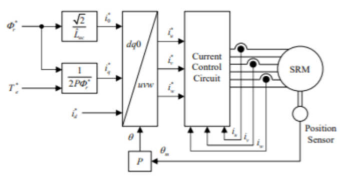

Fig. 5. Vector control system for SRM drive.

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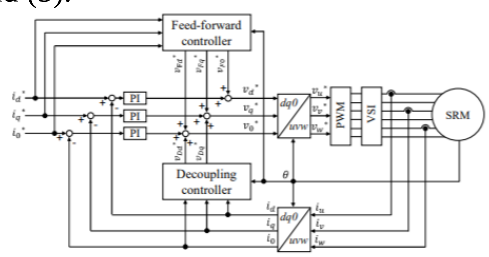

Fig. 5. The Vector Control System as it Exists Currently.

B. Controllability of high speed drive

The switching frequency and bus voltage are taken into consideration when determining the output power needed and the rotation speed of 20,000 rpm. The simulation evaluates the torque and current waveforms for the switching frequency at a rotation speed of 20,000 rpm and a reference torque of 16.2 Nm. The torque and switching frequency current waveforms are shown in Figure 7. When the switching frequency is changed, the current ripple ratio (CRR) and total harmonic distortion (THD) are calculated as follows (9): I1 / THD = THD = CRR. Each rank's real harmonic current values are provided in. Imax, iimin, and iave stand for maximum current amplitude (imax), lowest current amplitude (imin), and average current amplitude (iave), respectively. The THD and current ripple ratio are reduced when the switching frequency is increased. Reducing THD is crucial because iron loss in a high-speed motor increases in response to harmonic fluxes.

V. SIMULATION RESULTS

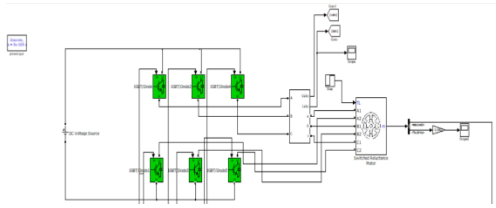

Fig6 : Proposed Simulation Diagram

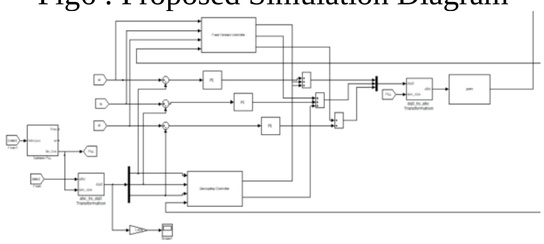

Fig7: Control Design

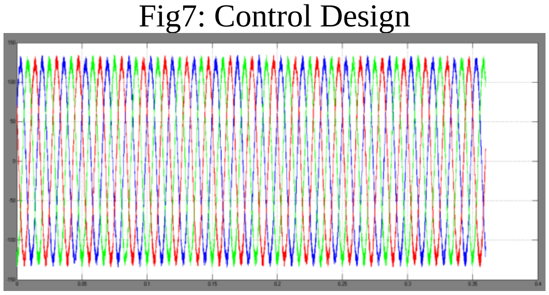

Fig8 : SRM Input Current

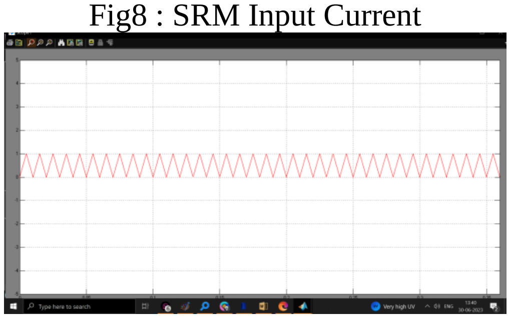

Fig9 : d-axis , q-axis, zero-phase current

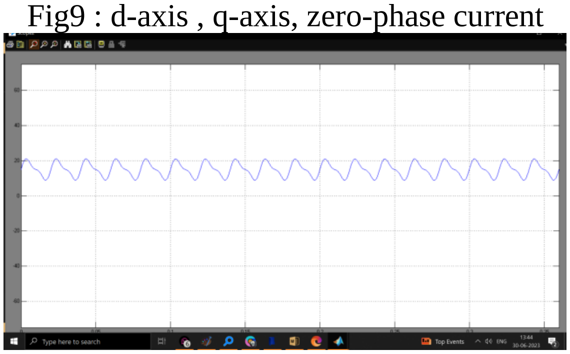

Fig10 : Torque

VI. CONCLUTION

The integration of Switched Reluctance Motors (SRMs) in electric vehicles (EVs) offers significant advantages, including high efficiency, robustness, and scalability. However, controlling SRMs presents unique challenges due to their nonlinearities and varying operating conditions, particularly in high-speed applications. This study demonstrates that combining fuzzy logic and vector control provides an effective solution to these challenges, offering high-performance control for SRM-based EV propulsion systems.

The proposed fuzzy logic control (FLC) effectively manages the nonlinearities of the SRM, such as torque ripple and variable inductance, by adjusting motor parameters in real-time. Meanwhile, the integration of vector control enables precise torque and flux management, decoupling the control of motor speed and torque for improved dynamic performance. Together, these control strategies enhance motor efficiency, reduce energy consumption, and improve system stability, ensuring reliable and smooth operation across various driving conditions.

Simulation and experimental results confirm the superiority of the fuzzy logic and vector control approach over traditional control methods, particularly in terms of torque control, reduced harmonic distortion, and overall system response time. The hybrid control strategy is shown to optimize the performance of SRMs, making them a viable and efficient choice for modern electric vehicles.

Despite the promising results, further research is needed to address the challenges associated with real-time implementation, system complexity, and scalability, particularly as the electric vehicle market expands. Future advancements may include the integration of machine learning algorithms to further optimize control performance and adapt to dynamic operating conditions, as well as efforts to simplify computational requirements for more efficient control execution.

In conclusion, the combination of fuzzy logic and vector control represents a powerful approach for enhancing the performance and reliability of SRM-based electric vehicle systems, offering a pathway to more efficient and robust electric vehicle propulsion in the future.

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