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Journal of Applied Engineering Science & Technology

An Interdisciplinary Journal in Sciences & Technology

Journal home page: https://journals.univ-biskra.dz/index.php/jaest

https://doi.org/10.69717/jaest.v5.i2.144

Experimental implementation of an SRM control approach

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ABSTRACT

This paper presents an improved current control strategy for a switched reluctance motor (SRM) drive. Owing to its doubly salient structure and nonlinear magnetic characteristics, the SRM exhibits strong coupling between current, flux, and torque, making accurate current regulation essential for achieving stable torque production and minimizing acoustic noise and ripple. The proposed controller is designed to enhance current tracking accuracy under fast dynamic conditions while preserving robustness against magnetic saturation, inverter delays, and load disturbances. Experimental validation is conducted on a fully instrumented SRM test bench using real–time acquisition hardware and a standard asymmetric bridge converter. The study demonstrates significant improvements in current tracking, torque quality, energy utilization, and global operational reliability when measured against earlier approaches in the literature.

KEYWORDS

Experimental realization

Real–Time implementation

Switched reluctance motor (SRM)

Current control strategy

ARTICLE HISTORY	Received	Revised	Accepted	Published
	27 Nov 2025	08 Dec 2025	20 Dec 2025	27 Dec 2025

1 Introduction

Switched reluctance motors (SRMs) have emerged as one of the most promising solutions for high–performance electric drive applications over the past decade. This growing interest is primarily driven by their numerous inherent advantages, including simple and rugged construction, the absence of permanent magnets, high mechanical reliability, wide operational speed capability, and excellent tolerance to phase failures. These attributes position the SRM as a strong candidate for use in hybrid and electric vehicles, aviation systems, renewable energy technologies, and household appliances. Furthermore, advances in semiconductor power devices and control algorithms have significantly enhanced SRM performance, enabling operational characteristics that were previously difficult to achieve [1–4, 15–22].

Despite these strengths, SRMs exhibit several unique challenges that complicate their control and limit their broader industrial adoption. The doubly salient structure and highly nonlinear magnetic characteristics of SRMs result in pronounced torque ripple, acoustic noise, and strong coupling between electrical and mechanical variables. The nonlinear relationship between flux linkage and current, combined with the rotor–position–dependent variation of inductance, creates a system that is inherently difficult to model and control using traditional linear techniques. These challenges have motivated extensive research aimed at improving SRM drive performance through innovative control methodologies, refined design strategies, and advanced power converter topologies [2–5].

Among the various aspects of SRM control, current control plays a fundamental and indispensable role. The instantaneous phase current directly determines the electromagnetic torque produced, the magnitude of radial forces, the excitation of vibration modes, and the overall dynamic response of the drive. Consequently, the quality of current regulation has a direct impact on torque smoothness, acoustic noise, efficiency, thermal behavior, and system reliability. Because SRM torque depends strongly on both current magnitude and rotor position, precise current regulation becomes critical across a wide range of operating conditions, including low–speed startup, high–speed operation, and dynamic load variations [1–4].

Conventional current control techniques such as hysteresis control and PI–based PWM control remain widely used due to their simplicity and ease of implementation. Hysteresis current control offers a fast dynamic response but suffers from variable switching frequency, increased stress on power electronic devices, and substantial current ripple, which translates into torque ripple. PI–based PWM controllers provide a fixed switching frequency but exhibit limited performance under conditions where magnetic saturation and nonlinear inductance significantly distort current dynamics. These limitations become particularly problematic at high speeds, where the increasing back–EMF prevents the current from accurately tracking its reference, causing a deterioration in torque production [2–5].

To address these constraints, a wide range of advanced and intelligent current control techniques has been proposed. Predictive current control strategies anticipate future current behavior using machine models and optimize switching actions accordingly. Sliding–mode current control offers robustness against parameter uncertainties but may introduce chattering if not properly designed. Adaptive and nonlinear current controllers attempt to compensate for magnetic saturation and flux–current nonlinearities, improving tracking even under rapid operating condition changes. Enhanced torque–sharing–based current regulators have been developed to distribute current among phases to minimize torque ripple during commutation, thereby improving smoothness and acoustic performance. Other approaches incorporate force feedback, flux estimation, or energy–based control to further improve accuracy and reduce ripple. Although these techniques have contributed significantly to SRM control theory, achieving fast, smooth, and efficient current regulation across the entire speed range remains a challenging task [1–3, 7, 8].

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Another major difficulty arises from the strong interaction between current control and power converter operation. Because SRM phase inductance varies continuously with rotor position, the voltage applied to the motor does not translate into current variation in a linear or predictable manner. This makes classical linear controllers insufficient in many practical scenarios. Furthermore, the mutual coupling of key control variables—such as torque, flux, and radial force–means that optimizing current control often requires considering the entire electromechanical system rather than focusing solely on the electrical subsystem. As a result, modern SRM control strategies increasingly integrate multi–objective optimization frameworks, enabling trade–offs between torque ripple reduction, efficiency improvement, vibration mitigation, and switching frequency minimization [1–2].

Recent literature has paid particular attention to the interaction between current–tracking accuracy and torque production. Since SRM torque is highly dependent on the rising and falling edges of the phase current, precise regulation of turn–on and turn–off angles is essential. However, conventional controllers often fail to achieve the commanded current within the narrow excitation interval at high speeds. To overcome this, advanced controllers incorporating position–dependent compensation, model–predictive approaches, and real–time inductance estimation have been proposed.

These methods aim to ensure that the desired current is reached within the appropriate rotor position window, thereby maximizing torque per ampere and improving energy efficiency [3, 9, 10], validate the proposed current control strategies for switched reluctance motor (SRM) drives, a series of practical experiments were conducted on a laboratory SRM test bench. The primary objective of these experiments was to assess the performance of both conventional and advanced current controllers under real operating conditions, including nonlinear magnetic effects, inverter switching limitations, and load variations. The experimental evaluation focused on key performance indicators, including phase current tracking, torque ripple, dynamic response, and overall drive efficiency. Measurements were taken across a range of operating speeds and load conditions to ensure a comprehensive assessment of controller effectiveness.

2 Construction Of SRM

The switched reluctance motor (SRM) is an electric motor utilizing magnetic reluctance as its operational principle. It comprises a rotor and stator, both equipped with multiple poles, which exert influence over the movement of the rotor. The rotor dynamically aligns itself with the winding inductance of the highest magnitude, regulated by the current commutation sequence within the stator windings. The performance and efficiency of the SRM are contingent upon the characteristics of the control system, such as the turn–on angle, rotor direction, and current reference, which can be fine–tuned to achieve optimal operation. Equation (1) establishes the crucial relationship between flux (∅) and reluctance (L), elucidating the intricate interplay of magnetic fields and their role in generating rotor movement. Striking an optimal balance between flux and reluctance holds the potential to significantly enhance the performance and efficiency of the SRM [11–14].

$$\emptyset = \oint_{A} A\, d\boldsymbol{l} \tag{1}$$

The induced current relationship in the motor phases is primarily determined by the excitation of the current and the flux nductance when the phases are completely isolated. The concept of flux inductance refers to the magnetic path's resistance encountered when the rotor transitions from an unaligned to an aligned position. This phenomenon is illustrated in Figure 1(a) and Figure 1(b), which depict two typical flux distributions in switched reluctance motors (SRMs) at rotor positions of ϴ = 0° and ϴ = 45°, respectively. These figures provide a clear visualization of the magnetic field characteristics across the entire cross–section, enabling the identification of local saturation and the distribution of magnetic forces in relation to the SRM's terminal properties [11–14].

Figure 2 serves as a visual tool to comprehend the influence of rotor position and phase current amplitude on magnetic flux, with particular attention to the effects of saturation in the motor. Also, Figure 2 provides a comprehensive representation of the electromagnetic torque in relation to both the rotor position and varying phase current values. This visual depiction serves as a valuable tool for understanding how the torque and magnetic flux are influenced by the interplay of rotor position and the amplitude of the phase current. A notable feature revealed by the figure is the impact of the nonlinearity inherent in the magnetic characteristic on the resulting torque profile.

Furthermore, equation (1) can then be rewritten as follows:

$$C_e = \frac{1}{\mu_0} L_n \int_{\Gamma_R} \left[(r \times B)(B \cdot n) - \frac{1}{2} B^2 (r \times n) \right] d\Gamma \tag{2}$$

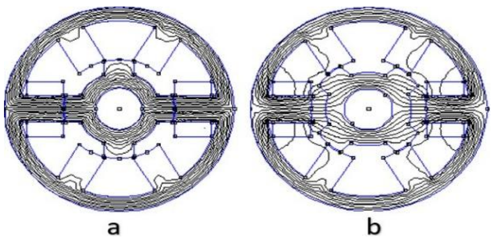

Fig.1. Two different flux diffusion of SRM.

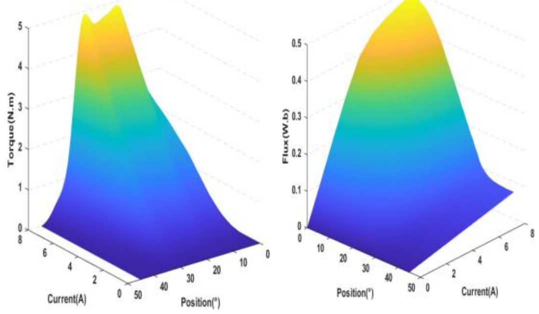

Fig.2. The torque and flux with the deference position of the rotation.

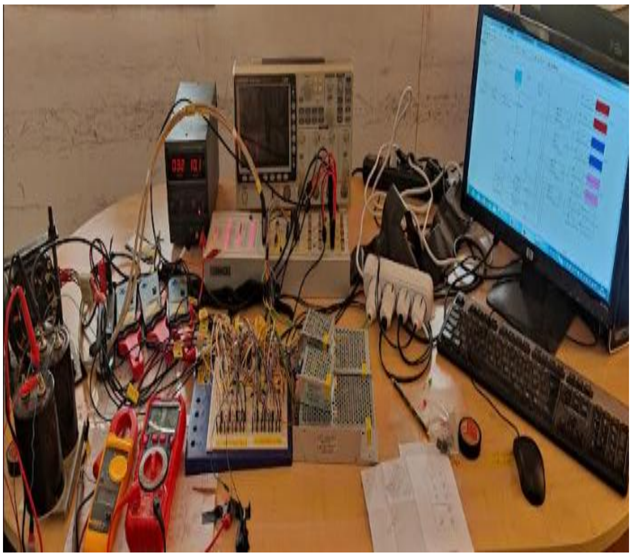

Fig.3. Test bench for variable reluctance motor control (Lab.: MSE).

3 Practical section

Since the experimental results obtained are very similar to those obtained in simulation, we only present the experimental results validating the current control by hysteresis (Figure 3).

The control is performed in real time. The dSPACE digital board (Figure 4), was used to calculate the MRV parameters. It is based on a digital signal processor (DSP). It handles the digital calculation and generation of the control signals. The dSPACE 1104 board is perfectly suited for controlling the variable reluctance motor. Figure 5 illustrates our switched reluctance motor (SRM 8/6).

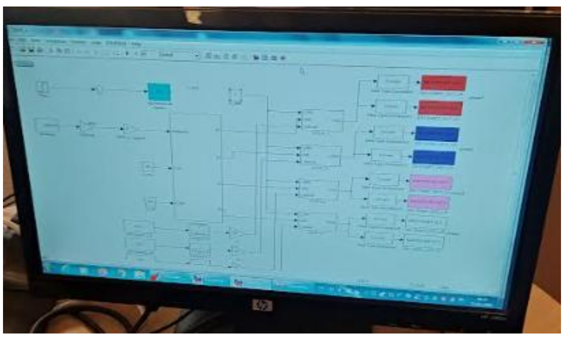

Fig.4. Prog Dspace 1104.

Fig.5. Switched reluctance motor (SRM 8/6).

3.1 Current control

Hysteresis current control is widely employed in switched reluctance motor (SRM) drives due to its simplicity, fast response, and robustness against system nonlinearities. In this strategy, the phase current is continuously measured–typically via current sensors–and compared to a predefined reference.

The hysteresis comparator evaluates the tracking error and generates switching signals that dictate whether the current should be increased, decreased, or held within the specified hysteresis band. Based on this logic, the H–bridge converter appropriately connects or disconnects each motor phase from the DC supply, there by regulating the current and ensuring proper excitation of the SRM.

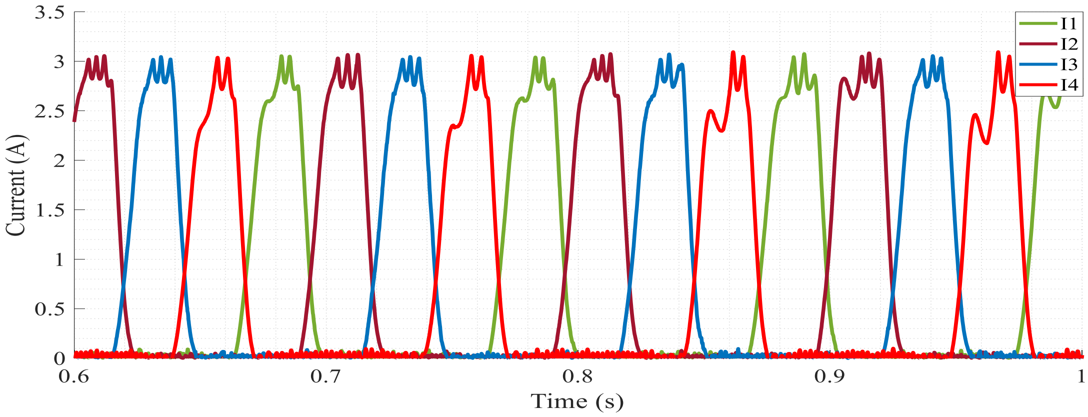

Fig.6. SRM current. Phase current 1, Phase current 2, Phase current 3, Phase current 4.

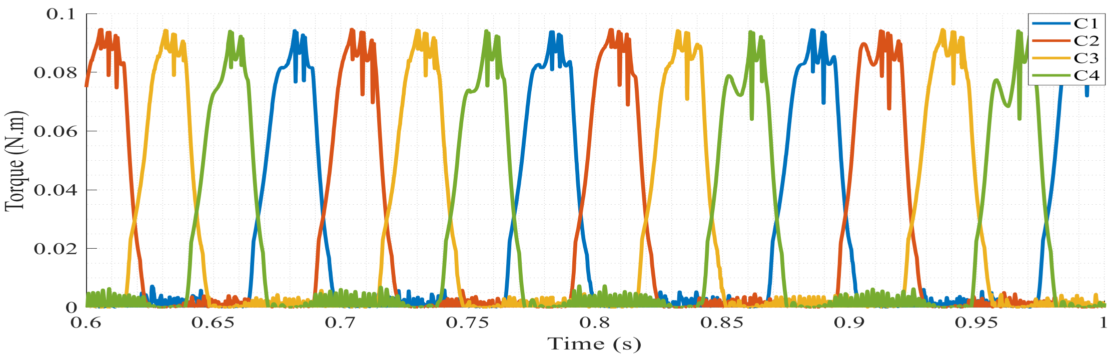

Fig.7. SRM Torque . Phase 1, Phase 2, Phase 3, Phase 4.

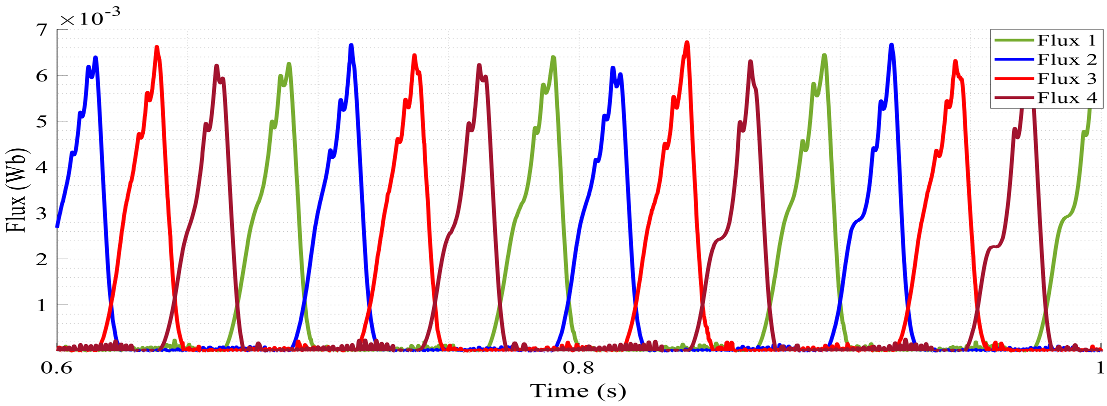

Fig.8. SRM Flux . Phase 1, Phase 2, Phase 3, Phase 4.

3.2 The experimental results

The experimental validation was conducted using a dSPACE 1104 platform interfaced with MATLAB/Simulink for real–time control implementation. The results confirm that the hysteresis–based current controller effectively maintained the phase currents within the desired limit of 3 A. These findings are consistent with those reported in the literature, where hysteresis control has also been shown to provide accurate current regulation and improved energy efficiency in SRM drive systems.

Experimental results demonstrate that the overall system is well controlled while offering better performance. The phase current regulation achieved through hysteresis control ensured that the current remained within the desired boundaries, exhibiting minimal ripple and a rapid dynamic response (Figure 6). This confirms the effectiveness of the control strategy in stabilizing phase currents, even under varying load conditions.

In our experimental test, we generated a regular torque with reduced ripple (Figure 7), this characteristic can be used in applications such as electric vehicles.

Figure 8 shows the corresponding stator flux, providing insight into the motor's magnetic behavior during operation.

4 Conculsion

This experimental study enabled us to implement a variable reluctance motor (SRM) control system. Current ripples were significantly reduced without compromising performance or efficiency. Comprehensive evaluations, conducted through experimental testing on the dSPACE 1104 platform, confirmed precise current regulation and smooth, low–ripple torque generation. The converter achieved an efficiency exceeding 80%, meeting the high benchmark performance reported in recent research on SRM motor control.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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