

Research Paper

AN LQI-BASED HIGH-PERFORMANCE SPEED CONTROL STRATEGY FOR SWITCHED RELUCTANCE MOTOR DRIVES

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Abstract

The growing demand for high-performance electric drive systems has led to increased interest in Switched Reluctance Motors (SRMs) due to their simple construction, robustness, and suitability for variable speed applications. However, SRMs exhibit nonlinear characteristics and significant torque ripple, making precise speed control a challenging task. This project presents the design and implementation of a Linear Quadratic Integral (LQI) controller for efficient speed control of SRMs. The proposed control strategy eliminates the need for an inner current control loop by directly generating voltage commands, thereby simplifying the system architecture and reducing computational complexity. The LQI controller is designed using a linearized state-space model of the SRM, enabling optimal control by minimizing a quadratic cost function that balances performance and control effort. The system is implemented using Pulse Width Modulation (PWM) techniques to reduce torque ripple and switching losses. A comparative analysis with conventional Proportional-Integral (PI) and Hysteresis Controllers (HC) demonstrates the superior performance of the LQI controller in terms of dynamic response, disturbance rejection, and robustness under varying operating conditions. Experimental and simulation results validate the effectiveness of the proposed method, showing reduced torque ripple, improved speed tracking, and enhanced system stability. The findings indicate that the LQI-based control approach is highly suitable for modern high-performance applications such as electric vehicles, robotics, and industrial automation systems.

Keywords: Switched Reluctance Motor (SRM), Linear Quadratic Integral (LQI), Speed Control, Torque Ripple Reduction, PWM, State-Space Modeling, Optimal Control.

I INTRODUCTION

The rapid advancement of electric drive systems has significantly increased the demand for efficient, reliable, and high-performance motor technologies across industrial, automotive, and renewable energy applications. Among the various electric machines, the Switched Reluctance Motor (SRM) has emerged as a promising alternative due to its

simple and rugged construction, absence of rotor windings or permanent magnets, and ability to operate under harsh environmental conditions [1]. These features make SRMs highly suitable for applications such as electric vehicles, hybrid electric vehicles, robotics, and variable speed drives [2]. Additionally, SRMs offer advantages like high torque density, fault tolerance, wide speed

range, and reduced manufacturing cost due to the elimination of rare earth materials [3]. Despite these benefits, SRMs suffer from inherent drawbacks such as high torque ripple, acoustic noise, and nonlinear magnetic characteristics, which complicate their control and limit their widespread adoption [4]. The performance of SRM drives is highly dependent on the effectiveness of the control strategy employed, especially under varying load and speed conditions [5]. Traditional control techniques such as Proportional-Integral (PI) and Hysteresis Controllers (HC) are widely used due to their simplicity and ease of implementation; however, they often fail to provide optimal performance across the entire operating range because of the nonlinear behavior of SRMs [6][7]. These limitations have motivated researchers to explore advanced control strategies that can enhance system performance while maintaining stability and robustness [8].

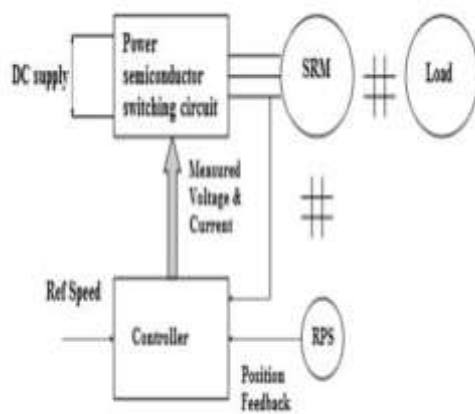


Fig.1 Block Diagram

In recent years, optimal control techniques have gained attention for addressing the challenges associated with SRM control. Among them, the Linear Quadratic Integral (LQI) controller has proven to be an effective approach due to its ability to provide optimal performance by minimizing a quadratic cost function while ensuring zero steady-

state error [9]. The LQI controller combines the advantages of state feedback and integral action, enabling improved dynamic response and disturbance rejection capabilities [10]. Unlike conventional methods, the LQI-based control strategy can directly generate voltage commands without requiring an inner current control loop, thereby reducing system complexity and torque ripple [11]. Furthermore, the use of a linearized state-space model allows systematic controller design and tuning for different operating conditions [12]. Advanced techniques such as Model Predictive Control (MPC), adaptive control, and sliding mode control have also been explored, but they often involve higher computational complexity and implementation challenges [13]. In contrast, the LQI controller provides a balanced trade-off between performance, simplicity, and computational efficiency, making it suitable for real-time embedded systems [14]. Therefore, this work focuses on the design and implementation of an LQI-based speed control strategy for SRMs to achieve enhanced performance, reduced torque ripple, and improved robustness in high-performance applications.

II LITERATURE SURVEY

The development of control strategies for Switched Reluctance Motors (SRMs) has been widely explored in literature due to the machine's nonlinear characteristics and torque ripple issues. Early studies focused on conventional control techniques such as Proportional-Integral (PI) controllers, which are widely adopted in industrial applications because of their simplicity and ease of implementation [1]. However, researchers have identified that PI controllers often fail to provide satisfactory performance under varying operating conditions due to the nonlinear magnetic characteristics of SRMs [2]. Hysteresis current

control (HCC) has also been extensively studied for SRM drives due to its robustness and fast dynamic response, but it introduces variable switching frequency and increased torque ripple [3]. To overcome these limitations, several works have proposed advanced current control strategies such as current chopping, continuous current control, and firing angle control methods, particularly for improving performance across different speed regions [4]. Additionally, optimization-based approaches, including evolutionary algorithms like Particle Swarm Optimization (PSO) and differential evolution, have been employed to tune controller parameters effectively and improve speed regulation and torque ripple reduction [5]. Research has also highlighted that improper current tracking and switching angle selection significantly contribute to torque pulsations and acoustic noise in SRMs, emphasizing the need for more sophisticated control techniques [6]. Furthermore, sensor-based control systems have been widely used for rotor position detection, but they increase system complexity and cost, leading to the development of sensorless control methods [7]. These methods estimate rotor position using electrical signals, thereby improving reliability and reducing hardware requirements [8].

In recent years, advanced and intelligent control strategies have gained significant attention for enhancing SRM performance. Predictive control techniques, such as Model Predictive Control (MPC), deadbeat control, and generalized predictive control, have been explored for improving dynamic response and reducing torque ripple [9]. These approaches provide better tracking accuracy and system efficiency but often involve high computational complexity, limiting their practical implementation in real-time systems [10]. Adaptive and intelligent control methods, including fuzzy logic control, neural networks, and hybrid

optimization algorithms, have also been proposed to address the nonlinear behavior of SRMs [11]. For instance, fuzzy logic-based controllers have demonstrated improved speed response and reduced torque ripple compared to traditional methods [12]. Similarly, hybrid optimization techniques combined with PI or fractional-order controllers have shown enhanced convergence speed and control accuracy [13]. Sliding mode control and active disturbance rejection control have also been studied for their robustness against parameter variations and external disturbances [14]. Despite these advancements, many of these methods require complex modeling, high computational resources, or extensive tuning procedures, making them less suitable for practical embedded applications [15]. Therefore, there is a growing need for control strategies that provide an optimal balance between performance, robustness, and implementation simplicity, which has led to increased interest in optimal control approaches such as LQI for SRM speed control systems.

III PROPOSED SYSTEM

The proposed system focuses on the implementation of a Linear Quadratic Integral (LQI) controller for efficient speed control of a Switched Reluctance Motor (SRM). The core objective is to enhance dynamic performance while reducing torque ripple and simplifying the control structure. In this approach, the SRM is modeled using a linearized state-space representation, where key state variables such as rotor speed and phase current are considered. Unlike conventional methods that rely on separate current and speed control loops, the proposed system directly generates the voltage command for the motor phases using the LQI controller. This eliminates the need for an inner current control loop, thereby reducing system complexity and computational

burden. The controller is designed by minimizing a quadratic cost function that balances system performance and control effort, ensuring optimal operation under varying load and speed conditions. Additionally, Pulse Width Modulation (PWM) is employed to regulate the applied voltage and achieve smooth motor operation.

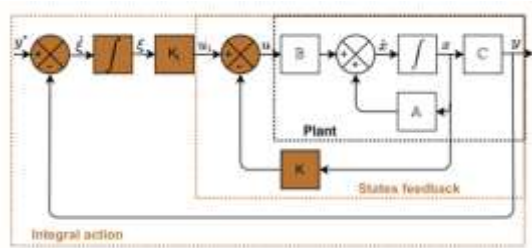
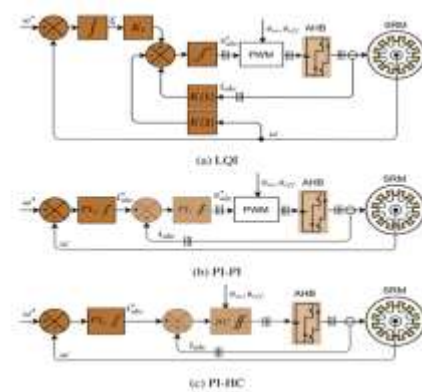


Fig.2 LQI block diagram based on servo system with state feedback and integral action.

The proposed system also incorporates a lookup table for selecting optimal switching angles based on operating conditions, which helps in minimizing torque ripple and improving efficiency. The controller gains are determined using systematic tuning of weighting matrices, allowing flexibility in achieving desired performance metrics such as settling time, overshoot, and steady-state error. Compared to traditional Proportional-Integral (PI) and Hysteresis Controllers (HC), the LQI-based system demonstrates superior disturbance rejection, consistent dynamic response, and improved robustness against parameter variations. Furthermore, the absence of complex algorithms or iterative optimization techniques makes the system suitable for real-time embedded implementation. Simulation and experimental validation confirm that the proposed system achieves better speed tracking, reduced acoustic noise, and enhanced overall performance, making it highly suitable for high-performance applications such as electric vehicles, industrial drives, and automation systems.



IV SYSTEM DESIGN

The system design of the proposed Switched Reluctance Motor (SRM) speed control system is based on an integrated control architecture that combines power electronics, sensing elements, and an optimal control algorithm to achieve high performance. The SRM drive consists of a DC power supply, an asymmetric half-bridge (AHB) converter, the SRM itself, a rotor position sensing mechanism, and a digital controller implementing the Linear Quadratic Integral (LQI) algorithm. The DC supply is fed to the AHB converter, which energizes the stator phase windings according to switching signals generated by the controller. The rotor position sensor provides real-time angular position data, which is essential for phase commutation and accurate control. The SRM is modeled using a linearized state-space representation, where rotor speed and phase current are considered as state variables, while input voltage acts as the control variable. The LQI controller is designed by augmenting the system with an integral state to eliminate steady-state error and applying state feedback to achieve optimal dynamic response. The controller computes the control input (phase voltage command) by minimizing a quadratic cost function that balances tracking performance and control effort. This voltage command is then modulated using Pulse Width Modulation (PWM) to generate appropriate

gate signals for the converter switches. Additionally, a lookup table is incorporated to determine optimal turn-on and turn-off angles based on operating conditions, which helps reduce torque ripple and improve efficiency. The entire system is implemented in a closed-loop configuration where the actual speed is continuously compared with the reference speed, and the error is processed by the controller to adjust the motor operation accordingly. This design ensures improved stability, fast response, reduced torque ripple, and robustness against disturbances, making it suitable for high-performance applications.

V RESULTS & ANALYSIS

All the simulation results were initially reproduced in a MATLAB/Simulink simulation environment. Since the results were consistent, we focused on presenting only the experimental findings. The suitability of the proposed LQI speed controller was verified through experiments that were conducted using the setup shown in Fig. 7. The setup comprises a three-phase 12/8 SRM and a Direct Current Machine (DCM) used to produce the load torque. The grid CA voltages are rectified and reduced by the Bidirectional DC-DC Converters (BDC) to provide the supply voltage for the AHB and H-bridge converters, which serve as the SRM and DCM drivers. The signal conditioning boards, equipped with the pi control, receive the signals from the absolute encoder and sensors, implement the control, and deliver the switching signals. Moreover, human machine interfaces (HMI) were developed in the LabVIEW environment for system handling. Note that the control and power circuits for the SRM and DCM are kept separate.

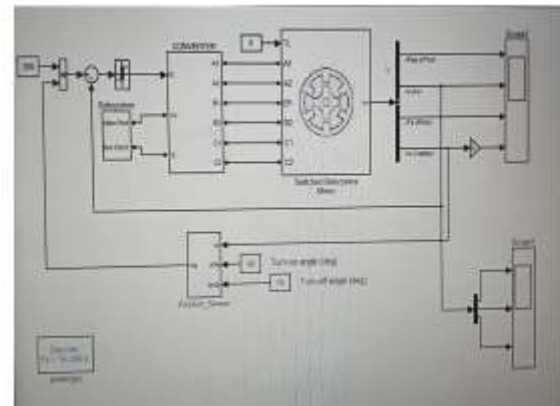


Fig.3 Stimulation Diagram

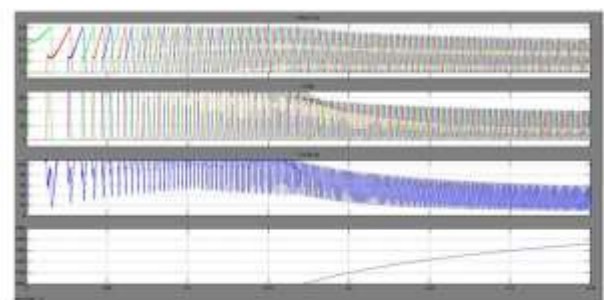


Fig.4 Output waveforms

VI CONCLUSION

This work proposes using LQI to speed control the SRM without an inner current control loop. The SRM modeling and the LQI design procedure were also presented. PI and Hysteresis controllers are widely used in SRM drivers and were chosen for comparison. Several tests were performed in the experimental setup to validate the control strategy and design developed. The LQI controller presented greater robustness to the model parameters variations (which occurs for different speeds and load torque), to the disturbance in the load and in the supply voltage, and to the reduction of the control sampling frequency. The SRM efficiency was almost equal for all controllers. However, the LQI produced less torque ripple at all operating points. The LQI also reduces the production of audible acoustic noise by concentrating the switching at a high frequency.

Furthermore, in microcontroller implementation, the LQI controller requires less memory usage, and its processing time is intermediate between PI-HC and PI-PI. The results show that the LQI controller is suitable for the control of SRM and can be used in several applications, such as ventilation, traction of electric and hybrid vehicles, starter motors, automation, and pumping

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