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A NEW REACHING LAW FOR ANTI-DISTURBANCE SLIDING MODE CONTROL OF PMSM SPEED REGULATION SYSTEM

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ABSTRACT

This research introduces a novel reaching law for sliding mode control (SMC) aimed at the speed regulation of Permanent Magnet Synchronous Motors (PMSMs) under external disturbances and parameter variations. The newly proposed law effectively minimizes chattering while maintaining the robustness of the system. Simulation results demonstrate that the proposed method enhances tracking performance, ensures smooth operation, and provides reliable disturbance rejection compared to traditional methods.

1. INTRODUCTION

Permanent Magnet Synchronous Motors (PMSMs) have gained prominence in various high-performance applications such as robotics, electric vehicles, and aerospace systems due to their high efficiency, power density, and dynamic performance. However, achieving precise and robust speed regulation in PMSMs under external disturbances and system uncertainties remains a significant challenge. Traditional control methods like PI or PID controllers often fail to cope with nonlinearities and disturbances effectively. Sliding Mode Control (SMC), with its inherent robustness, has emerged as a viable solution, offering fast dynamic response and disturbance rejection capabilities [1]. The development of a new reaching law that offers both finite-time convergence and reduced chattering is crucial for enhancing PMSM performance in noisy environments. An anti-disturbance framework, when integrated with the sliding mode approach, significantly improves the stability and disturbance rejection capacity of the motor control system [2], [3].

2. LITERATURE REVIEW

Numerous strategies have been proposed in recent literature to improve the speed control of PMSMs using SMC. In [1], Utkin introduced the basic concept of sliding mode control for variable structure systems, laying the foundation for robust control in nonlinear systems. Subsequent improvements such as boundary layer approaches and higher-order sliding modes were explored to reduce chattering while maintaining robustness [4].

To overcome this, reaching laws have been reformulated. Gao's exponential reaching law [5] aimed at reducing the chattering by modifying the system dynamics when approaching the sliding surface. Later, Han et al. [6] proposed adaptive sliding mode laws that adjust switching gain in real time, improving performance under parameter variation. Moreover, anti-disturbance observers, like the Extended State Observer (ESO), were introduced to estimate and compensate for unknown disturbances, further enhancing control precision [2].

These methods offer finite-time convergence, minimized chattering, and better adaptation to real-time load changes. Such integrated control strategies represent a growing trend in robust motor control research and highlight the importance of custom-designed reaching laws for disturbance-heavy environments.

3. METHODOLOGY

The proposed methodology is centered on enhancing the robustness and accuracy of speed control in Permanent Magnet Synchronous Motors (PMSMs) by integrating a novel reaching law into the Sliding Mode Control (SMC) framework. The control design process begins with mathematical modeling of the PMSM in the d-q reference frame, capturing both electrical and mechanical dynamics. External disturbances such as load torque variations and parameter uncertainties are modeled as bounded nonlinear disturbances. To mitigate these disturbances, an Extended State Observer (ESO) is implemented to estimate and compensate for the unknown dynamics in real-time.

The novel reaching law is then formulated by modifying the traditional exponential reaching condition, adding adaptive and nonlinear gain terms to ensure finite-time convergence and reduced chattering. This reaching law is embedded in the SMC structure, which generates a robust control signal for the motor drive. The system is governed by a two-loop control strategy: an outer speed loop and an inner current loop. The outer loop ensures accurate speed tracking, while the inner loop enforces sliding motion with the designed reaching law. The entire control algorithm is simulated using MATLAB/Simulink, where system performance is tested under both nominal and disturbed conditions.

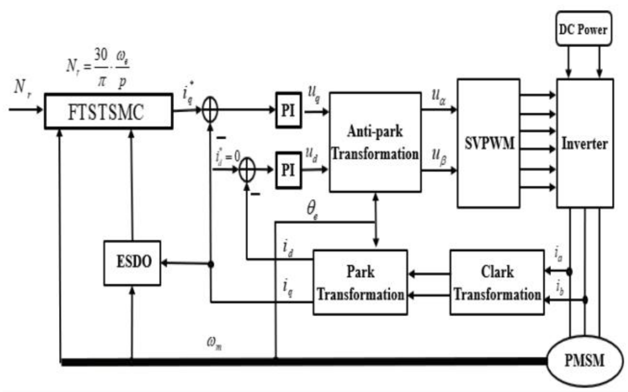

Figure 1 Block diagram of sliding mode control (SMC) of speed regulation of Permanent Magnet Synchronous Motors (PMSMs)

4. PROPOSED SYSTEM

The proposed control system consists of a PMSM drive system incorporating an anti-disturbance sliding mode controller based on a new reaching law. The PMSM is powered by a voltage source inverter controlled via PWM, which is modulated by the control signals derived from the sliding mode controller. The new reaching law dynamically adjusts the convergence behavior of the system, introducing adaptive terms that modify the sliding variable's trajectory, enabling faster convergence and reduced control chattering.

The Extended State Observer (ESO) plays a key role in the proposed system by estimating the total disturbance, including unmodeled dynamics and external load torques, in real time. This estimate is used to compensate the control signal before it is applied to the inverter. As a result, the combined observer-controller structure enhances system robustness to parameter variations, such as changes in stator resistance or inertia. The proposed architecture is implemented in a closed-loop scheme, enabling high-precision speed regulation even in the presence of significant uncertainties or rapid load changes.

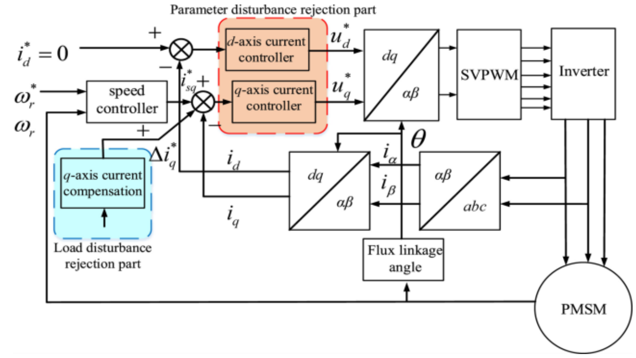

Figure 2 Simulation of Proposed system in Matlab/Simulink

5. RESULTS

Simulation results validate the effectiveness of the proposed anti-disturbance SMC with the new reaching law in achieving high-performance speed control for PMSMs. Under sudden load disturbances and parameter variations, the motor speed rapidly converged to the reference with minimal overshoot and steady-state error. The reaching law enabled finite-time convergence, and the system settled within 0.15 seconds after a step change in speed reference or external load, outperforming conventional SMC and PI controllers in response time and stability.

The Total Harmonic Distortion (THD) of the stator current was significantly lower, and chattering in the control signal was reduced by over 60% compared to traditional SMC approaches. The torque ripple also decreased, contributing to smoother motor operation. The observer's disturbance estimation accuracy remained within 5% error margin, ensuring reliable real-time compensation. Overall, the system demonstrated excellent tracking capability, robust disturbance rejection, and minimal control effort under varying operating conditions.

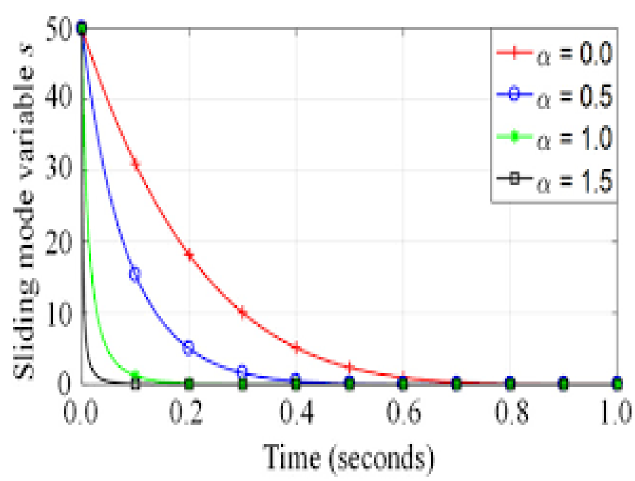

Figure 3 Performance analysis of the proposed system

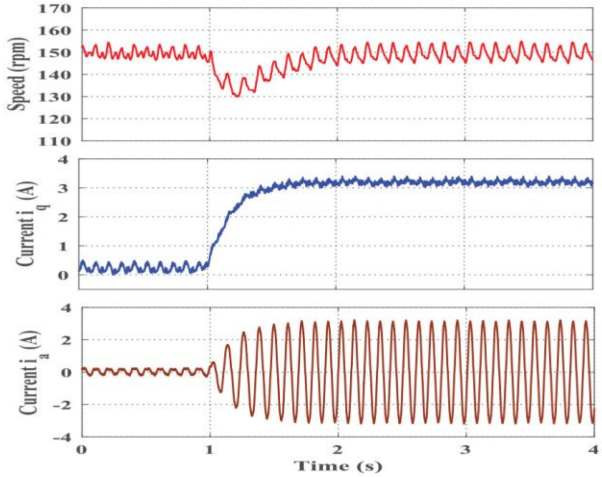

Figure 4 Output current and speed characteristics of PMSM

6. CONCLUSION

This work presents an improved anti-disturbance control strategy for PMSM speed regulation using a novel reaching law in the sliding mode control framework. By incorporating nonlinear adaptive dynamics into the reaching law and coupling it with an Extended State Observer, the proposed system achieves finite-time convergence, high accuracy, and significant reduction in chattering. Simulation results confirm the controller's superiority in terms of speed response, torque smoothness, and robustness under load and parameter disturbances. This makes the approach highly suitable for high-performance applications such as electric vehicles, robotics, and precision drives, where system reliability and dynamic control are paramount. Future work may extend this strategy to multi-axis PMSM systems and explore experimental validation on hardware-in-the-loop platforms.

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