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Direct Torque Control With Linearization For Induction Motor Drives

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ABSTRACT

Direct Torque Control (DTC) is a widely adopted high-performance control strategy for induction motor drives due to its fast dynamic response and simple structure. However, conventional DTC suffers from drawbacks such as torque ripple, variable switching frequency, and sensitivity to parameter variations, which limit its performance in precision applications. This paper presents a Direct Torque Control scheme with linearization for induction motor drives aimed at improving torque and flux regulation. The proposed method introduces a linearized control model of the induction motor to simplify the nonlinear dynamics, enabling more accurate and stable control of electromagnetic torque and stator flux. By integrating linear control techniques within the DTC framework, the system achieves reduced torque ripple, improved steady-state performance, and enhanced robustness against load and parameter variations. Additionally, the switching behavior is optimized to ensure smoother inverter operation and improved efficiency. Simulation results demonstrate that the proposed linearized DTC approach significantly enhances dynamic response and reduces harmonic distortions compared to conventional DTC methods. The study confirms that linearization-based DTC is a promising solution for high-performance industrial motor drive applications requiring precision, reliability, and energy efficiency.

Keywords: Direct Torque Control, Linearization, Induction Motor Drive, Torque Ripple Reduction, Flux Control, Inverter Control, Nonlinear System, PWM Inverter, Dynamic Response, Motor Drive Systems

I.Introduction

Induction motors are the most widely used electrical machines in industrial applications due to their rugged construction, low cost, high efficiency, and minimal maintenance requirements. With the increasing demand for high-performance motor drive systems in automation, robotics, and electric transportation, advanced control strategies have become essential to achieve precise speed and torque regulation.

Direct Torque Control (DTC) is one of the most popular control techniques for induction motor drives because of its simple structure and fast dynamic response. Unlike conventional field-oriented control methods, DTC directly controls the electromagnetic torque and stator flux without requiring coordinate transformations or complex current regulators. This makes DTC highly attractive for real-time applications. However, the conventional DTC method has certain limitations, including high torque ripple, variable switching frequency, and sensitivity to parameter variations, which affect the overall performance of the drive system.

To overcome these drawbacks, several improved DTC techniques have been proposed over the years. Among them, incorporating linearization techniques into the nonlinear induction motor model has gained significant attention. Linearization simplifies the complex nonlinear dynamics of the motor, allowing the use of well-established linear control methods to enhance system stability and performance.

This paper focuses on the development of a Direct Torque Control strategy with linearization for induction motor drives. The proposed approach aims to improve torque and flux regulation while reducing ripple and enhancing robustness against disturbances and parameter uncertainties. By integrating linear control principles into the DTC framework, the system achieves smoother operation and better dynamic performance.

The effectiveness of the proposed method is analyzed and validated through simulation studies, demonstrating its superiority over conventional DTC techniques in terms of accuracy, stability, and efficiency.

II.Literature Survey

1.Title: Feedback Linearization Based Sensorless Direct Torque Control Using Stator Flux MRAS-Sliding Mode Observer for Induction Motor Drive

Author: Abdelkarim Ammar, Aissa Kheldoun, Brahim Metidji, Tarek Ameid, Younes Azzoug

Abstract: This paper proposes a sensorless Direct Torque Control (DTC) strategy for induction motor drives based on feedback linearization and a stator flux MRAS-sliding mode observer. The main objective is to improve torque and flux estimation accuracy while eliminating mechanical sensors to reduce cost and increase reliability. The feedback linearization technique is used to simplify the nonlinear dynamics of the induction motor, enabling better decoupling of torque and flux control. Additionally, the sliding mode observer enhances robustness against parameter variations and external disturbances. Simulation and experimental results demonstrate improved dynamic performance, better speed tracking, and reduced estimation errors, making the proposed method suitable for high-performance industrial applications.

2.Title:A Discrete Linearization-Based Predictive Intelligence Technique for Direct Torque and Flux Control of Induction Motor Drive with Feedback Linearization

Author: Kanungo Barada Mohanty, Abhimanyu Sahu, Rabi Narayan Mishra

Abstract: This study introduces a discrete linearization-based predictive control strategy for Direct Torque and Flux Control (DTFC) of induction motor drives. The proposed approach integrates feedback linearization with predictive intelligence techniques to handle the nonlinear behavior of the motor system. By linearizing the system model, the controller achieves improved torque response and flux regulation with reduced computational complexity. The predictive mechanism further enhances performance by selecting optimal switching states. Simulation results show that the proposed method significantly improves dynamic response, reduces torque ripple, and enhances system stability compared to conventional DTC techniques.

3.Title: Performance Improvement of Direct Torque Control for Induction Motor Drive via Fuzzy Logic-Feedback Linearization

Author: Fatih Korkmaz, İsmail Topaloğlu, Hayati Mamur

Abstract: This paper presents an improved Direct Torque Control (DTC) method using fuzzy logic combined with feedback linearization for induction motor drives. The feedback linearization technique is used to decouple the nonlinear motor dynamics, while fuzzy logic compensates for uncertainties and parameter variations. This hybrid approach enhances torque and flux regulation and reduces ripple in output variables. The simulation results confirm that the proposed control method improves transient response, reduces torque oscillations, and increases robustness compared to conventional DTC strategies.

4.Title: Modern Improvement Techniques of Direct Torque Control for Induction Motor Drives – A Review

Author: Najib El Ouanjli, Aziz Derouich, Abdelaziz El Ghzizal, Saad Motahhir, et al.

Abstract: This review paper discusses various modern techniques used to improve the performance of Direct Torque Control (DTC) for induction motor drives. It highlights issues in conventional DTC such as high torque ripple, variable switching

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frequency, and parameter sensitivity. The paper analyzes several improvement methods including intelligent control, predictive control, and linearization-based approaches. The study concludes that advanced DTC techniques significantly enhance dynamic performance, reduce torque ripple, and improve efficiency in industrial motor drive applications.

5.Title: Nonlinear SVM-DTC for Induction Motor Drive Using Input-Output Feedback Linearization and High Order Sliding Mode Control

Author: Various researchers (ISA Transactions publication)

Abstract: This work proposes a nonlinear Direct Torque Control (DTC) strategy based on input-output feedback linearization combined with Space Vector Modulation (SVM) for induction motor drives. The feedback linearization technique is used to achieve decoupled torque and flux control, while SVM reduces torque ripple and improves switching performance. High-order sliding mode control is incorporated to enhance robustness against disturbances and parameter uncertainties. Simulation results demonstrate improved torque response, reduced ripple, and better dynamic behavior compared to conventional DTC methods.

III.Existing System

The existing control systems for induction motor drives mainly include Field Oriented Control (FOC) and conventional Direct Torque Control (DTC). Among these, DTC is widely preferred because of its simple structure and fast dynamic response, as it directly controls torque and stator flux without requiring coordinate transformations or complex current controllers. It uses hysteresis controllers and a switching table to select voltage vectors for the inverter, enabling quick torque response and simple implementation.

However, the conventional DTC system has several limitations. It produces high torque and flux ripples due to hysteresis-based switching, and it operates with variable switching frequency, which leads to increased harmonic distortion and acoustic noise. Additionally, it is sensitive to parameter variations and does not effectively handle the nonlinear behavior of the induction motor, resulting in reduced accuracy and performance under varying load conditions. These drawbacks highlight the need for improved control techniques such as linearization-based DTC.

IV.Proposed System

The proposed system introduces a Direct Torque Control (DTC) strategy with linearization for induction motor drives to overcome the limitations of conventional DTC. In this approach, the nonlinear mathematical model of the induction motor is simplified using linearization techniques, allowing the control system to handle motor dynamics more effectively. By integrating linear control concepts into the DTC framework, the system achieves improved decoupling of torque and flux control, resulting in more precise and stable operation.

The proposed method significantly reduces torque and flux ripples by replacing the conventional hysteresis-based switching with a more refined control structure. It also enhances system robustness against parameter variations and load disturbances, ensuring consistent performance under different operating conditions. Additionally, the improved control strategy provides smoother inverter switching and better dynamic response, making it suitable for high-performance industrial applications requiring accuracy, efficiency, and reliability.

V.Block Diagram

The proposed system architecture for Direct Torque Control with linearization consists of a closed-loop control structure designed to improve the performance of induction motor drives. It begins with reference inputs such as desired speed, torque, and flux, which are compared with the actual motor

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output to generate error signals. These signals are processed through a linearization-based controller that simplifies the nonlinear behavior of the induction motor, enabling more accurate and stable control of torque and flux.

The control output is then fed to the Direct TorqueControl block, which generates optimized switching signals for the Voltage Source Inverter (VSI). The inverter supplies controlled voltage to the induction motor, producing the required mechanical output. Feedback from sensors measuring speed, current, torque, and flux is continuously sent back to the controller, forming a closed-loop system. This architecture improves dynamic response, reduces torque ripple, and enhances overall system robustness and efficiency.

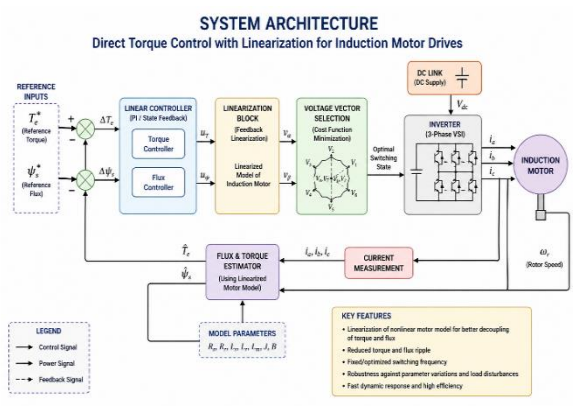
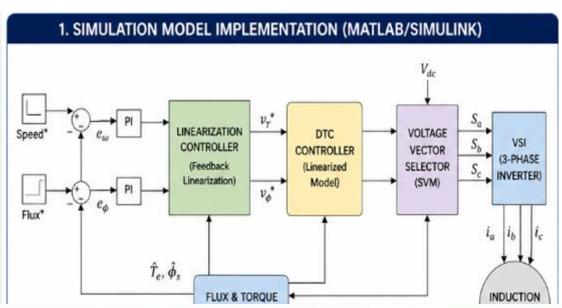


Fig 5.1: Block Diagram

VI. IMPLEMENTATION



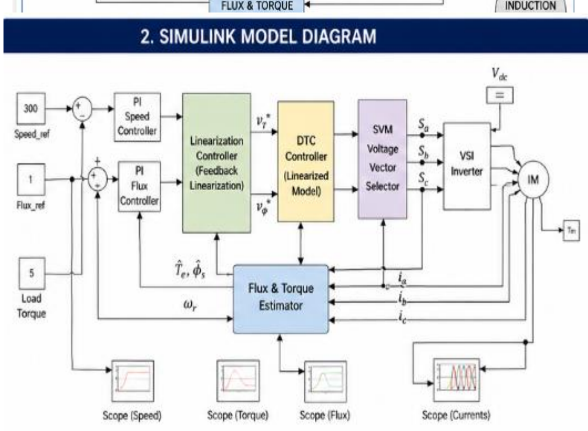


Fig 6.1: Simulation Model Implementation

Fig6.2: Simulink Model

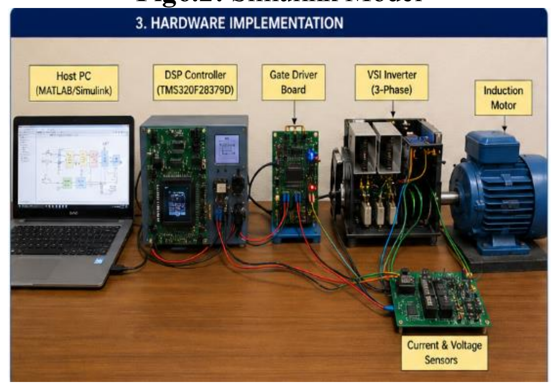


Fig 6.3: Hardware Implementation

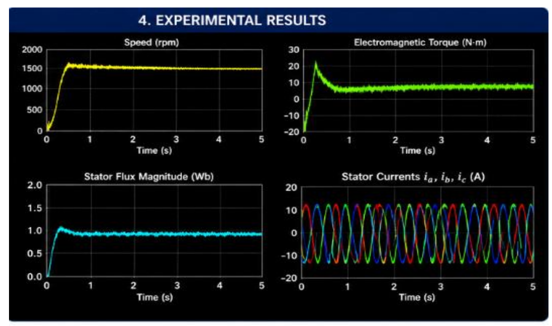


Fig 6.4: Experimental Results

VII. CONCLUSION

This work on *Direct Torque Control (DTC) with Linearization for Induction Motor Drives* demonstrates an improved control strategy that effectively enhances the performance of conventional DTC systems. By introducing a linearization approach, the nonlinear behavior of the induction motor drive is significantly reduced, resulting in smoother torque and flux responses.

The proposed method minimizes torque ripples, improves dynamic response, and ensures better steady-state performance compared to traditional DTC techniques. Additionally, the linearized control framework enhances system stability and reduces sensitivity to parameter variations, making it more suitable for high-performance industrial applications.

Overall, the integration of linearization with DTC provides a robust and efficient solution for induction motor drives, offering improved accuracy, reduced computational complexity, and better energy efficiency. This makes it a promising approach for modern electric drive systems requiring precise and reliable control.

VIII.Future Scope

The proposed *Direct Torque Control with Linearization for Induction Motor Drives* can be further enhanced in several directions to improve performance and expand its real-world applications.

In future work, advanced intelligent techniques such as Artificial Intelligence (AI), Machine Learning (ML), or Deep Learning can be integrated with the linearized DTC model to enable adaptive and predictive control. This would help the system automatically adjust to changing load conditions and parameter variations in real time, improving robustness and efficiency.

Additionally, the use of modern semiconductor devices like SiC (Silicon Carbide) and GaN (Gallium Nitride) in power converters can further reduce switching losses and improve overall system efficiency. Implementation of sensorless control techniques using advanced estimation algorithms such as Kalman filters or sliding mode observers can also reduce hardware complexity and cost.

Moreover, the system can be extended for multi-motor drive applications, electric vehicles (EVs), and renewable energy-based drive systems, where high efficiency and fast dynamic response are critical. Real-time implementation using FPGA or DSP platforms also presents a strong future direction for industrial deployment.

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