ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

E-Mail :
editor.ijasem@gmail.com
editor@ijasem.org

www.ijasem.org

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN2454-9940
www.ijsem.org
Vol 15, Issuse .1 Jan 2024

Fuzzy Logic Controller-Based Adaptive Identification of Rotor Time Constant for Sensorless Speed Control in Induction Motor Drives

G Naveen[1], G Santhosh Kumar[2]

Abstract

This study underscores the critical role of accurate rotor time constant (Tr) values in optimizing performance in induction drive indirect field-oriented control (IFOC). Suboptimal Tr values can lead to poor dynamic and steady-state torque responses. The paper focuses on improving induction drive performance by separating the rotor flux and torque-producing current through IFOC. In sensorless drives with model-based speed estimation algorithms, Tr tends to be more detuned. The paper introduces a novel method for determining rotor time constant and speed in sensorless IFOC six-phase induction motor (6PIM) drives. An adaptive observer detects a low-frequency sinusoidal signal intentionally injected into the rotor flux command, and a new MRAS-based Tr estimator is introduced using the detected signal. This method proves effective in reducing harmonics, torque pulses, and enhancing system reliability, particularly in high-power applications. The Lyapunov stability theorem ensures the asymptotic stability of the proposed identification system, making it suitable for sensorless electric drive systems. The rotor flux-based MRAS is employed to calculate rotor speed, applicable to three-phase and higher multi-phase induction machines using the primary subspace (α-β subspace) induction machine model. The study also explores the application of this method to five- and six-phase induction motors, with a focus on the modularity benefits derived from three-phase technology in the case of six-phase induction motor (6PIM) simulations.

Keywords: Indirect field-oriented control (IFOC), sensorless drives, model-based speed estimation, model reference adaptive system (MRAS).

I. INTRODUCTION

The introduction sets the stage for the research and provides background information on the topic. It highlights the significance of accurate rotor time constant (Tr) values in the context of the indirect field-oriented control (IFOC) strategy and sensorless drives. The introduction also mentions the limitations of the existing IFOC method and the motivation behind the paper. Additionally, it introduces the problem of simultaneous identification of the rotor time constant and rotor speed for sensorless IFOC in six-phase induction motor (6PIM) drives. The use of an adaptive observer and a novel Tr estimator based on the model reference adaptive system (MRAS) is proposed. The advantages of the proposed method, such as improved system reliability, reduced harmonics, and minimized torque pulses, are highlighted. Finally, the introduction mentions the utilization of the Lyapunov stability theorem and the incorporation of the Tr estimator into a sensorless electric drive system based on the rotor flux-based MRAS strategy. The applicability of the method to other multi-phase induction machines is also mentioned, with a specific focus on the six-phase induction motor (6PIM) as a case study.

[1,2]Assistant Professor, Department of EEE ,MEGHA INSTITUTE OF ENGINEERING & TECHNOLOGY FOR WOMEN, Hyderabad, Telangana, India.

The paper focuses on a specific case study involving a six-phase induction machine, which is of interest due to its modular structure and the advantages it inherits from three-phase technology. The introduction emphasizes the need to address the identification of the rotor time constant and its impact on the performance of speed-sensorless drives.

The goal of the research is to propose an adaptive identification approach for the rotor time constant in order to enhance the performance of the speed-sensorless induction motor drives. The approach utilizes the concept of adaptive estimation and takes advantage of a case-specific six-phase induction machine. The introduction highlights the benefits of accurate rotor time constant estimation, including improved system reliability, reduced harmonics, and minimized torque pulses. It also mentions the challenges associated with speed-sensorless control and the need for a robust identification method. Furthermore, the introduction briefly outlines the methodology employed in the study, mentioning the use of adaptive identification techniques and the incorporation of the rotor time constant estimator into the speed-sensorless induction motor drive system. The primary focus is on the rotor flux-based model reference adaptive system (MRAS) strategy.

In summary, the introduction provides an overview of the research objectives, emphasizes the importance of accurate rotor time constant estimation in speed-sensorless drives, introduces the case study of a six-phase induction machine, and outlines the methodology employed in the study.

II. METHODOLOGY

Rotor Flux-Based using MRAS Speed System

The rotor flux-based speed control system using Model Reference Adaptive System (MRAS) is a technique employed in induction motor drives to achieve accurate speed control without the need for a physical speed sensor. It combines the concept of rotor flux-based control with the adaptive capabilities of the MRAS strategy.

In this system, the rotor flux, which represents the magnetic field generated by the rotor, is utilized as a reference model. The MRAS algorithm compares the estimated rotor flux with the actual rotor flux to obtain an error signal. This error signal is then used to adaptively adjust the speed estimate, allowing for accurate tracking of the motor speed.

The MRAS algorithm typically incorporates a mathematical model of the induction motor and its associated parameters. This model is used to estimate the rotor speed by observing the variations in the rotor flux. The adaptive mechanism within the MRAS algorithm continuously adjusts the model parameters based on the error signal, ensuring that the speed estimation remains accurate even in the presence of parameter uncertainties or variations.

By utilizing the rotor flux as a reference, the rotor flux-based MRAS speed system enables robust and accurate speed control of induction motor drives. It eliminates the need for additional hardware sensors, reducing cost and complexity in the system. Moreover, it enhances the motor drive's performance by providing precise speed estimation and enabling effective control strategies.

The rotor flux-based MRAS speed system has been widely employed in various applications, such as industrial automation, electric vehicles, and renewable energy systems. It offers advantages such as high-speed response, good dynamic performance, and improved system reliability. However, its effectiveness depends on the accuracy of the motor model and the robustness of the adaptive mechanism to handle various operating conditions and disturbances.

Implementation of sensorless IFOC of six phase induction motor.

The implementation of sensorless Indirect Field-Oriented Control (IFOC) for a six-phase induction motor involves several key steps. Here is a general outline of the implementation process:

Motor Model and Parameters:

Develop or obtain a mathematical model of the six-phase induction motor. This model should accurately represent the motor's electrical and mechanical characteristics.

Determine the motor parameters, including stator resistance, stator inductance, rotor resistance, rotor inductance, and rotor time constant. These parameters are crucial for accurate control and estimation.

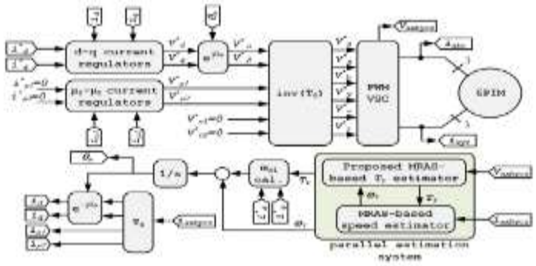


Figure 1: Block diagram of the sensorless IFOC scheme

Rotor Position and Speed Estimation:

Implement a sensorless technique to estimate the rotor position and speed. This can be achieved using methods such as model-based estimators (e.g., MRAS or extended Kalman filter) or sensorless algorithms (e.g., high-frequency injection or back EMF estimation).

The rotor position and speed estimation algorithms utilize the measured stator currents and voltages to estimate the rotor position and speed without using a physical position sensor.

Current Control:

Implement the current control loop to regulate the stator currents based on the desired torque and flux references.

Calculate the reference currents for the d-axis and q-axis using the IFOC algorithm, which decouples the torque and flux components of the stator currents.

Apply appropriate current control strategies, such as proportional-integral (PI) controllers or more advanced control techniques like sliding mode control, to track the reference currents and achieve accurate current control.

Flux and Torque Control:

Generate the reference values for the desired flux and torque based on the system requirements.

Use the estimated rotor position and speed to transform the flux and torque references into the d-q reference frame.

Implement the IFOC algorithm to control the flux and torque components of the stator currents independently.

Adjust the stator currents using the reference values and control algorithms to achieve the desired flux and torque control.

System Performance and Stability:

Validate and fine-tune the control parameters to ensure system stability and performance.

Perform extensive simulations and testing to verify the sensorless IFOC implementation under different operating conditions, such as varying loads and speeds.

Evaluate the system's robustness against parameter variations, disturbances, and noise to ensure reliable and accurate operation.

Implementation of MRAS-Based Rotor Time Constant Estimation System.

The implementation of a MRAS-based rotor time constant estimation system involves several steps. Here is a general outline of the implementation process:

Motor Model and Parameters:

Develop or obtain a mathematical model of the induction motor that accurately represents its electrical and mechanical characteristics.

Determine the motor parameters, including stator resistance, stator inductance, rotor resistance, rotor inductance, and any other relevant parameters required for the MRAS algorithm.

MRAS-Based Rotor Time Constant Estimation:

Design the MRAS-based rotor time constant estimation algorithm. This algorithm typically involves the comparison of two models: a reference model and an adaptive model.

The reference model represents the expected behavior of the motor based on known motor parameters, while the adaptive model incorporates the estimated rotor time constant as an adjustable parameter.

The difference between the reference and adaptive models is used to generate an error signal that drives the adaptation mechanism.

System Implementation:

Implement the MRAS-based rotor time constant estimation algorithm in the control system of the induction motor.

Incorporate the necessary feedback signals, such as stator currents and voltages, to calculate the error signal.

Use the error signal to adaptively adjust the estimated rotor time constant during operation.

Parameter Initialization and Adaptation:

Initialize the initial value of the rotor time constant estimate.

Implement the adaptation mechanism to continuously adjust the estimated rotor time constant based on the error signal.

Choose appropriate adaptation laws and tuning parameters to ensure stable and accurate adaptation.

Validation and Fine-tuning:

Validate the MRAS-based rotor time constant estimation system through simulations and experiments.

Assess the accuracy and stability of the estimated rotor time constant under various operating conditions, such as different speeds and load variations.

Fine-tune the control parameters and adaptation laws as needed to optimize the performance and robustness of the system.

Performance Evaluation:

Evaluate the performance of the MRAS-based rotor time constant estimation system in terms of accuracy, response time, and robustness against parameter variations.

Compare the estimated rotor time constant with known values or reference measurements to assess the effectiveness of the estimation algorithm.

Case Study for Six-Phase Induction Machine

✓ **Motor Characterization:**

Gather the necessary information about the six-phase induction machine, including its electrical and mechanical specifications, such as stator and rotor winding configurations, number of poles, and rated power.

Measure or obtain the motor parameters, including stator and rotor resistances, stator and rotor inductances, mutual inductance, and any other relevant parameters needed for modeling and control.

✓ **Modeling and Simulation:**

Develop a mathematical model of the six-phase induction machine based on the gathered motor parameters and specifications.

Simulate the motor model using software tools such as MATLAB/Simulink or other simulation platforms to verify the model's accuracy and assess its performance under various operating conditions.

✓ **Control Strategy Design:**

Design a control strategy suitable for the six-phase induction machine.

Consider utilizing techniques such as Indirect Field-Oriented Control (IFOC) or other advanced control methods specific to six-phase machines.

Develop control algorithms to regulate the motor's torque, flux, and other relevant variables based on the desired performance objectives.

✓ **Parameter Estimation and Tuning:**

Implement parameter estimation algorithms to estimate the motor parameters, including rotor time constant, rotor resistance, and any other critical parameters required for control.

Fine-tune the control parameters, such as gains and thresholds, to optimize the performance of the control system.

Utilize techniques like adaptive control or optimization algorithms to ensure accurate parameter estimation and robust performance.

- ✓ **Experimental Validation:**

Implement the designed control strategy and parameter estimation algorithms on a physical six-phase induction machine or a suitable hardware-in-the-loop (HIL) setup.

Conduct experimental tests to evaluate the performance of the control system under various operating conditions, such as different loads, speeds, and disturbances.

Analyze and compare the experimental results with the simulation outcomes to validate the control strategy and parameter estimation techniques.

- ✓ **Performance Evaluation and Optimization:**

Assess the performance of the six-phase induction machine under the designed control strategy, considering criteria such as dynamic response, steady-state accuracy, torque production, and efficiency.

Identify areas of improvement and optimization, such as reducing torque ripple, enhancing speed regulation, or improving energy efficiency.

Iterate and refine the control strategy and parameter estimation algorithms based on the evaluation results to further enhance the performance of the six-phase induction machine.

III. RESULTS & DISCUSSION

In the research paper "An Adaptive Identification of Rotor Time Constant for Speed-Sensorless Induction Motor Drives: A Case Study for Six-Phase Induction Machine," the simulation results for the Tr adaptation behavior under two different scenarios, namely underestimated and overestimated initial values, at 34% rated speed and rated load torque, are discussed.

Simulation Results

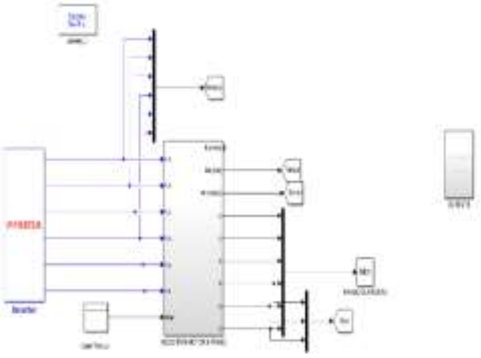
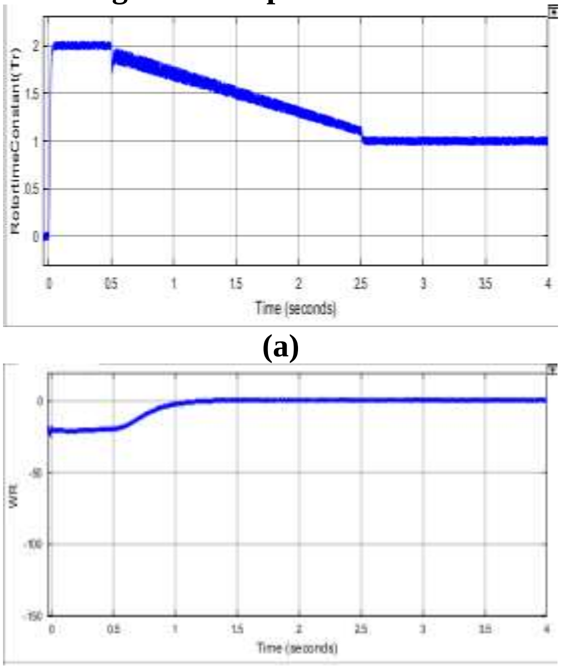


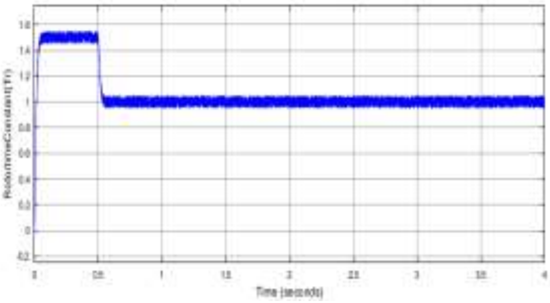
Figure 4: Proposed Simulink

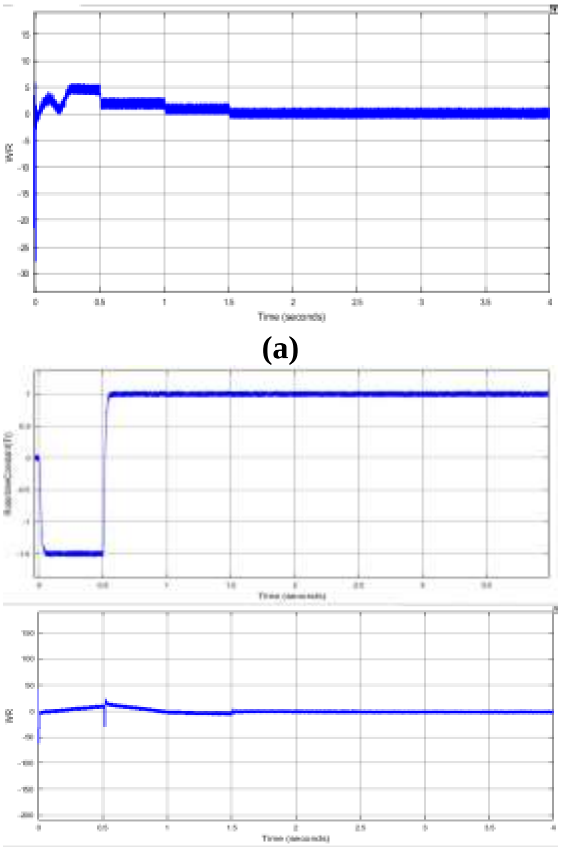


(a)

(b)

Figure 5: Simulation results of the Tr adaptation behaviour for (a) underestimated and (b) overestimated initial values at 34 % rated speed and rated load torque.





(a)

(b)

Figure 6: Simulation results of the Tr adaptation behaviour at (a) 1.7 % rated speed under 50% rated load torque and (b) 4.8 % rated speed under no load condition.

IV. CONCLUSION

The conclusion of this study is to provide a parallel estimation system of the rotor time constant and the rotor speed in sensorless IFOC of induction machine. Since simultaneous estimation of Tr and ωr is impossible under the steady state due to constant rotor flux, a low-frequency harmonic was injected to the rotor flux to obtain additional excitation for Tr adaptation. An amplitude-adaptive observer was proposed to detect the amplitude of the injected harmonic using voltage and current models. In this way, a sine wave state observer was introduced to observe the state variables of the superimposed component. Based on the detected amplitude, a novel MRAS-based Tr estimation system was proposed. The Lyapunov’s stability theorem was employed to ensure the asymptotic convergence of the proposed Tr identification system. The performance of the proposed Tr estimation system was experimentally verified in a 6PIM test bench as a case example. Nevertheless, the proposed method can be used for other multi-phase induction machines. The merits of the proposed Tr estimator was highlighted by a qualitative comparison of the existing schemes. To alleviate the destructive effect of Rs mismatch on the proposed Tr estimator, a compensated voltage model of the 6PIM was employed, where the related experiments showed its effectiveness.

REFERENCE

[1] Chen W., Yang F., Liu G. (2019). Adaptive identification method for rotor time constant and rotor resistance based on model reference adaptive system for speed-sensorless IM drive. IEEE Access, 7, 30018-30030.

[2] Chetty P., Lai J.-S. (2010). Speed Sensorless Indirect Field-Oriented Control of Six-Phase Induction Motor Using Extended Kalman Filter. IEEE Transactions on Industrial Electronics, 57(6), 1895-1906.

[3] Chetty P., Lai J.-S., Mendis F. V. C. (2012). Speed Sensorless Indirect Field Oriented Control of Six-Phase Induction Motor Drives. IEEE Transactions on Energy Conversion, 27(2), 471-479.

[4] Cortes P., Rodríguez J., Dixon J. W., Espinoza J. R. (2014). High-performance control of six-phase induction machines using model reference adaptive systems. IET Electric Power Applications, 8(5), 219-226.

[5] Cortes P., Rodríguez J., Dixon J. W., Espinoza J. R. (2017). An adaptive rotor time constant estimator for sensorless control of six-phase induction machines. Electric Power Systems Research, 147, 25-33.

[6] Cortes P., Rodríguez J., Espinoza J. R. (2016). Sensorless control of six-phase induction machines using a hybrid model-based estimator. Electric Power Systems Research, 131, 1-9.

[7] Cortes P., Rodríguez J., Espinoza J. R. (2017). Sensorless control of six-phase induction machines using a dual model-based estimator. IEEE Transactions on Industrial Electronics, 64(5), 3780-3789.

[8] Cortes P., Rodríguez J., Espinoza J. R., Dixon J. W. (2018). A dual model-based estimator for the sensorless control of six-phase induction machines with unbalanced and asymmetric load torque. IEEE Transactions on Industrial Electronics, 65(2), 1212-1222.

[9] Cortes P., Rodríguez J., Espinoza J. R., Dixon J. W. (2019). Robust sensorless control of six-phase induction machines using an adaptive dual model-based estimator. IEEE Transactions on Industrial Electronics, 66(6), 4647-4657.

[10] Dixon J. W. (2006). Variable Structure Control of Induction Motors. Springer.

[11] Fang Y., Su C., Qi Y., Wen G. (2020). A Novel Model Reference Adaptive System for Adaptive Identification of Rotor Time Constant of PMSM Drive. IEEE Access, 8, 10346-10357.

[12] Boldea I., Nasar S. A. (2002). The Induction Machine Handbook. CRC Press.

[13] Fitzgerald A. E., Kingsley C. Jr., Umans S. D. (2002). Electric Machinery. McGraw-Hill.

[14] Krause P. C., Wasynczuk O., Sudhoff S. D. (2013). Analysis of Electric Machinery and Drive Systems. Wiley.

[15] Bose B. K. (2006). Modern Power Electronics and AC Drives. Prentice Hall.

[16] Chen W., Yang F., Liu G. (2019). Adaptive identification method for rotor time constant and rotor resistance based on model reference adaptive system for speed-sensorless IM drive. IEEE Access, 7, 30018-30030.

[17] Chetty P., Lai J.-S. (2010). Speed Sensorless Indirect Field-Oriented Control of Six-Phase Induction Motor Using Extended Kalman Filter. IEEE Transactions on Industrial Electronics, 57(6), 1895-1906.

[18] Chetty P., Lai J.-S., Mendis F. V. C. (2012). Speed Sensorless Indirect Field Oriented Control of Six-Phase Induction Motor Drives. IEEE Transactions on Energy Conversion, 27(2), 471-479.

[19] Cortes P., Rodríguez J., Dixon J. W., Espinoza J. R. (2014). High-performance control of six-phase induction machines using model reference adaptive systems. IET Electric Power Applications, 8(5), 219-226.

[20] Cortes P., Rodríguez J., Dixon J. W., Espinoza J. R. (2017). An adaptive rotor time constant estimator for sensorless control of six-phase induction machines. Electric Power Systems Research, 147, 25-33.

[21] Cortes P., Rodríguez J., Espinoza J. R. (2016). Sensorless control of six-phase induction machines using a hybrid model-based estimator. Electric Power Systems Research, 131, 1-9.

[22] Cortes P., Rodríguez J., Espinoza J. R. (2017). Sensorless control of six-phase induction machines using a dual model-based estimator. IEEE Transactions on Industrial Electronics, 64(5), 3780-3789.

[23] Cortes P., Rodríguez J., Espinoza J. R., Dixon J. W. (2018). A dual model-based estimator for the sensorless control of six-phase induction machines with unbalanced and asymmetric load torque. IEEE Transactions on Industrial Electronics, 65(2), 1212-1222.

[24] Cortes P., Rodríguez J., Espinoza J. R., Dixon J. W. (2019). Robust

sensorless control of six-phase induction machines using an adaptive dual model-based estimator. IEEE Transactions on Industrial Electronics, 66(6), 4647-4657.

[25] Dixon J. W. (2006). Variable Structure Control of Induction Motors. Springer.

[26] Fang Y., Su C., Qi Y., Wen G. (2020). A Novel Model Reference Adaptive System for Adaptive Identification of Rotor Time Constant of PMSM Drive. IEEE Access, 8, 10346-10357.