DOI: https://doi.org/10.15407/techned2025.06.052

IMPROVED ROTOR FLUX ESTIMATION FOR FIELD-ORIENTED CONTROL IN INDUCTION MOTOR DRIVES

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The field-oriented control (FOC) method is a widely used technique for precise speed regulation in three-phase induction motor drives. The resistance values of the motor vary from their rated values because of increased temperature during operation. The research aims to improve the accuracy of rotor flux linkage (RFL) estimation, thereby sustaining the performance of the FOC method under resistance variations. The paper proposes a more advanced approach to estimating and integrating motor resistances into the RFL calculation. A new structure, featuring voltage, current, and virtual current models, is used to determine the stator and rotor resistance. These estimated resistance values replace the rated resistance values in the current model, which are then used to calculate the RFL vector. Simulations are performed to verify the accuracy of the estimated resistance values and the effectiveness of the improved FOC method under different operating conditions. The simulation results demonstrate that the calculated resistances closely match the preset resistance values, confirming that the enhanced FOC method retains high estimation accuracy even when motor resistance changes. References 18, figures 9.
Keywords: field-oriented control, MRAS, voltage model, current model, rotor resistance, stator resistance.

Introduction. Field-oriented control (FOC) is an effective technique that enables precise control of a three-phase induction motor (IM) by decoupling the magnetic flux's torque and magnitude . As a result, FOC has drawn significant attention from both industrial and academic researchers [1–3]. However, real-world applications expose FOC systems to various operating conditions that negatively impact their performance, especially fluctuations in motor resistance caused by temperature changes during operation [4, 5]. These fluctuations can lead to inaccurate estimates of the rotor flux linkage (RFL) angle, which is crutial for maintaining optimal performance in motor control systems. Wang et al. [6] discuss advanced control strategies, emphasizing that while FOC enables efficient torque and flux decoupling, it also requires complex parameter tuning to handle varying resistance levels. A notable weakness in [7] is the dependence on static models for resistance calculations, which can cause inefficiencies under dynamic temperature conditions. While they offer a robust framework for IM control, the absence of a real-time adaptation mechanism for resistance changes may restrict their use in scenarios with large temperature fluctuations. Additionally, their work does not address integration with advanced methodologies like the multi-model approach proposed in this paper.

This work presents an innovative approach based on the current model [8] to tackle these challenges in estimating RFL for FOC techniques. Furthermore, an improved MRAS model is employed to precisely determine the stator and rotor resistances of the motor and integrate this data into the RFL angle calculation within the current model. This method uses a trio of models: a voltage model [9–11], a current model [12, 13], and a virtual current model [14], to evaluate the stator and rotor resistances in real-time [15, 16]. The FOC method can sustain higher accuracy and stability during motor operation by dynamically adjusting the calculated resistances, rather than relying on static rated values [17]. The proposed approach improves the

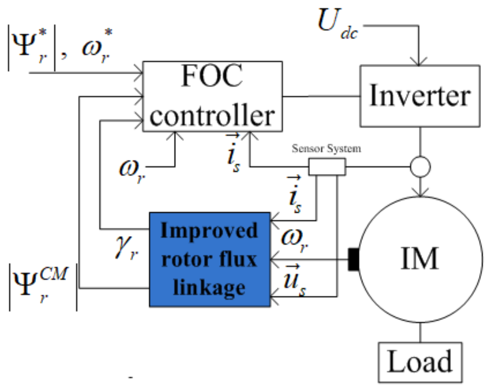

Fig. 1 – Block diagram of IM using enhanced FOC

accuracy of RFL angle estimation by adjusting to changes in rotor and stator resistance during motor operation. Additionally, simulation results have confirmed the validity of this analysis.

The Dynamic Field-Oriented Control of a Three-Phase Induction Motor. Employing the equation system for the IM [18], a Field Oriented Control (FOC) scheme is developed for the IM's drive system, as shown in Fig. 1. The system includes the following key components: IM, where RFL dynamics play a crucial role in regulating speed; a load that varies by application; a three-phase AC inverter power supply, which controls both speed and torque through its voltage and frequency outputs; and a sensor array that measures the motor's current, voltage, and speed signals. The FOC controller operates by decoupling the torque and flux components of the stator current, allowing for independent control of the motor. A Current Model (CM) is utilized to estimate the RFL. Additionally, the system integrates estimators for both stator and rotor resistances.

Improved Rotor flux linkage in the FOC technique. The CM estimates the RFL using the stator current and rotor speed measurements obtained from the sensor system. Operating within the [α, β] coordinate frame, the RFL components are calculated using the mathematical expressions provided in equations (1) – (4):

$$\Psi_{r\alpha}^{CM}=\int_0^t\left(\frac{L_m}{L_r}R_{r\_est}i_{s\alpha}-\frac{1}{L_r}R_{r\_est}\Psi_{r\alpha}^{CM}-\omega_r\Psi_{r\beta}^{CM}\right)dt\ , \tag{1}$$

$$\Psi_{r\beta}^{CM}=\int_0^t\left(\frac{L_m}{L_r}R_{r\_est}i_{s\beta}-\frac{1}{L_r}R_{r\_est}\Psi_{r\beta}^{CM}+\omega_r\Psi_{r\alpha}^{CM}\right)dt\ , \tag{2}$$

$$\left|\Psi_r^{CM}\right|=\sqrt{\left(\Psi_{r\alpha}^{CM}\right)^2+\left(\Psi_{r\beta}^{CM}\right)^2}\ , \tag{3}$$

$$\gamma_r=arctg\left(\frac{\Psi_{r\beta}^{CM}}{\Psi_{r\alpha}^{CM}}\right)\ . \tag{4}$$

Estimation of Stator and Rotor Resistances Based on the Current Model. A resistance estimation method is proposed to simultaneously determine the stator and rotor resistances by integrating three distinct models: the voltage model (VM), the CM, and the virtual current model. These models employ the measured current and voltage signals as input variables to accurately estimate the motor parameters. First, the CM is used to derive the RFL and its angle needed for implementing the FOC strategy, as defined in equations (1) – (4). However, deviations in rotor resistance (R_r) directly impact the accuracy of RFL estimation. To mitigate this effect, a virtual current model is introduced to predict the stator current components in the stationary [α, β] reference frame, with the estimation process detailed in equations (5) – (7). Fig. 2 illustrates the discrepancy between the predicted and measured stator currents, which is utilized as an error signal to adjust the estimated value of R_r.

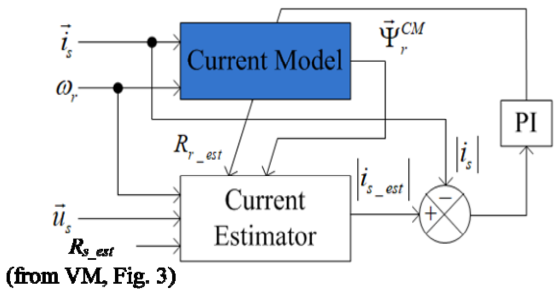

Fig. 2 – Rotor resistance estimation diagram

$$\frac{di_{s\alpha\_est}}{dt}=\frac{L_r}{L_sL_r-L_m^2}u_{s\alpha}-\left[\frac{\left(\dfrac{L_rR_{s\_est}}{L_m}+\dfrac{L_mR_{r\_est}}{L_r}\right)}{\dfrac{\left(L_sL_r-L_m^2\right)}{L_m}}\right]i_{s\alpha}+\frac{R_{r\_est}L_m}{L_r\left(L_sL_r-L_m^2\right)}\Psi_{r\alpha}^{CM}+\frac{L_m}{\left(L_sL_r-L_m^2\right)}\omega_r\Psi_{r\beta}^{CM}\ , \tag{5}$$

$$\frac{di_{s\beta\_est}}{dt} = \frac{L_r}{L_sL_r - L_m^2}u_{s\beta} - \left[\frac{\left(\frac{L_rR_{s\_est}}{L_m}+\frac{L_mR_{r\_est}}{L_r}\right)}{\frac{\left(L_sL_r-L_m^2\right)}{L_m}}\right] i_{s\beta} + \frac{R_{r\_est}L_m}{L_r\left(L_sL_r-L_m^2\right)}\Psi^{CM}_{r\beta} - \frac{L_m}{\left(L_sL_r-L_m^2\right)}\omega_r\Psi^{CM}_{r\alpha}, \qquad (6)$$

$$\left|i_{s\_est}\right| = \sqrt{\left(i_{s\alpha\_est}\right)^2+\left(i_{s\beta\_est}\right)^2}. \qquad (7)$$

Second, the VM estimates the RFL using the formulations given in equations (8) – (10). Similar to the CM, any variation in the stator resistance (R_s) directly affects the accuracy of RFL estimation in the VM. To mitigate this issue, the error between the RFL estimated by the CM and that obtained from the VM is processed through a PI controller to adapt the R_s estimation. The structure of the R_s estimator is illustrated in Fig. 3.

$$\Psi^{VM}_{r\alpha} = \frac{L_r}{L_m}\left[\int_0^t \left(u_{s\alpha} - R_{s\_est}i_{s\alpha}\right)dt - \frac{L_sL_r-L_m^2}{L_r}i_{s\alpha}\right], \qquad (8)$$

$$\Psi^{VM}_{r\beta} = \frac{L_r}{L_m}\left[\int_0^t \left(u_{s\beta} - R_{s\_est}i_{s\beta}\right)dt - \frac{L_sL_r-L_m^2}{L_r}i_{s\beta}\right], \qquad (9)$$

$$\left|\Psi^{VM}_{r}\right| = \sqrt{\left(\Psi^{VM}_{r\alpha}\right)^2+\left(\Psi^{VM}_{r\beta}\right)^2}. \qquad (10)$$

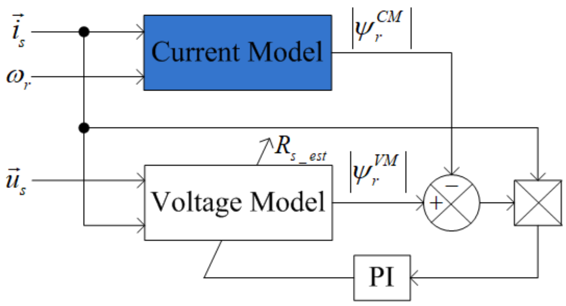

Fig. 3 – Stator resistance estimation diagram

Results and Discussion. The three-phase induction motor model is developed using the actual motor parameters: stator resistance of 3.179 Ω, rotor resistance (referred to the stator side) of 2.118 Ω, and inductances of 0.209 H for both stator and rotor windings, along with 0.192 H for the magnetizing branch. The motor's reference speed is set to reach 1000 rpm at 0.5 s and is held constant throughout the test period. In the case study, the effectiveness of the resistance estimation method is evaluated by simultaneously increasing the stator and rotor resistances by 30% at 2.0 s. This disturbance requires a current density of approximately 280 A/mm², which significantly challenges the estimator's capability.

Simulating the operation of the IM drive based on the improved FOC method with CM-based RFL, Fig. 4 illustrates that the RFL vector components in the [α, β] plane from the CM are also accurate and stable, ensuring efficient system operation. Fig. 5 presents the reference and simulated IM speeds undeer varying R_s and R_r resastances; the control system maintains the motor speed close to the reference value despite minor overshoots during the starting process. When both resistances are increased by 30% from their nominal values at 2.0 s, this change affects the RFL and rotor speed in the estimated models. Although the initial change in R_s and R_r leads to a deviation between the reference and estimated values, the estimator exhibits good adaptability by accurately adjusting to the changes in R_s and R_r, as shown in Figs. 6 and 7. Finally, the simulation results in Figs. 8 and 9 show a negligible discrepancies between the actual and estimated resistances.

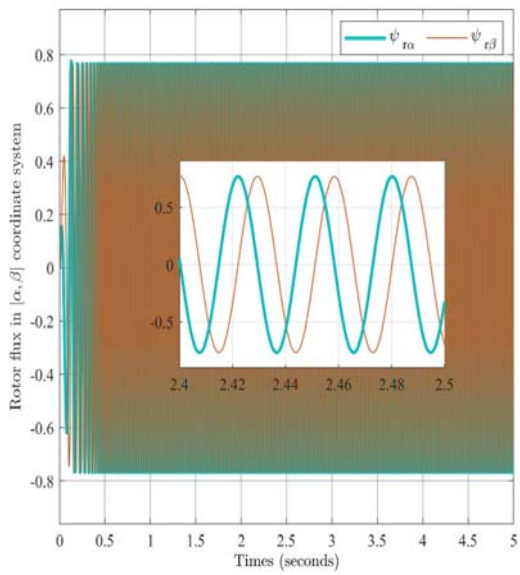

Fig. 4 – Rotor flux vector from the current model

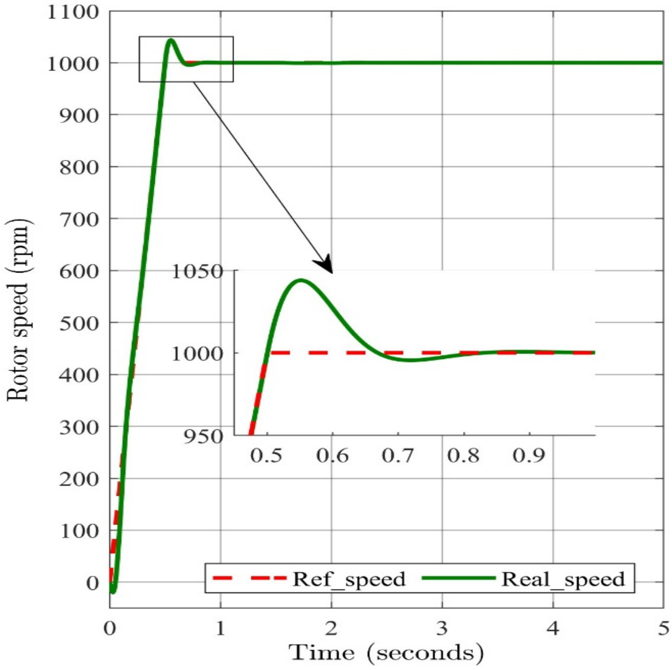

Fig. 5 – Rotor speed

Conclusions. The study presents a practical approach to improving the precision and reliability of field-oriented control method in environments where variations in motor resistances can compromise system performance. By simultaneously employing the voltage, current, and virtual current models, the proposed approach enables accurate updates of stator and rotor resistances, thereby enhancing adaptability in estimating the rotor flux linkage angle. Simulation results demonstrate that replacing rated value with the estimated resistances allows the field-oriented control system to maintain robust stability and control performance during operation. This method shows strong potential for future experimental validation on real hardware platforms, contributing to improved reliability and adaptability in practical applications.

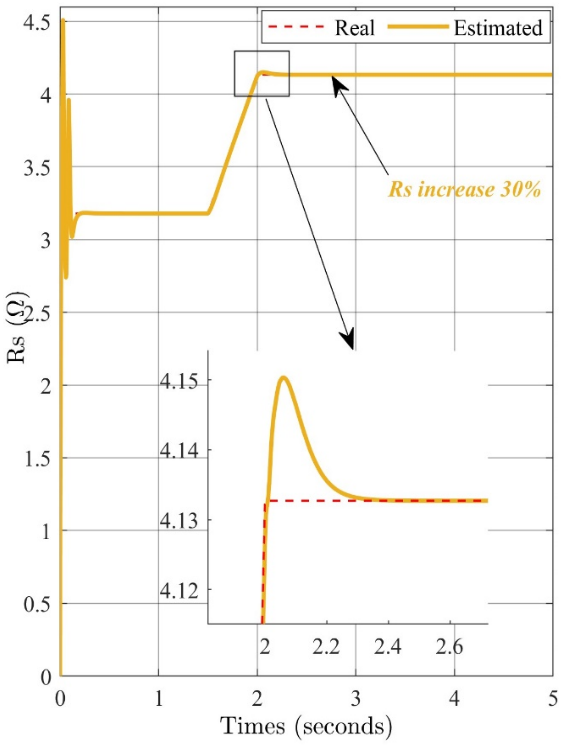

Fig. 6 – Stator resistance: Real and Estimated

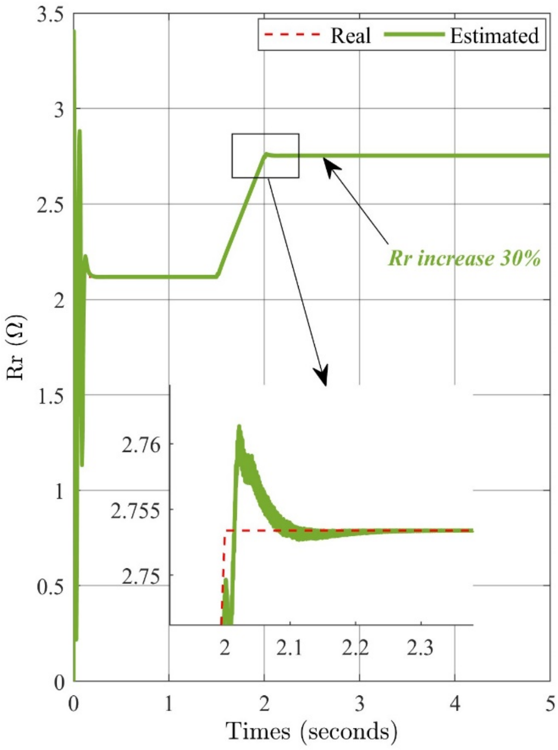

Fig. 7 – Rotor resistance: Real and Estimated

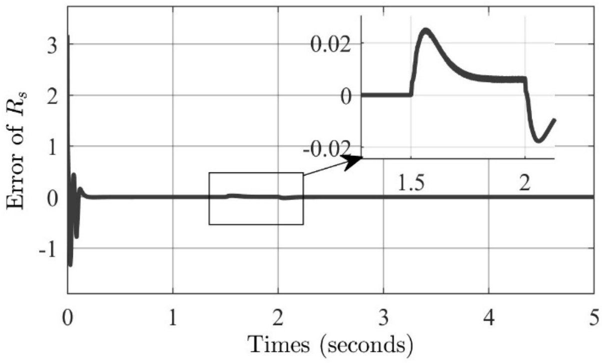

Fig. 8 – Error of stator resistance

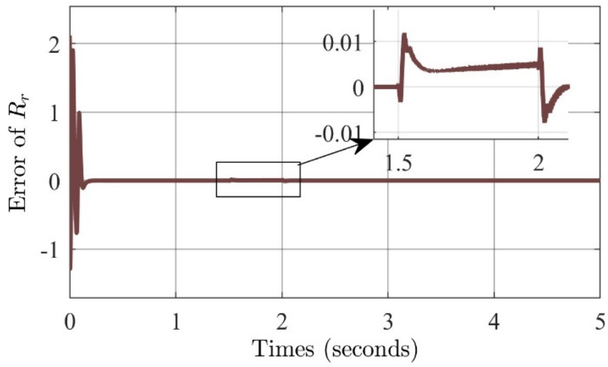

Fig. 9 – Error of rotor resistance

This research is funded by Ton Duc Thang University under grant number FOSTECT.2024.20.

1. Li J. Field-oriented control drive circuit design. *Journal of Physics: Conference Series.* 2023. Vol. 2649. Issue 1. P. 012045. DOI: https://doi.org/10.1088/1742-6596/2649/1/012045.

2. Tran C.D., Kuchar M., Nguyen P.D. Research for an enhanced fault-tolerant solution against the current sensor fault types in induction motor drives. *Electrical Engineering & Electromechanics.* 2024. No 6. Pp. 27–32. DOI: https://doi.org/10.20998/2074-272X.2024.6.04.

3. Begh M.A.W., Herzog H. Comparison of field oriented control and direct torque control. *Robotics and control systems*. 2024. Pp. 1–16. DOI: https://doi.org/10.36227/techrxiv.171332371.13141782/v1.

4. Popovych O.M., Golovan I.V. Modeling of induction motors in electromechanical systems considering stator iron losses. *Tekhnichna Elektrodynamika*. 2024. No 5. Pp. 24–29. DOI: https://doi.org/10.15407/techned2024.05.024. (Ukr)

5. Ha I.-J., Lee S.-H. An online identification method for both stator-and rotor resistances of induction motors without rotational transducers. *IEEE Transactions on Industrial Electronics.* 2000. Vol. 47. No 4. Pp. 842–853. DOI: https://doi.org/10.1109/41.857964.

6. Wang F., Zhang Z., Mei X., Rodríguez J., Kennel R. Advanced control strategies of induction machine: Field oriented control, direct torque control and model predictive control. *Energies.* 2018. Vol. 11. Issue 1. P. 120. DOI: https://doi.org/10.3390/en11010120.

7. Perduková D., Palacký P., Fedor P., Bober P., Fedák V. Dynamic identification of rotor magnetic flux, torque and rotor resistance of induction motor. *IEEE Access.* 2020. Vol. 8. Pp. 142003–142015. DOI: https://doi.org/10.1109/ACCESS.2020.3013944.

8. Brandstetter P. Sensorless control of induction motor using modified MRAS. *International Review of Electrical Engineering.* 2012. Vol. 7. No 3. Pp. 4404–4411.

9. Orlowska-Kowalska T., Korzonek M., Tarchala G. Performance analysis of speed-sensorless induction motor drive using discrete current-error based MRAS estimators. *Energies.* 2020. Vol. 13. Issue 10. P. 2595. DOI: https://doi.org/10.3390/en13102595.

10. Reddy G.B., Poddar G., Muni B.P. Parameter estimation and online adaptation of rotor time constant for induction motor drive. *IEEE Transactions on Industry Applications.* 2022. Vol. 58. No 2. Pp. 1416–1428. DOI: https://doi.org/10.1109/TIA.2022.3141700.

11. Adamczyk M., Orlowska-Kowalska T. Online stator and rotor resistance estimation for current sensor fault-tolerant control of induction motor drives. International Conference on *Electrical Drives and Power Electronics* (*EDPE*), The High Tatras, Slovakia, 25-27 September 2023. Pp. 1–6. DOI: https://doi.org/10.1109/EDPE58625.2023.10274048.

12. Asfu W.T. Stator current-based model reference adaptive control for sensorless speed control of the induction motor. *Journal of Control Science and Engineering*. 2020. Vol. 2020. No 1. Article ID 8954704. DOI: https://doi.org/10.1155/2020/8954704.

13. Ray N.K., Das S., Goswami G. Active power based MRAS for estimation of rotor resistance in field-oriented control of induction motor drive. IEEE 4th International Conference on *Sustainable Energy and Future Electric Transportation* (SEFET). Hyderabad, India, 31 July – 03 August 2024. Pp. 1–6. DOI: https://doi.org/10.1109/SEFET61574.2024.10718249.

14. Tran C.D., Truong M.N. Sensorless Control for Induction Motor Drive Applying CB-MRAS Integrating Stator Resistance Estimation. *International Review of Modeling and Simulations* (*IREMOS*). 2024. Vol. 17. No 4. DOI: https://doi.org/10.15866/iremos.v17i4.24107.

15. Lee S.-B., Habetler T.G. An on-line stator winding resistance estimation technique for temperature monitoring of line-connected induction machines. *Conference Record of the 2001 IEEE Industry Applications Conference.*

36th IAS Annual Meeting (*Cat. No. 01CH37248*), Chicago, IL, USA, 30 September – 04 October 2001. Vol. 3. Pp. 1564–1571. DOI: https://doi.org/10.1109/IAS.2001.955744.

16. Ha I.-J., Lee S.-H. An online identification method for both stator-and rotor resistances of induction motors without rotational transducers. *IEEE Transactions on Industrial Electronics.* 2000. Vol. 47. No 4. Pp. 842–853. DOI: https://doi.org/10.1109/41.857964.

17. Tran C.D., Kuchar M., Sotola V., Nguyen P.D. Fault-tolerant control based on current space vectors against total sensor failures. *Sensors.* 2024. Vol. 24. Issue 11. P. 3558. DOI: https://doi.org/10.3390/s24113558.

18. Dinh B.H., Tran C.D. An improved voltage model based on stator resistance estimation for FOC technique in the induction motor drive. *Advances in Electrical & Electronic Engineering.* 2024. Vol. 22. No 2. DOI: https://doi.org/10.15598/aeee.v22i2.5745.

ПОКРАЩЕНА ОЦІНКА РОТОРНОГО ПОТОКУ ДЛЯ ПОЛЬОВО-ОРІЄНТОВАНОГО КЕРУВАННЯ АСИНХРОННИМИ ДВИГУНАМИ

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Метод польово-орієнтованого керування (ПОК) є широко застосовуваним підходом для точного регулювання швидкості трифазних асинхронних двигунів. Значення опорів двигуна відрізняються від номінальних через підвищення температури під час роботи. Метою дослідження є підвищення точності оцінки потокозчеплення ротора (ПЗР), що надасть можливості підтримувати ефективність методу ПЗР у разі змін опору. У роботі запропоновано вдосконалений підхід до оцінки та інтеграції опорів двигуна в розрахунок ПЗР. Запропонована структура, що включає моделі напруги, струму та віртуального струму, використовується задля визначення опору статора та ротора. Оцінені значення опору замінюють номінальні у моделі струму, після чого використовуються для розрахунку вектора ПЗР. Моделювання проводиться задля перевірки точності оцінених значень опору та ефективності вдосконаленого методу ПЗР за різних умов експлуатації. Результати моделювання показують, що розрахункові опори точно відповідають попередньо встановленим значенням опору, підтверджуючи високу точність оцінювання за допомогою вдосконаленого методу ПЗР навіть у разі зміни опорів двигуна. Бібл. 18, рис. 9.

Ключові слова: польово-орієнтоване керування, MRAS, модель напруги, модель струму, опір ротора, опір статора.

Received 08.05.2025
Accepted 28.07.2025