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FEATURES OF INTEGRATING ANSYS AND SIMULINK SOFTWARE FOR MATHEMATICAL MODELING OF TRANSIENT PROCESSES IN AN ASYNCHRONOUS MOTOR

ОСОБЛИВОСТІ ОБ'ЄДНАННЯ ПРОГРАМ ANSYS ТА SIMULINK ДЛЯ МАТЕМАТИЧНОГО МОДЕЛЮВАННЯ ПЕРЕХІДНИХ ПРОЦЕСІВ В АСИНХРОННОМУ ДВИГУНІ

The paper presents an algorithm for creating a coupled model to study transient processes in an asynchronous motor with a squirrel-cage rotor using Ansys Simplorer-Maxwell2D and Simulink environments. An integrated model is proposed, combining electromagnetic calculations in Ansys Maxwell2D with a control system in Simulink. This approach enables more accurate analysis of electromechanical processes during transient studies.

The combined use of the software allows the model of the asynchronous motor to account for magnetic core saturation, leakage fields in stator slots, current displacement in rotor slots, eddy currents in the rotor shaft, hysteresis, short-circuit rings, and slot skew. Key aspects of the development, debugging, and data exchange between the software environments are discussed.

The proposed approach can be applied to improve methods for designing and analyzing electric drives, as well as for educational purposes in higher technical education. Future research prospects include extending the model to incorporate energy converters.

Keywords*: asynchronous motor, transient processes, coupled modeling, electric drive, dynamic characteristics.*

У роботі розглядається алгоритм створення спільної моделі для дослідження перехідних процесів в асинхронному двигуні з короткозамкненим ротором у середовищах Ansys Simplorer-Maxwell2D та Simulink. Запропоновано інтегровану модель, що поєднує електромагнітні розрахунки в Ansys Maxwell2D з моделлю системи керування у середовищі Simulink. Такий підхід дозволяє значно підвищити точність розрахунків електромеханічних характеристик під час моделювання перехідних процесів, які супроводжують пуск, зупинку, а також зміну навантаження асинхронного електропривода.

Спільне використання зазначених програмних засобів дає змогу врахувати складні фізичні явища, які неможливо або складно відобразити у спрощених математичних моделях: насичення магнітопроводу, розсіювання магнітного поля в пазах статора, витіснення струму в провідниках ротора, вихрові струми у валу, явище гістерезису, вплив короткозамкнутих кілець, а також ефект скосу пазів. Описано основні етапи побудови моделі, методи налагодження та особливості обміну даними між середовищами Ansys та Simulink на основі ко-симуляції.

Запропонований підхід може бути використаний для вдосконалення методів аналізу та проєктування електроприводів, особливо у випадках, коли потрібна висока точність. Окрім цього, така модель є ефективним навчальним інструментом у вищій технічній освіті для демонстрації складних електромагнітних процесів. Перспективи подальших досліджень включають розширення моделі з урахуванням перетворювачів енергії, а також включення теплових і механічних моделей для комплексного аналізу електроприводних систем.

Ключові слова*: асинхронний двигун, перехідні процеси, взаємне моделювання, електропривод, динамічні характеристики.*

Problem's formulation

Asynchronous motors (AMs) are the most common type of electric machines in industry and household applications due to their simple design, high reliability, and efficiency. They are widely used in electric drives for various purposes and operating conditions. The most challenging operating condition for AMs is the transient state, which is accompanied by significant currents (up to 7 times the nominal current) and electromagnetic torque (up to 4 times the nominal torque).

The analysis of transient processes involves determining electromagnetic parameters, which are often assumed constant and calculated without considering design specifics. Using the Ansys Simplorer-Maxwell 2D software (student version) enables the AM model to account for magnetic core saturation, stator slot leakage fields, current displacement in rotor slots, eddy currents in the rotor shaft, hysteresis, short-circuit rings, and slot skew, as well as determining nonlinear electromagnetic parameters. The Matlab Simulink software, with its mathematical packages and virtual modeling capabilities for electric drives, facilitates the development of control systems. The integrated use of Ansys Simplorer-Maxwell 2D and Simulink allows for consideration of AM design specifics and virtual modeling of control systems.

Developing an integrated model that combines the AM and control systems is a crucial task for improving the accuracy of calculations and optimizing the operating conditions of electric drives.

Analysis of recent research and publications

Analysis of recent studies and publications confirms that co-simulation using Ansys Maxwell, Simplorer, and Simulink is an effective approach for precise modeling of electric drive characteristics, as it accounts for the design specifics of asynchronous motors (AMs) and their control systems.

In [1], co-simulation of an AM and its control system is demonstrated, where finite element analysis in Ansys Maxwell enables the determination of electromagnetic field distribution and calculation of electromagnetic torque, while Ansys Simplorer models the interactions between the motor and the inverter. Simulink is used to develop the control system, allowing real-time testing of vector control and direct torque control algorithms. This approach significantly enhances the accuracy of motor characteristic calculations, reduces errors in determining AM performance, and optimizes energy consumption.

Study [2] focuses on using co-simulation to analyze direct torque control of AMs. Ansys Maxwell facilitates the determination of electromagnetic parameters that are challenging to obtain with traditional mathematical models. Ansys Simplorer models the interaction between the inverter and the motor, while Simulink implements the control system, enabling evaluation of direct torque control efficiency and comparison with vector control. The results show that co-simulation reduces torque ripple, improves the dynamic performance of the electric drive, and accounts for nonlinear dependencies.

In [3], co-simulation is employed to evaluate the performance of an asynchronous motor (AM) under traction load. The use of Maxwell enables the assessment of magnetic core saturation effects on AM characteristics. Simplorer is utilized to analyze transient processes in the power supply system, while Simulink is used to test control algorithms, facilitating the calculation of energy consumption and power losses in the system. The study confirms that co-simulation provides more accurate results compared to classical methods, particularly in calculating thermal regimes.

In [4], a Simulink model of direct torque control is presented, applied in co-simulation with Maxwell to improve the prediction of transient processes. Simplorer enables modeling of the electromechanical interaction between the motor and the converter, accounting for the impact of switching processes on drive performance.

Analysis in [5] demonstrates the effectiveness of co-simulation for predicting the characteristics of synchronous reluctance machines. The combination of Ansys Maxwell, Simplorer, and Simulink allows for the determination of electromagnetic parameters, energy losses, and optimal operating conditions.

In [6], the finite element method is used to analyze electromagnetic processes in an asynchronous motor (AM), with Maxwell providing more accurate results compared to classical d-q models.

In [8], co-simulation of the AM startup mode is conducted using Maxwell2D and Simplorer, with a control system developed in Matlab Simulink. The study also highlights the advantages of the finite element method over traditional mathematical models, confirming the effectiveness of Maxwell2D in co-simulation.

Studies [7, 11—12] explore the capabilities of co-simulation in Simulink and ANSYS environments for analyzing electric drive control algorithms. [7] focuses on torque modeling, [9] demonstrates the benefits of vector control systems in reducing torque ripple and improving switching performance, and [10] evaluates the impact of pulse-width modulation control of the inverter on energy losses in a traction AM. In [11], direct torque control is combined with Maxwell for magnetic field analysis, while [12] investigates control algorithms under near-real-world conditions, enabling a comprehensive evaluation of their effectiveness in transient processes.

Overall, modern research confirms that co-simulation using Ansys Maxwell, Simplorer, and Simulink enables the consideration of nonlinear electromagnetic characteristics of the magnetic core, AM geometric parameters, and the impact of switching processes in energy converters and control systems. This approach reduces errors in determining electromagnetic torque and characteristics, making it promising for optimizing electric drives by comprehensively accounting for all key system parameters.

Formulation of the study purpose

The purpose of the study is to develop an integrated model of an electric drive with an asynchronous motor, combining field modeling in Ansys Maxwell2D with a control system in MATLAB Simulink, to achieve more accurate analysis of transient processes during motor startup.

Presenting main material

The development of a model for co-simulation of transient processes in an asynchronous motor (AM) begins with creating a project in Ansys Simplorer, where a portion of the electric drive control system is designed (Fig. 1). The schematic in Fig. 1 represents a virtual model that includes the AM field model created in Maxwell 2D [13] and a voltage control system. This model enables comprehensive analysis of electromagnetic and control processes in real time within the framework of co-simulation with MATLAB Simulink.

To establish a connection between Maxwell 2D and MATLAB Simulink, Ansys Simplorer is first opened, and a new project is created via the menu for creating a new file. Next, the project name is specified, and an appropriate directory for saving is selected. Then, the AM field model, developed in Maxwell 2D, is added. The parameters of the developed AM model are configured based on reference and calculated data [13, 14].

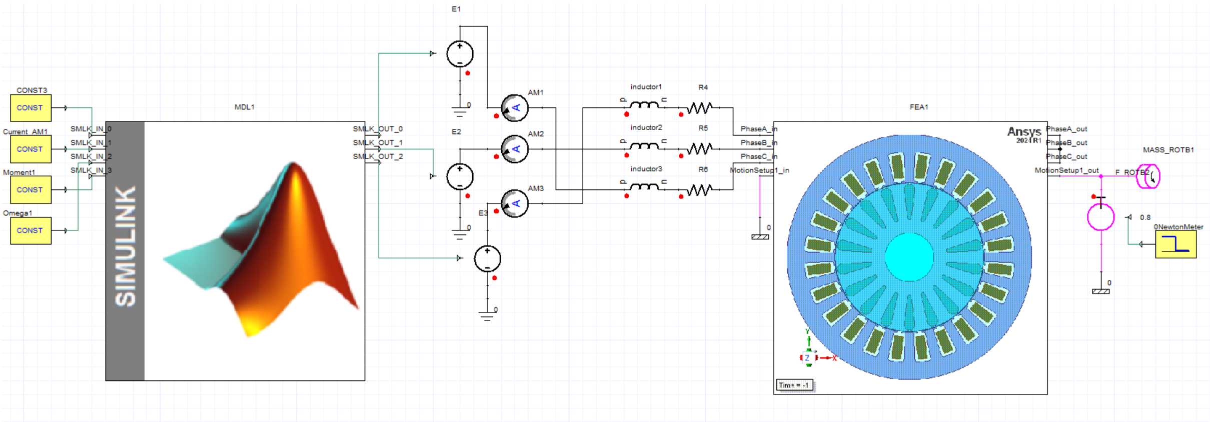


Fig. 1. The virtual model of the electric drive, developed in MATLAB Simulink and Ansys Simplorer environments

The next step involves adding a co-simulation module to enable interaction between Ansys Simplorer and MATLAB Simulink. In the project management window, navigate to “Twin Builder — Add Component — Add Simulink Component” and select the Co-Simulation Module. This adds the Ansoft Co-Simulation Interface element to the schematic (Fig. 2). This element serves as a link between the two software environments, facilitating the transfer of variables between them. In its parameters, the variables to be transferred must be specified, and proper connection with other schematic components must be ensured. If necessary, the “Real Quantity Input” data conversion module is added to ensure correct connection. The Real Quantity Input block (Q = BLS) in Ansys Simplorer is used to input real numerical values into the model, enabling the transfer of analog signals between different system components. The Real Quantity Input functional block serves as an interface between mathematical and physical models, with its primary purpose being the transmission of variable parameters — such as current, voltage, speed, or torque—to functional blocks, ensuring accurate modeling of control systems.

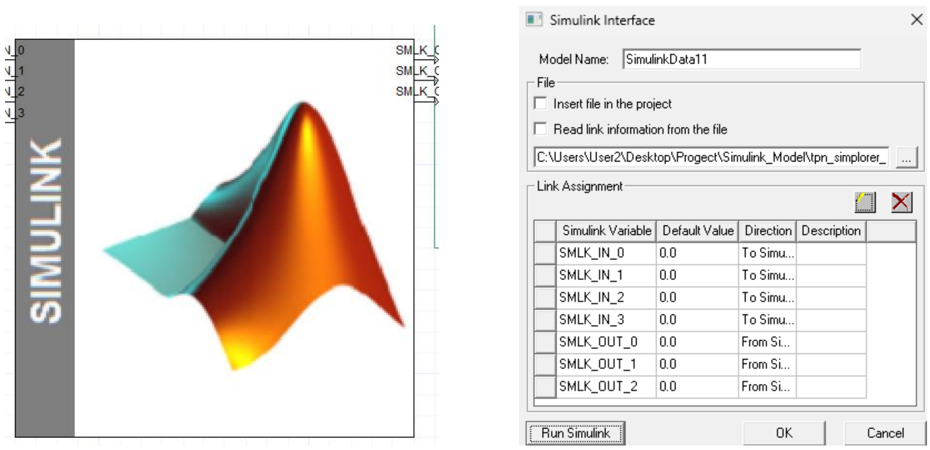


Fig. 2. Structure of the Interaction Module between Ansys Simplorer and Simulink Using the Ansoft Co-Simulation Interface

Parallel to the development of the electromagnetic model in Ansys Simplorer, a control system model is created in MATLAB Simulink. To achieve this, MATLAB is launched, and a new project is initiated in the Simulink environment (Fig. 3). Within this project, a dedicated module implements the startup system for the asynchronous motor (AM) from the power grid.

The electrical part of the model is constructed using the Simscape Electrical library, which includes all necessary power electronics components, control nodes, and measurement elements. To verify the simulation results in Simulink, a simplified mathematical model of the asynchronous motor is also developed. This model accounts for electromagnetic parameters determined based on [13]. Additionally, control and measurement blocks are incorporated into the system to record key characteristics and enable comparative analysis of simulation results.

To facilitate interaction between Simulink and Ansys Simplorer, a dedicated co-simulation module, AnsoftSFunction, specifically the S-Function block, is added. This block is responsible for transferring data such as voltage, current, torque, and speed between the two environments. In the module's settings, the correct path to the asynchronous motor (AM) model files used in co-simulation must be specified, along with the parameters for variable exchange between MATLAB and Ansys (Fig. 4). This ensures accurate signal transmission between the two control system models.

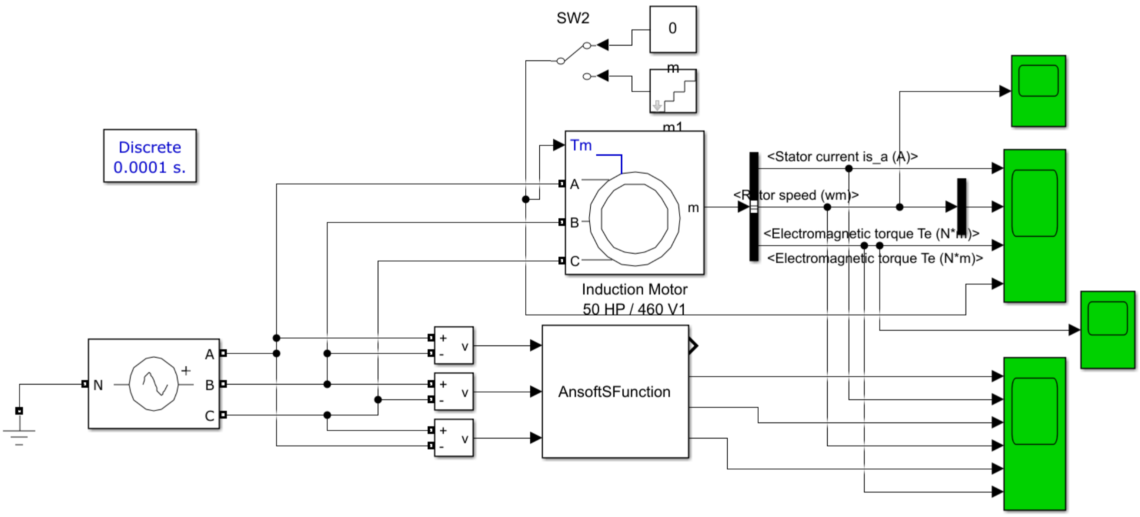


Fig. 3. Structural Diagram of the Control System in MATLAB Simulink

After completing the steps of adding and configuring the software blocks, co-simulation is initiated. Before launching the model in Ansys Simplorer, it is necessary to verify the correct connection of all elements. Then, in the MATLAB Simulink environment, the model is executed, during which the interaction between Simulink and Ansys Simplorer is validated.

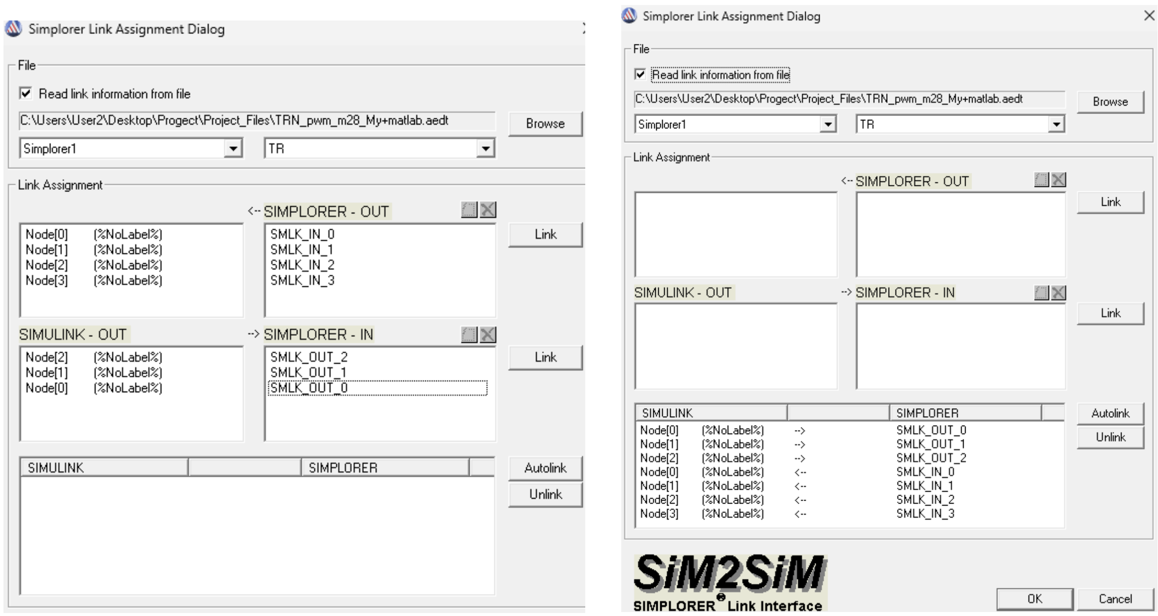


Fig. 4. Parameters of the S-Function Block for Data Transfer between Simulink and Ansys Simplorer

In co-simulation within environments like Simplorer and Simulink, specific steps must be followed to establish connectivity and apply the Co-Simulation Module blocks. After creating both the electromechanical model (Fig. 1) and the control system model (Fig. 3), the first step is to add input-output ports to the Sim-to-Sim Interface block (Fig. 4). These ports must then be connected using the "Link" command. Next, in the settings window (Fig. 2), the Simulink project from which the ports for co-simulation will be used is selected, after which they are automatically added to the created Co-Simulation module. The subsequent step involves launching the control system through the Simulink environment. This approach enables simultaneous simulation of both models.

To compare the transient characteristics of the AM startup mode, simulations were performed in the MATLAB Simulink model, Ansys Simplorer (Fig. 1), and MATLAB Simulink (Fig. 3). The startup characteristics of the AM in the MATLAB Simulink-Ansys Simplorer model are shown in Fig. 5, while those in the MATLAB Simulink model are depicted in Fig. 6. For the mathematical modeling, an AM of type 4AA63A4U3 [15] was selected, with a power rating of 250 W and a rotational speed of 1500 rpm. In the MATLAB Simulink AM model, electromagnetic parameters were used as defined in the reference [15].

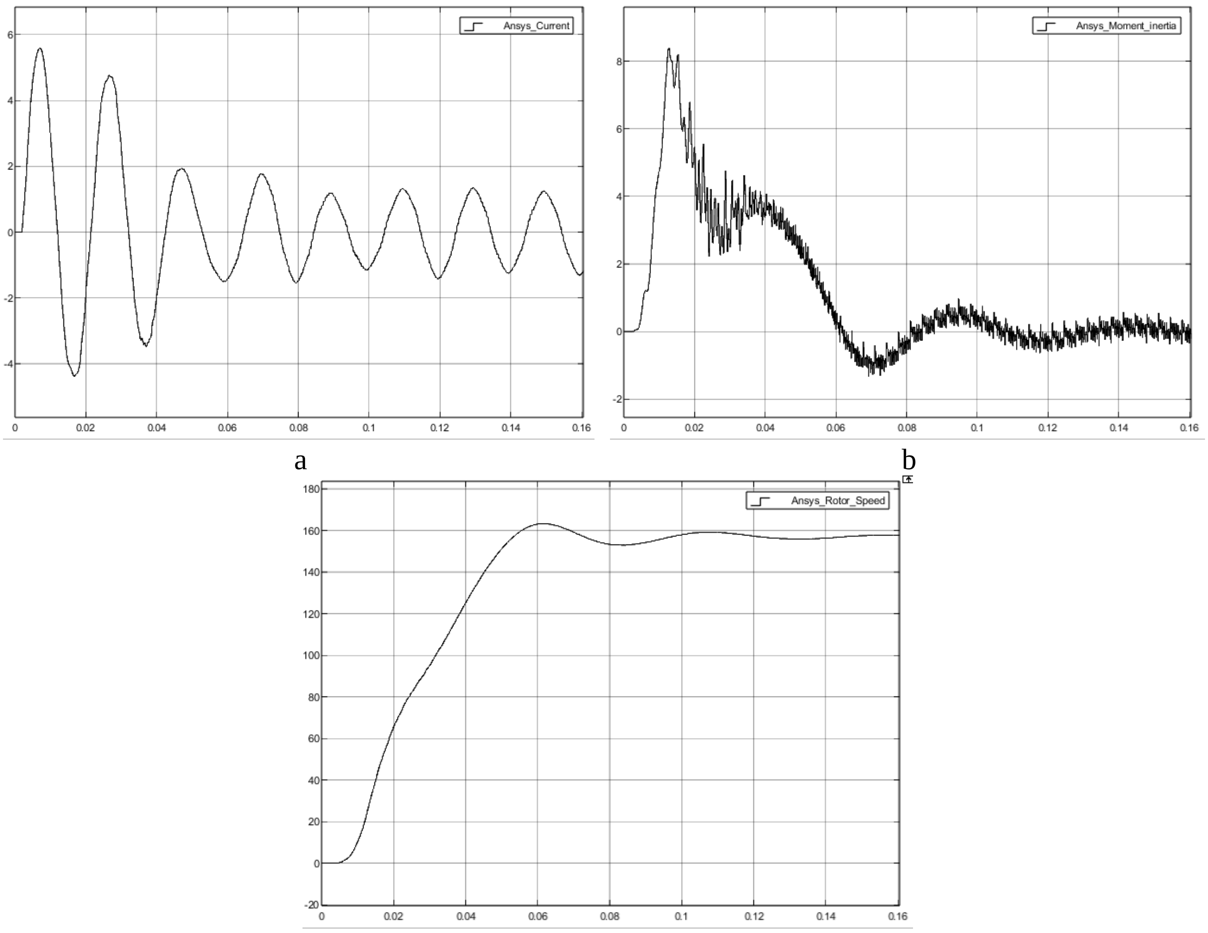
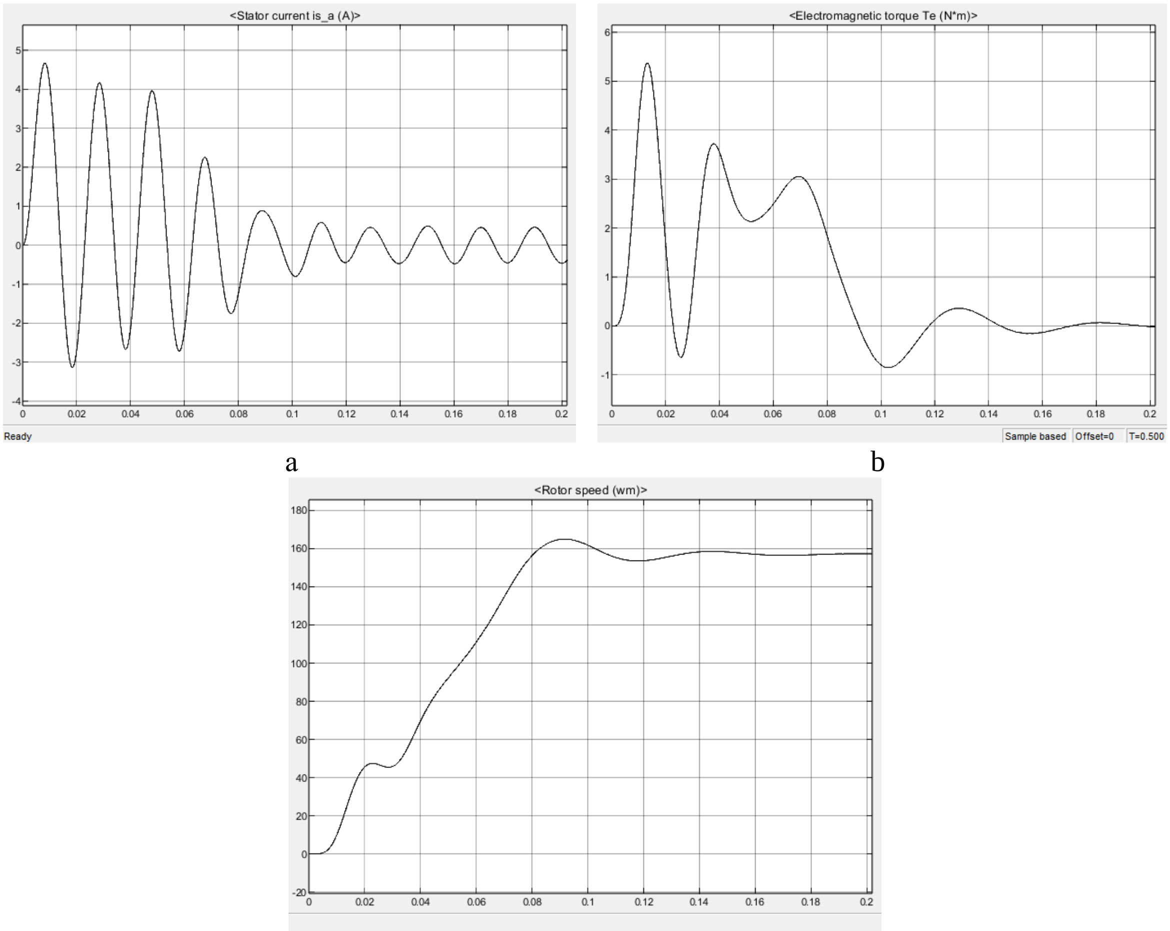


Fig. 5. Startup Characteristics of the Field Model of the 4AA63A4U3 Asynchronous Motor (AM): a — Startup current in the stator winding of phase A; b — Electromagnetic torque; c — Angular velocity of the rotor



a b

c

Fig. 6. Startup Characteristics of the AM with Constant Electromagnetic Parameters (4AA63A4U3): a — Startup current in the stator winding of phase A; b — Electromagnetic torque; c — Angular velocity of the rotor

Comparative analysis of the startup characteristics shows that the model developed in MATLAB Simulink and Ansys Simplorer, which accounts for the nonlinearity of magnetic materials and the geometric parameters of the AM, differs from the MATLAB Simulink model with constant electromagnetic parameters. Specifically, the maximum current value is 12 % higher, the electromagnetic torque is 11 % lower, and the transient process completes 6.2 % faster. The electromagnetic torque (Fig. 5, b) exhibits harmonics caused by the toothed geometry of the rotor and stator. When compared to reference data [15], the simulation results in MATLAB Simulink and Ansys Simplorer indicate that the maximum startup current in Ansys Simplorer exceeds the reference value by 12 %, while in MATLAB Simulink, it is 14 % lower.

Conclusions

In this study, integrated models were developed for the joint simulation of transient processes in an induction motor (IM) using Ansys Simplorer, Maxwell2D, and Simulink environments. The proposed methodology enables the combination of a finite element model with a control system.

The analysis of the simulation results demonstrated that the proposed approach improves modeling accuracy compared to the use of constant electromagnetic parameters typically found in reference data [15].

Promising directions for future research include the expansion of the model to analyze the operation of induction motors powered by energy converters.

References

[1] RefreeDrive Project. (2019). *Finite Elements Model Co-Simulation of an Induction Motor Drive for Traction Application*. [Online]. Available: https://www.refreedrive.eu/wp-content/downloads/Finite_element_model_co-simulation_of_an_induction_motor_drive_for_traction_application_aiecon2019_RFDa.pdf

[2] A. K. Singh, P. Kumar, C. U. Reddy, and K. Prabhakar. (2016). *Simulation of Direct Torque Control of Induction Motor Using Simulink, Simplorer, and Maxwell Software*. [Online]. Available: https://www.researchgate.net/publication/302479453

[3] *Performance Evaluation of an Induction Motor Drive for Traction Application*. Academia.edu. [Online]. Available: https://www.academia.edu/67039178

[4] *Direct Torque Control of Induction Motor Simulink Model*. MathWorks File Exchange. [Online]. Available: https://www.mathworks.com/matlabcentral/fileexchange/78396

[5] *Co-Simulation Analysis for Performance Prediction of Synchronous Reluctance Machine Drives*. MDPI Electronics. [Online]. Available: https://www.mdpi.com/2079-9292/10/17/2154

[6] *Modeling and Simulation of Induction Motor Based on Finite Element Analysis*. ResearchGate. [Online]. Available: https://www.researchgate.net/publication/313455870

[7] *Torque Control of Induction Motor Using Simulink/Matlab*. CS Journals. [Online]. Available: https://csjournals.com/IJITKM/ICFTEM/pdf/2.%20eceee/38-%20357

[8] *Modeling and Simulation of Induction Motor Based on Finite Element Analysis*. IJPEDS. [Online]. Available: https://ijpeds.iaescore.com/index.php/IJPEDS/article/view/5826

[9] *Space Vector Modulation Based Direct Torque Control of Induction Motor Using Matlab/Simulink/Maxwell/Simplorer*. Academia.edu. [Online]. Available: https://www.academia.edu/33109158

[10] Nishanth, F. (2022). Simulation and analysis of inverter fed three phase induction motor using SVPWM technique. arXiv. https://arxiv.org/abs/2209.05254

[11] *Direct Torque Control of an Induction Motor Drive*. MathWorks Documentation. [Online]. Available: https://www.mathworks.com/help/sps/ug/power-motordrive-IM-DTC-HYST.html

[12] *Direct Torque Control of Induction Motor*. IJAMTES. [Online]. Available: https://ijamtes.org/gallery/1%20conf-ee.pdf

[13] M. Zahrebaiev, M. Zvonetskiy, and O. S'yanov. (2024). *Mathematical modeling of transient processes in a squirrel-cage induction motor using a field-based approach*. Mathematical Modeling. DSTU. no. 2(51), pp. 66–76.

[14] M. Zahrebaiev, M. Zvonetskiy, O. Ryazantsev, and O. S'yanov. (2024). *The influence of electromagnetic parameters of a squirrel-cage induction motor on transient processes*. Scientific Proceedings of Dnipro State Technical University (Technical Sciences), no. 2(45), pp. 136–145.

[15] *Electric motors of the AIR, 4A, AO, VAO, VR, AIM series: supply, repair, description and reference data*. Ukrnasosservice. [Online]. Available: https://ukr-nasos.com.ua/ru/uslugi/elektrodvigatelya-seriy-air-4a-ao-prodazha-remont-opisanie-i-obmotochnyie-dannyie.html

Список використаної літератури

1. Finite Elements Model Co-Simulation of an Induction Motor Drive for Traction Application [Електронний ресурс] / RefreeDrive Project. – Режим доступу: https://www.refreedrive.eu/wp-content/downloads/Finite_element_model_co-simulation_of_an_induction_motor_drive_for_traction_application_aiecon2019_RFDa.pdf , вільний.
2. Simulation of Direct Torque Control of Induction Motor Using Simulink, Simplorer, and Maxwell Software [Електронний ресурс] / A. K. Singh, P. Kumar, C. U. Reddy, K. Prabhakar. – Режим доступу: https://www.researchgate.net/profile/Amit-Singh-5/publication/302479453_Simulation_of_direct_torque_control_of_induction_motor_using_Simulink_simplorer_and_maxwell_software/links/5773b07808ae4645d609d187/Simulation-of-direct-torque-control-of-induction-motor-using-Simulink-simplorer-and-maxwell-software.pdf , вільний.

3. Performance Evaluation of an Induction Motor Drive for Traction Application [Електронний ресурс] / Academia.edu. – Режим доступу: https://www.academia.edu/67039178/Performance_Evaluation_of_an_Induction_Motor_Drive_for_Traction_Application , вільний.
4. Direct Torque Control of Induction Motor Simulink Model [Електронний ресурс] / MathWorks File Exchange. – Режим доступу: https://www.mathworks.com/matlabcentral/fileexchange/78396-direct-torque-control-of-induction-motor-simulink-model , вільний.
5. Co-Simulation Analysis for Performance Prediction of Synchronous Reluctance Machine Drives [Електронний ресурс] / MDPI Electronics. – Режим доступу: https://www.mdpi.com/2079-9292/10/17/2154 , вільний.
6. Modeling and Simulation of Induction Motor Based on Finite Element Analysis [Електронний ресурс] / ResearchGate. – Режим доступу: https://www.researchgate.net/publication/313455870_Modeling_and_Simulation_of_Induction_Motor_based_on_Finite_Element_Analysis/fulltext/589b685baca2721ae1b7938d/Modeling-and-Simulation-of-Induction-Motor-based-on-Finite-Element-Analysis.pdf , вільний.
7. Torque Control of Induction Motor Using Simulink/Matlab [Електронний ресурс] / CS Journals. – Режим доступу: https://csjournals.com/IJITKM/ICFTEM/pdf/2.%20eceee/38-%20357-Torque%20Control%20of%20Induction%20Motor%20Using%20Simulink.pdf , вільний.
8. Modeling and Simulation of Induction Motor Based on Finite Element Analysis [Електронний ресурс] / IJPEDS. – Режим доступу: https://ijpeds.iaescore.com/index.php/IJPEDS/article/view/5826 , вільний.
9. Space Vector Modulation Based Direct Torque Control of Induction Motor Using Matlab/Simulink/Maxwell/Simplorer [Електронний ресурс] / Academia.edu. – Режим доступу: https://www.academia.edu/33109158/Space_Vector_Modulation_Based_Direct_Torque_Control_of_Induction_Motor_using_Matlab_Simulink_Maxwell_Simplorer , вільний.
10. Nishanth, Fnu. Simulation and Analysis of Inverter Fed Three Phase Induction Motor Using SVPWM Technique [Електронний ресурс] / Fnu Nishanth // arXiv. – 2022. – Режим доступу: https://arxiv.org/abs/2209.05254.
11. Direct Torque Control of an Induction Motor Drive [Електронний ресурс] / MathWorks Documentation. – Режим доступу: https://www.mathworks.com/help/sps/ug/power-motordrive-IM-DTC-HYST.html , вільний.
12. Direct Torque Control of Induction Motor [Електронний ресурс] / IJAMTES. – Режим доступу: https://ijamtes.org/gallery/1%20conf-ee.pdf , вільний.
13. Zahrebaiev Mykhailo, Zvonetskiy Mykhailo, S’yanov Oleksandr. (2024). Mathematical modeling of transient processes in a squirrel-cage induction motor using a field-based approach. Mathematical Modeling. DSTU. № 2(51) 2024. 66-76
14. Загребаєв М.С., Звонецький М.С., Рязанцев О.В., С'янов О.М. Вплив електромагнітних параметрів асинхронного двигуна з короткозамкнутою кліткою на перехідні процеси. Збірник наукових праць Дніпровьского державного технічного університету (технічні науки). Кам’янське, ДДТУ, 2024. №2 (45), 216 с., 136-145
15. Elektrodvyhuny serii AYR, 4A, AO, VAO, VR, AYM postavka, remont, opys ta dovidny-kovi danni. Ukrnasosservis. [Electric motors of the AIR, 4A, AO, VAO, VR, AIM series supply, repair, description and reference data. Ukrnasoservice]. ukr-nasos.com.ua. Re-trieved from https://ukr-nasos.com.ua/ru/uslugi/elektrodvigatelya-seriy-air-4a-ao-prodazha-remont-opisanie-i-obmotochnyie-dannyie.html [in Ukrainian]

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