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Development of Imitation Model of an Electromechanical Energy Converter with a Solid Rotor in ANSYS RMxprt, Maxwell and Twin Builder

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Abstract
This paper presents the development of a platform for coupling modeling (co-simulation) of an electromechanical energy converter using ANSYS Maxwell and ANSYS Twin Builder. The researched electromechanical energy converter is based on the operation principle of an induction motor with an external hollow solid rotor. The paper reveals the specifics of modeling this type of special electric machine. In the work, step-by-step modeling of the machine in ANSYS RMxprt, export of the model in ANSYS Maxwell 2D and 3D with further co-simulation in Twin Builder was performed. It shows how to set up the project to import an object calculated by the finite element method from ANSYS Maxwell into the Twin Builder sheet. Coupling simulation of an electromechanical energy converter with a stable three-phase power source was performed. The simulation model considers the presence of a step mechanical load during the run-up to the rated speed. Such structure of a coupling project gives better simulation results compared to the use of simulation models with concentrated parameters, based on the implementation of differential equations of electromagnetic transients using functional blocks. The obtained characteristics showed a high coincidence of the expected results according to the indicators of phase currents of the stator winding, moving torque and rotation speed. This paper will be useful for coupling modeling special-purpose electrical machines that are not available in the ANSYS Twin Builder library as ready-made blocks.

INTRODUCTION

Technological processes related to heating, mixing and transportation of viscous and loose materials have found wide use in various branches of the national economy (industry, agriculture, energy) [1]. Increasing the efficiency, economy and versatility of devices that provide processing of the specified materials is determined by the level of development and implementation of scientific research in industry, operation, in the development of new design solutions, technologies. The primary importance is the use of electromechanical devices as nodes of a technological chain, which undoubtedly refers to modern trends in the field of scientific achievements of the XXI century [2–4].

The problem of creating energy-saving and environmentally friendly raw material processing technologies in various industries and agriculture has become particularly acute in connection with the rise in energy prices and the resulting impracticality of operating old-style energy-intensive complexes [5–14].

A reasonable alternative to traditional complexes, which contain separately formed units of equipment, are electro-technical complexes based on multifunctional energy converters (MFEC) of the electromechanical type, which provide for the effective use of dissipative component energy, structural, functional and thermal integration [15]. In Fig. 1 shown a typical simplified scheme of fuel preparation for thermal power plants.

Such complexes occupy several floors of the workshop, require the presence of a gas boiler room to produce steam, electric motors, reducers, voltage regulators, fans and electric heaters, magnetic separation and magnetic processing systems.

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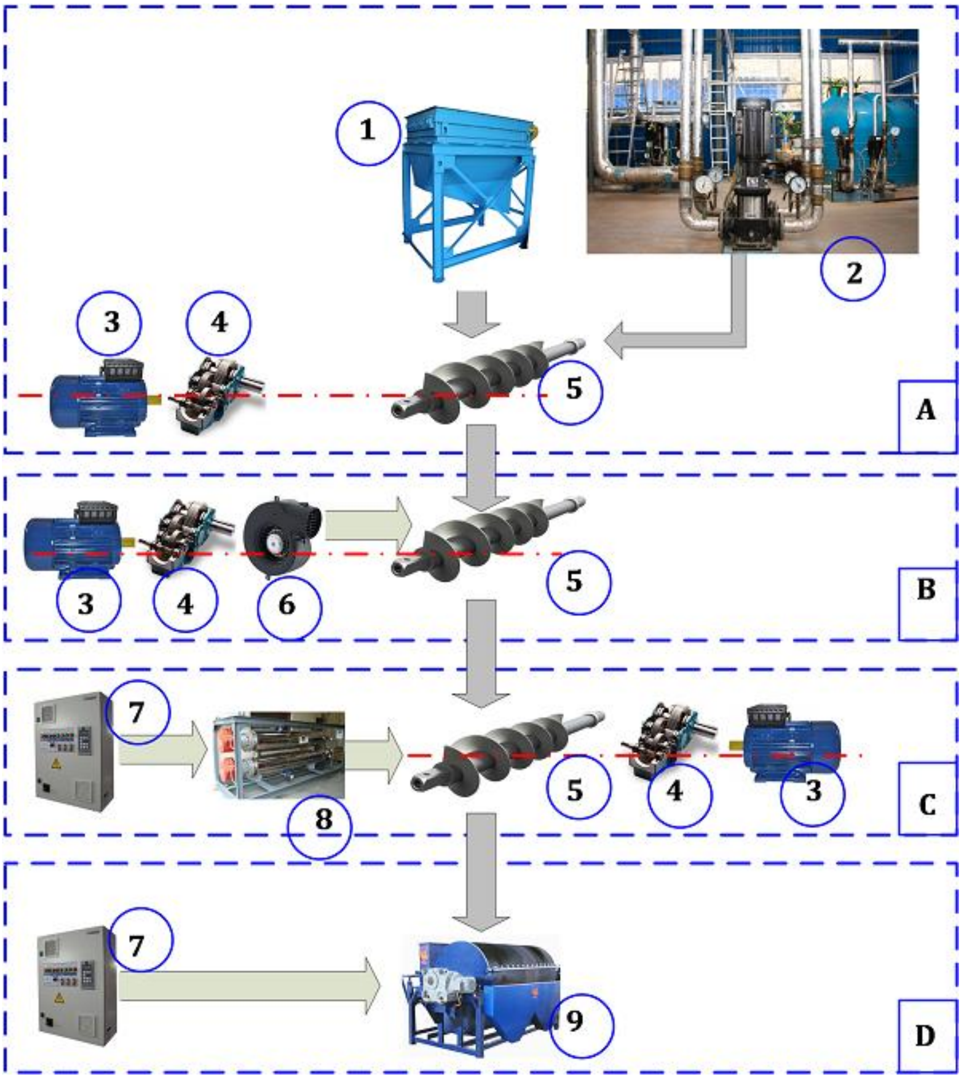


Figure 1. Traditional scheme of processing raw materials to produce CHP fuel: *A* – phase of mixing and preparation of raw materials; *B* – primary drying phase; *C* – final drying phase; *D* – phase of magnetic processing; *1* – bulk bunker; *2* – gas boiler room; *3* – electric motor; *4* – reducer; *5* – screw; *6* – fan; *7* – frequency converter/voltage regulator; *8* – electric heater; *9* – magnetic separator

In addition, environmentally harmful additives are used during fuel preparation. According to a similar principle, of course, considering the specifics of the technological process, complexes for the processing of grain, paraffin, fuel oil and other loose and easily melting substances are being built. All these complexes are connected by the following functional features:

- presence of a voltage regulation system;
- presence of an electric motor;
- presence of a reducer;
- the presence of an auger;
- availability of a material heating system.

Such complexes have low energy efficiency due to energy losses both in individual nodes and in the material transfer links between processing phases. Due to the use of a gas boiler house and chemical impurities, the level of environmental danger is increasing. In addition, the overall reliability of the complex is very low, as it is determined by the product of the reliability coefficients of individual elements of the system [16, 17].

In this regard, the development of such complex, which would be able to perform the above functions of the already existing complexes, but devoid of economic, mechanical and environmental disadvantages, is proposed. In a schematic form, the improved complex for the production of fuel for thermal power plants has the form shown in Fig. 2.

The technological process involves the use of only one electromechanical MFEC device, which combines several functions for material processing:

- ensuring a low rotation speed without using a mechanical reducer or frequency converter;
- mixing and transporting material;
- grinding of large fractions of raw materials;
- heating;
- electromagnetic processing.

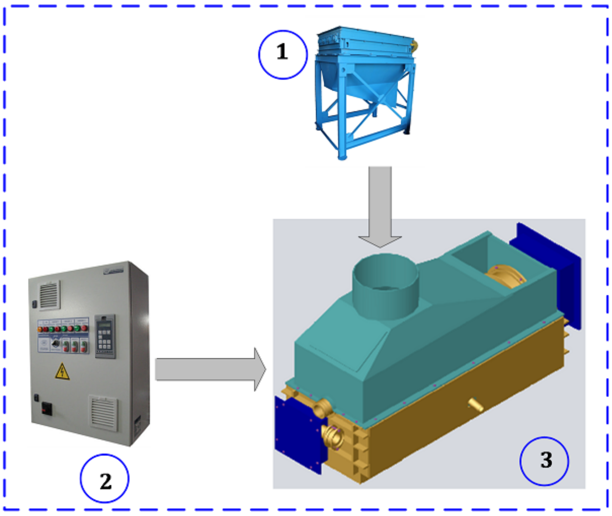


Figure 2. Modified scheme of processing raw materials for the production of CHP fuel: *1* – bulk bunker; *2* – unregulated or regulated power supply system; *3* – multifunctional energy converter (MFEC)

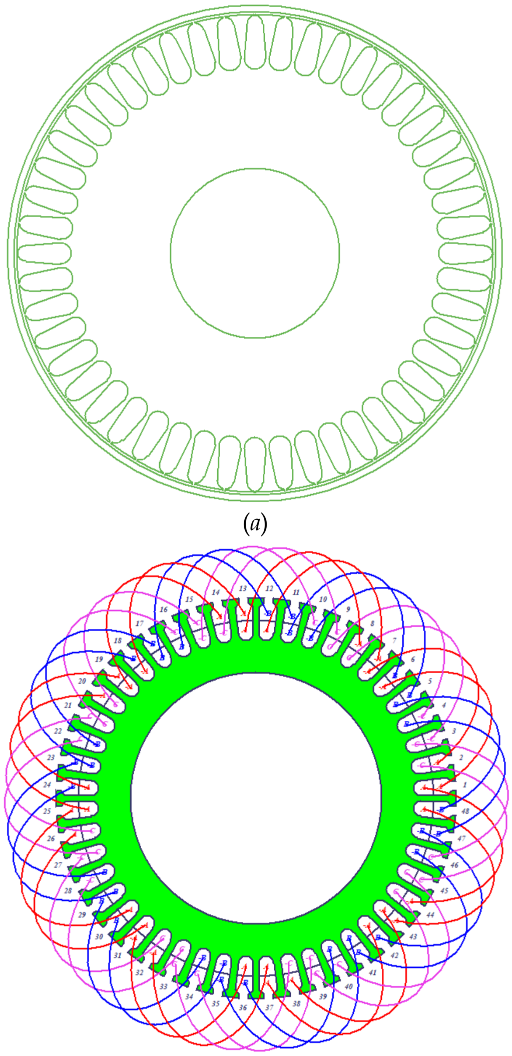
The aim of this paper is to develop a simulation model of the system of stabilization of the speed of rotation of the rotor of the MFEC. Because the design of the hollow solid rotor makes it difficult to install a speed sensor, in the model, as in real frequency control systems, the speed will be calculated from flux linkages and stator winding currents. The results of the research are the basis for the production of an experimental sample of the MFEC control system.

IMITATION MODEL

In the previous work, the construction of the MFEC model in ANSYS RMxprt [18] using a specialized template for electric machines with an external solid rotor was given in detail [19]. The study of an induction motor with an external solid rotor was described in works [14, 20, 21]. The study of a special electric motor in ANSYS Maxwell and Twin Builder is presented in [22]. The conducted studies finished with the calculation of the MFEC parameters and obtaining the working and mechanical characteristics under static loading in ANSYS RMxprt and Ansys Maxwell 2D.

Studies of electric machines in ANSYS Maxwell and Twin Builder (also known as Simplorer) are present in works [23–30]. These papers, like many similar ones, are devoted to the study of standard types of electric machines, which are significantly different from MFEC. In this regard, the materials presented in this paper have differences that reveal the specifics of special performance electric machines simulation.

In this paper, the MFEC model obtained earlier (Fig. 3) is used, with further studies of transient electromechanical processes in ANSYS Twin Builder.



(*a*)

(*b*)

Figure 3. MFEC model in RMxprt: cross section (*a*) and stator winding (*b*)

To do this, it is needed to import the field model in Twin Builder, but before some additional operations must be performed:

- create a 3D model of the machine to consider the features of the MFEC geometry and improve field calculations (Fig. 4). The figure shows the main calculation objects of the model: the inner stator, the outer hollow solid rotor, the shaft and the three-phase winding. Areas of symmetry (dependent, independent) and additional geometry (inner region, outer region, band) are hidden on the figure;
- change the stator windings excitation from the direct assignment of currents or voltages to the use of an external circuit in the Circuit Editor (Fig. 5);
- perform the calculation of the MFEC characteristics in Maxwell 3D in the transient mode with a run-up from zero speed to the rated speed, considering mechanical transients and load torque (Fig. 6) [18];

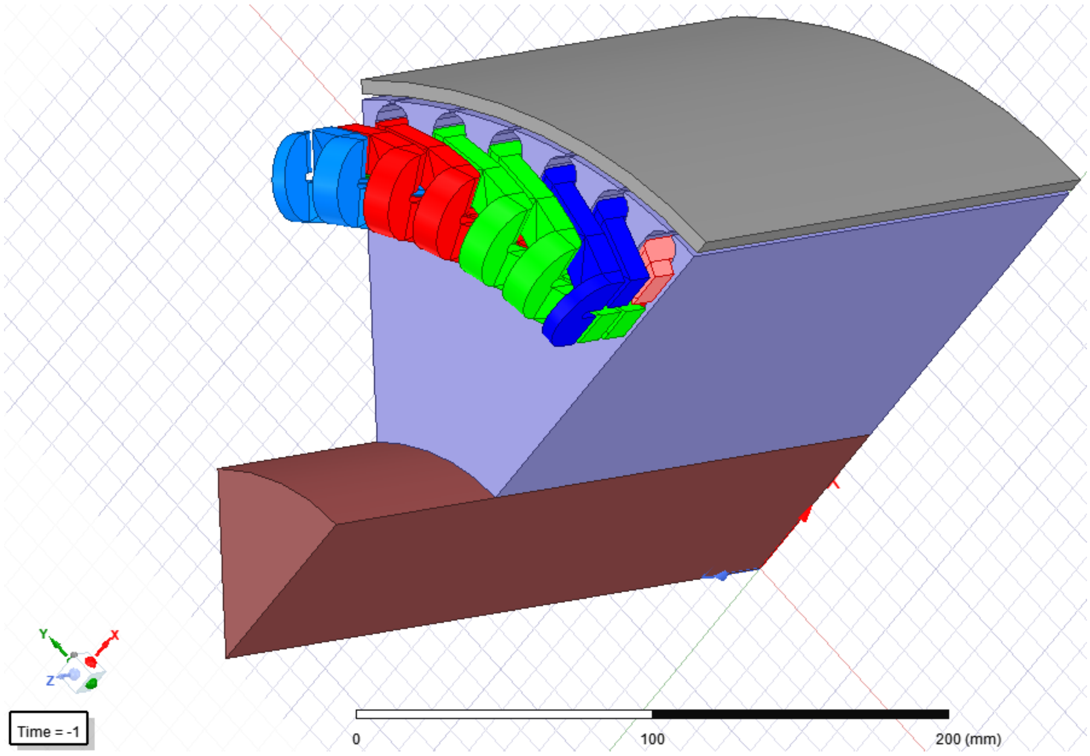


Figure 4. Model of the MFEC in Ansys Maxwell 3D (1/8 part) taking into account longitudinal and transverse symmetry

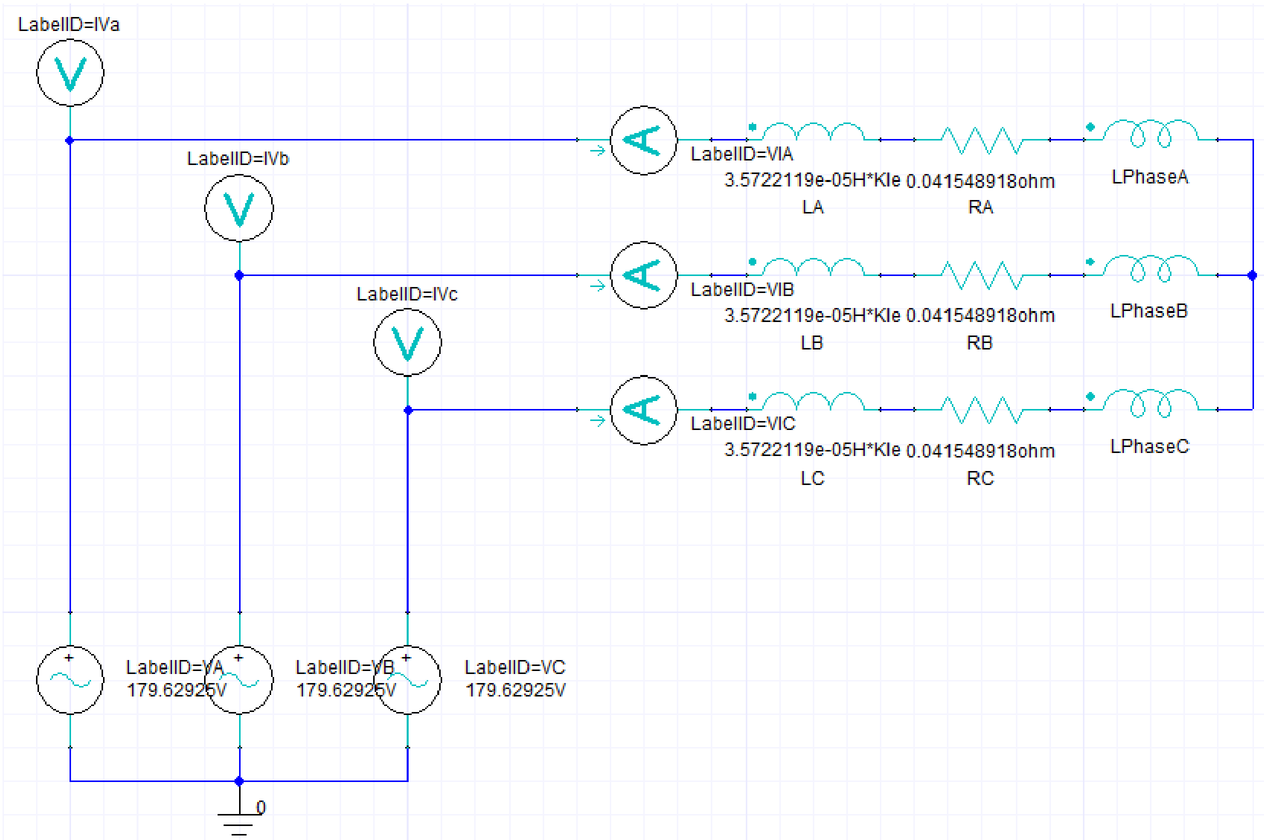


Figure 5. Scheme of excitation of the stator windings in the Circuit Editor

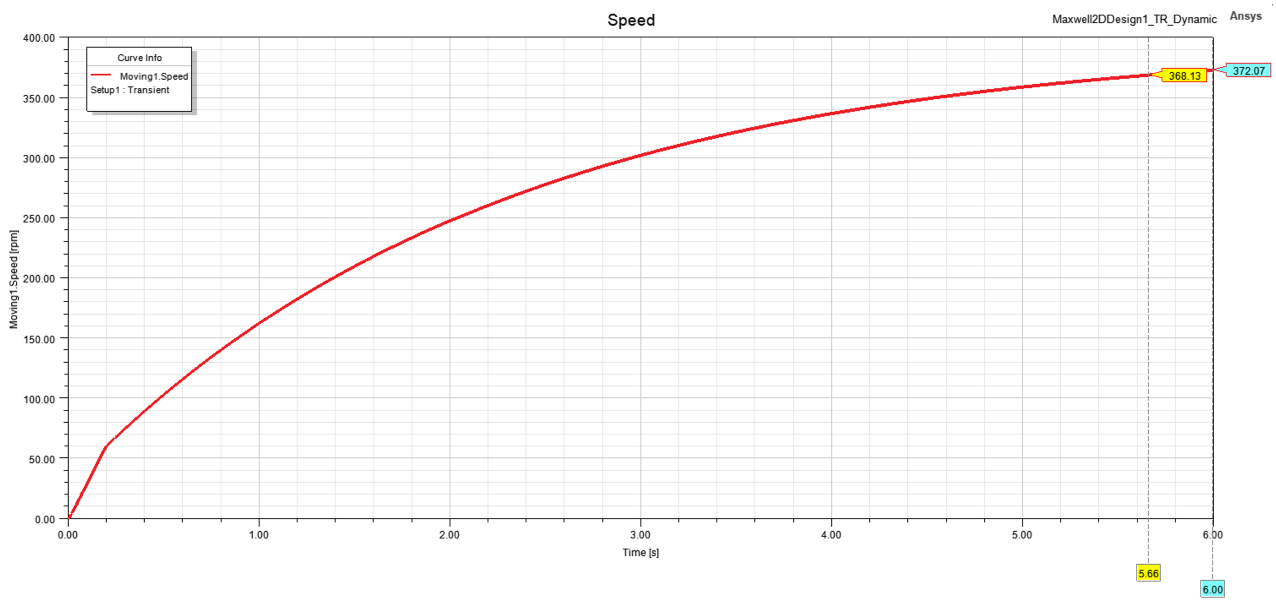


Figure 6. Characterization of the speed of the MFEC run-up in Maxwell 3D

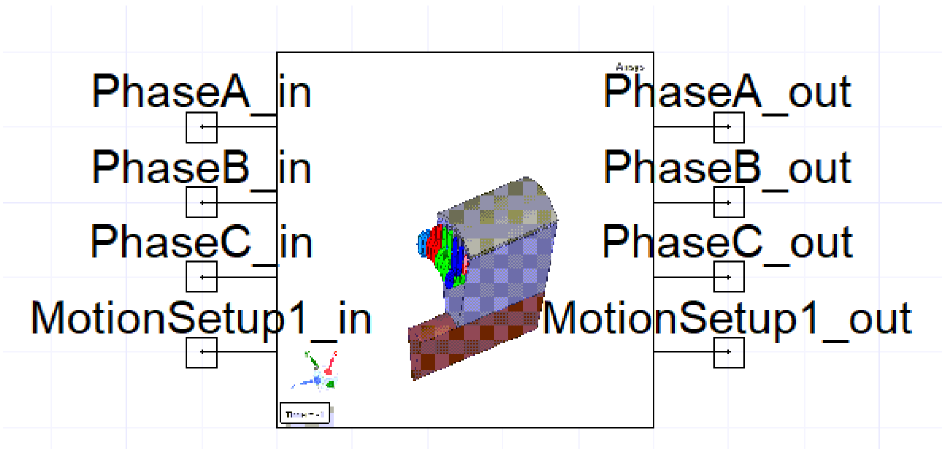


Figure 7. Twin Builder box: MFEC object imported from Ansys Maxwell 3D

- in the project "Design Settings", "Advanced Product Coupling" tab, activate "Enable transient-transient link with Twin Builder" checkbox.

Only after that, the transient Maxwell 3D co-simulation component can be added to the Twin Builder project (Fig. 7) – this is only way for correct import to perform co-simulation of ANSYS Twin Builder and ANSYS Maxwell.

The first stage of the calculations consisted in checking the fundamental possibility of compatible modeling without technical errors. For this, the electrical input ports of the MFEC object (PhaseA_in, PhaseB_in, PhaseC_in) were connected to a stable three-phase power source with a frequency 50 Hz and the output of the windings was connected in a star node (PhaseA_out, PhaseB_out, PhaseC_out).

The output mechanical ports were connected to a static load (MotionSetup1_out) and the grounding element (MotionSetup1_in), which blocks the stator rotation (Fig. 8).

After importing an object from Maxwell 3D, the active resistances and inductances of the stator winding are not automatically transferred, so these elements were placed into the scheme with the values specified in the Circuit Editor scheme (Fig. 5).

In addition, the rotor moment of inertia is not transferred from the Maxwell 3D model. To take it into account, the MASS_ROT1 element was added to the model, in the parameters of which the moment of inertia of the MFEC is set at 7 kg·m^2.

In the STEP1 step function block, the initial value of the load torque is 10 Nm, in a simulation time 0.2 s – 120 Nm.

SIMULATION RESULTS

The results of the simulation of the ANSYS Maxwell – Twin Builder coupling project are shown in Fig. 9–12.

Comparing the characteristics of the MFEC rotor run-up under load in Maxwell (Fig. 6) and Twin Builder (Fig. 12), the speed dependences are identical, and the markers at the corresponding moments of time have a high convergence of the rotation speed values.

So, the set task of MFEC co-simulation using Maxwell 3D and Twin Builder was accomplished. The future studies will be devoted to the MFEC co-simulation, powered by a frequency converter with the implementation of a rotor speed stabilization system.

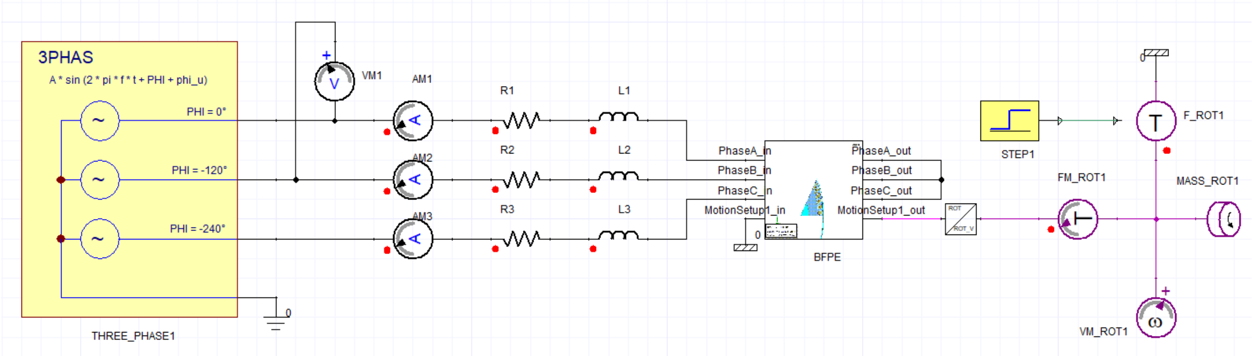


Figure 8. Twin Builder: simulation model of the MFEC with the Maxwell object

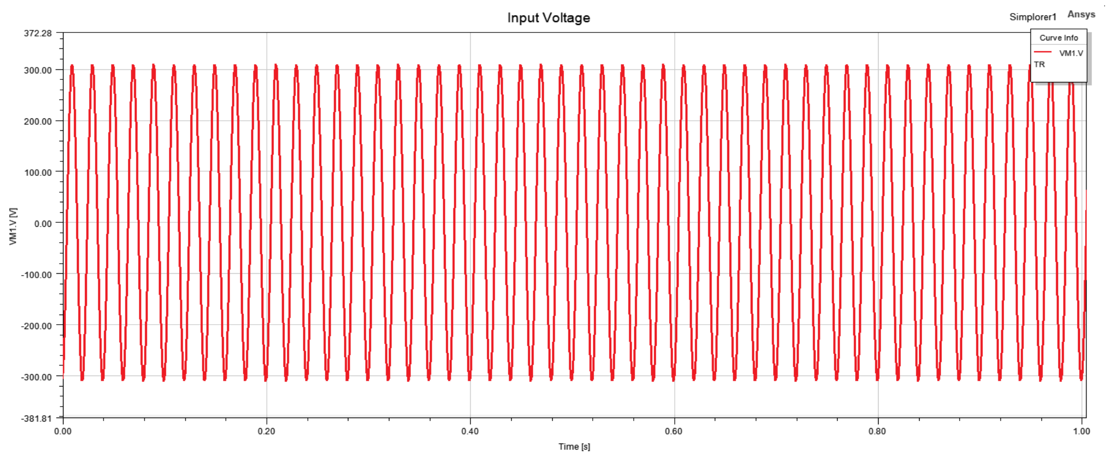


Figure 9. Change in MFEC input voltage of phase A (shown for the first second), V

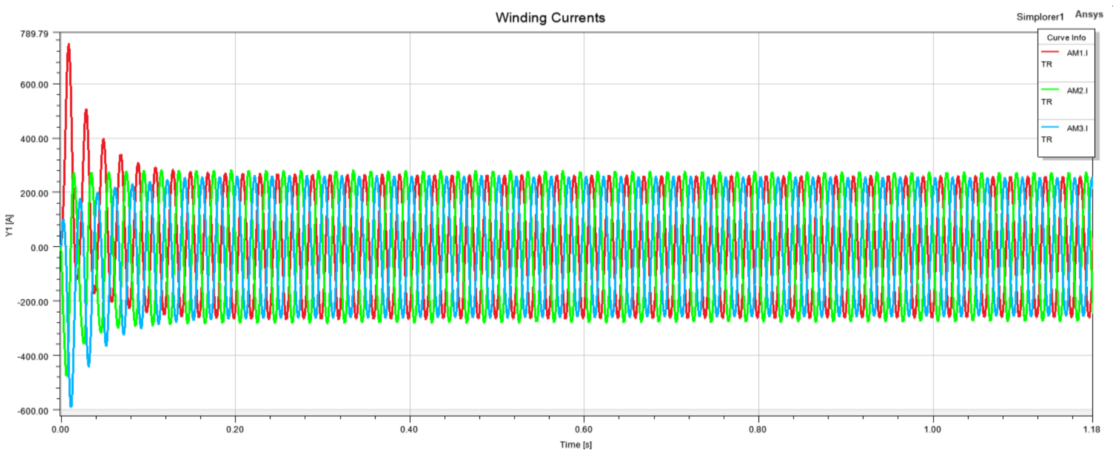


Figure 10. Change in MFEC of the stator winding phase currents (shown for the first second), A

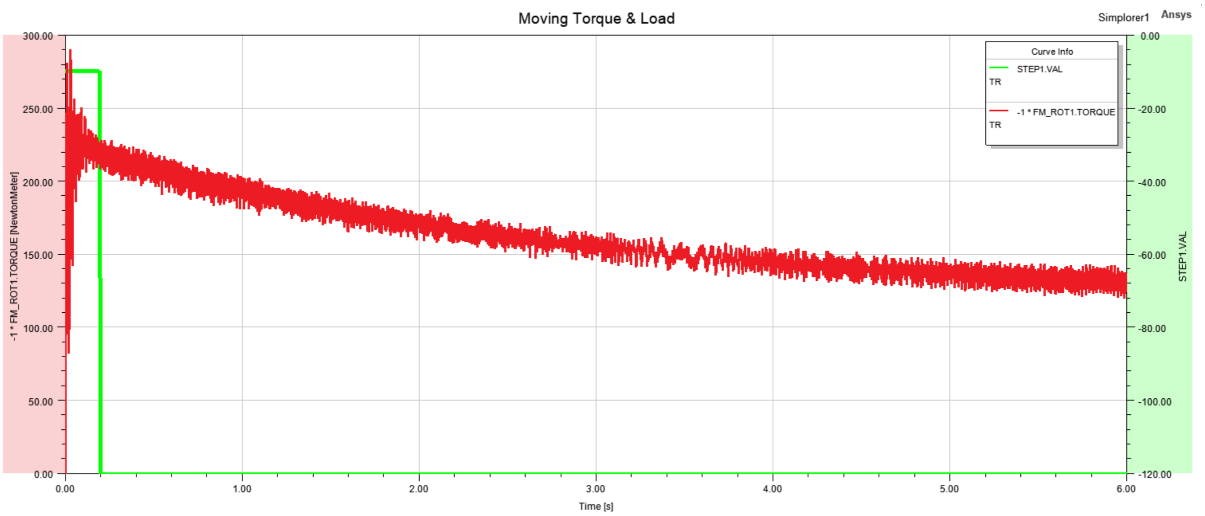


Figure 11. Dependence of the torque, combined with the load torque value, Nm

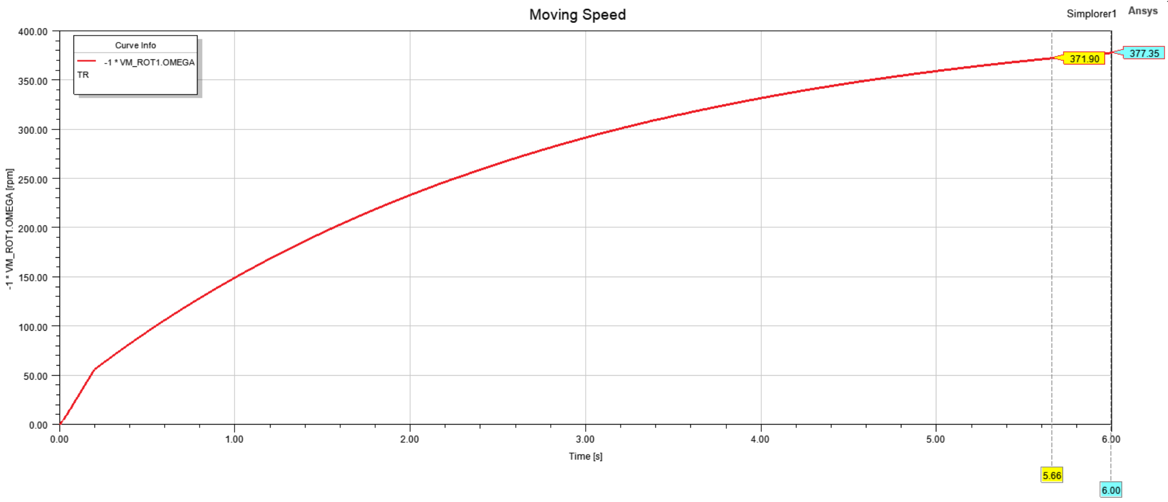


Figure 12. Characteristic of the rotor rotation speed, rpm

CONCLUSIONS

In the simulation modeling software ANSYS Twin Builder, as well as in analogues (Simulink, SciLab), library blocks are provided for common types of electrical machines, the construction of which is based on the implementation of differential equations with using of functional elements. However, this approach is significantly inferior in modeling accuracy to the model built using the finite element method, since a fundamental transition from concentrated to distributed parameters is performed on the distribution values of magnetic induction and magnetic intensity in the calculated 3D space. Because of this, using the coupling field calculation simulation in Maxwell together with Twin Builder power and control elements, significantly improves the expected results.

In this work, a specific design of electrical machine as the MFEC – an induction motor with an external solid rotor – does not have any relevant components in the built-in library at all, so co-simulation is the only way to study the machine in transient modes. The task of implementing the specified approach was successfully completed, and the obtained results are the basis for further research on the MFEC.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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Розробка імітаційної моделі електромеханічного перетворювача енергії з масивним ротором в ANSYS RMxprt, Maxwell і Twin Builder

Владислав Плюгін, Микола Заблодський, Євген Цегельник, Олексій Словіковський

Анотація. У статті представлено розробку платформи сумісного моделювання електромеханічного перетворювача енергії з використанням ANSYS Maxwell та ANSYS Twin Builder. Електромеханічний перетворювач енергії, який досліджується, за принципом дії є асинхронним двигуном із зовнішнім порожнистим масивним ротором. В статті розкрита специфіка моделювання такого типу спеціальної електричної машини. В роботі виконано поетапне моделювання машини в ANSYS RMxprt, експорт моделі в ANSYS Maxwell 2D та 3D. Показано, яким чином виконати налаштування проєкту для імпорту оюʼєкту, розрахованому методом скінченних елементів в ANSYS Maxwell у поле Twin Builder. Виконано сумісне моделювання електромеханічного перетворювача енергії при живленні від стабільного трифазного джерела. В імітаційній моделі врахована наявність ступінчастого механічного навантаження під час розбігу до номінальної швидкості. Така структура сумісного проєкту дає більш якісні результати моделювання у порівнянні з використанням імітаційних моделей з зосередженими параметрами, заснованих на імплементації диференційних рівнянь електромагнітних перехідних процесів з використанням функціональних блоків. Одержані характеристики показали високий збіг очікуваних результатів за показниками фазних струмів обмотки статора, обертального моменту та швидкості. Дана робота буде корисна для проведення моделювання електричних машин спеціального виконання, які відсутні у бібліотеці готових модулів ANSYS Twin Builder.

Ключові слова: асинхронна машина, масивний ротор, зовнішній ротор, сумісне моделювання, ANSYS Maxwell, ANSYS Twin Builder.

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