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Simulation Model of Double Motors Screw Unit with a Solid Rotor in ANSYS Twin Builder

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Abstract
This article is devoted to solving the problem of simulation modeling of the electric drive system of two induction machines with an external solid rotor, rigidly connected to each other. This design is due to research aimed at optimizing mechanical characteristics and increasing the stability of the mixing regime of mixtures of loose materials of different dispersions using a multifunctional screw-type energy converter (MFEC). The task presents difficulties from the point of view of ensuring the productivity of drying wet loose material. On the one hand, in order to ensure a given percentage of moisture reduction during its advancement along the surface of the screw, it is necessary to have a low speed of rotation of the rotor to increase the contact time of the material with the hot surface of the rotor. On the other hand, reducing the rotation speed of the rotor reduces the intensity of its heating, which negatively affects the performance of the unit as a whole. A third challenge is to provide high torque at low rotational speed to prevent high-density material from buckling. In the previous publications of the authors, a study was conducted to solve such problems due to a specific combination of motor and brake modules of the auger, but such an approach did not give positive results. Solving the specified problems is possible due to the reproduction of such a complex electromechanical system and electric drive system in the ANSYS Twin Builder software. The article shows a detailed vector field-oriented control (FOC) system applied to two modules of the screw unit. Each of the modules represents a reduced-order model (ROM) that works in coupling simulation with the electromechanical processes in ANSYS Twin Builder. This paper will be useful both for specialists in the field of electric drive and for researchers who are engaged in the development of digital twins of complex systems.

INTRODUCTION

This paper deals with simulation modeling in the ANSYS Twin Builder program of an atypical electric machine, or rather a unit – a multifunctional energy converter (MFEC) of a screw type, which is designed for mixing, drying and transportation of loose materials, such as grain, coal slurry, concentrates for manufacturing fuel briquettes [1–4]. The MFEC consists of rigidly connected induction motors with an external hollow ferromagnetic (solid) rotor, on the surface of which the turns of the screw are welded. The rotor is set in motion due to interaction with the field created by the stationary winding of the stator, the same field, due to the effect of eddy currents, heats the rotor to a temperature of 150…200°C without the presence of working material. That is, it is risky to turn on the unit without a load due to the significant temperatures of the rotor, which separates the stator winding with an air gap of 1 mm. In addition, the motor rotor does not have a fan, as it is a ferromagnetic tube that rotates at a speed of 60…120 rpm. When the unit operates with a layer of loose material, the latter performs the function of a cooler when heated [5–7]. At the same time, the temperature of the rotor is kept within 100…135°C. The winding has the heat resistance class of polyamide insulation H, which is sufficient for long-term operation of the unit in conditions of elevated temperatures [8].

In previous modifications of the MFEC, two stators were mounted on a common shaft, and the rotor tube was common to the stators [1–4]. Power was supplied to the stators from a thyristor voltage regulator in a different order of alternating phases, thus, one of the stators worked in the driving mode, and the second one - in the braking mode by reverse switching [9–13]. Using this method, it was possible

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to achieve a low speed of rotation of the rotor without the use of reducers and a frequency converter while maintaining a high intensity of heating the rotor. A significant drop in torque turned out to be a disadvantage of this design. Because of that, even small impurities in the loose material caused the rotor to stop.

In the modern modification of the MFEC proposed by the authors of this article, the aggregate modules are made independent of each other (Fig. 1). If it is necessary to increase the length of the rotor surface, the MFEC modules are connected together using an adapter and a flange. The connection operation can be performed several times, but this article considers the combination of the unit from two modules of the MFEC (Fig. 2).

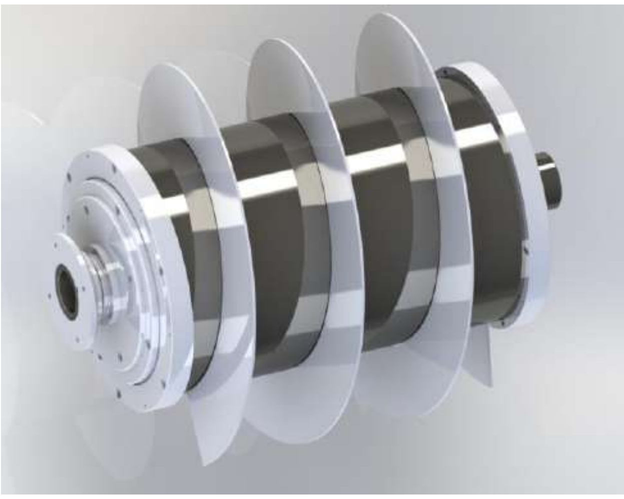

Figure 1. Independent MFEC unit

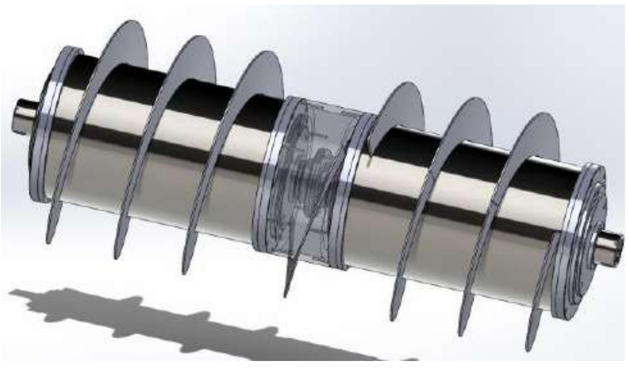

Figure 2. Connection of two MFEC units into a single screw machine

Power supply of the unit modules from MFEC is provided with the use of frequency converters, since in modern conditions of technological development, their cost has significantly decreased compared to the time 15 years ago, when the previous modification of the screw unit was created. In this regard, structural improvements and modifications of the MFEC were made, and a control system project was developed [14–18]. This article shows the development of the use of the vector field-oriented control system (FOC) in ANSYS Twin Builder, which was successfully tested in the authors' previous research [19].

The purpose of this paper is to develop a simulation model of a screw unit, which consists of two MFEC modules powered by separate frequency converters. The solution of the given task will allow to test the idea of this method of connecting the MFEC and to find the optimal control parameters. A related task is to solve the problem of balance between several interrelated factors:

1) provide a low speed of rotation of the rotor in the range of 60...80 rpm;
2) provide a high and stable value of the torque of the rotor to overcome the resistance of the mixture of different density and consistency;
3) provide stable heating of the rotor surface at low rotation speeds.

If in the previous modifications there were no such problems due to the fact that the machine worked at a slip of 0.8, which is a rather high value of the magnetization frequency of 40 Hz. When working from a frequency converter with a torque stabilization function at low speeds, the frequency may drop significantly, so additional mechanisms are needed to implement the planned tasks.

The successful solution of the tasks is the only thing that separates the authors' research project from practical implementation. The use of ANSYS software, which is the basis for the development of digital twins, allows the virtual experiment to be as close as possible to real conditions and gives a certain percentage of the guarantee of the same behavior of the machine when it is actually manufactured in factory conditions.

MAIN PART

In previous studies, the vector control system of an asynchronous motor with a massive rotor in ANSYS Twin Builder has already been considered in detail [19, 20]. In [19], the FOC control method was implemented in the system with stabilization of the rotor rotation frequency and endurance of the machine's acceleration at a given speed.

In this work, the goal is not only to maintain the speed, but also to ensure the compatible operation of the two MFEC modules. In fact, this means the implementation of the “electric shaft” function. In addition, it is worth emphasizing once again the conditions that must be agreed among themselves:

1) ensure the speed of rotation of the rotor during the simultaneous operation of two modules at the level of 60...80 rpm;
2) to ensure a constant and high starting torque. For an experimental model of MFEC with a power of 1 kW, such a moment will have a value at the level of 100... 120 Nm;

3) prevent a significant drop in current frequency to prevent a decrease in the intensity of rotor heating.

The Twin Builder project [21–24] does not envisage the use of a built-in model of an electric machine. Firstly, it is simply absent for an asynchronous motor; secondly, it has a low accuracy of reproduction of characteristics. Importing the RMxprt model into the Twin Builder box is also not possible because for such a specific type of electric machine as an induction motor with an external massive rotor, there is only a template, the purpose of which is to prepare for the generation of a 2D or 3D model in ANSYS Maxwell. With a view to testing the hypothesis, rather than achieving critically accurate simulation results, this article will consider a 2D model of the MFEC (Fig. 3, 4) that has been prepared for import into Twin Builder. To do this, you need to set the EddyCurrent project type, add an external power supply circuit in the Circuit Editor, and also configure the ECEIM module for different power supply frequencies (Fig. 5).

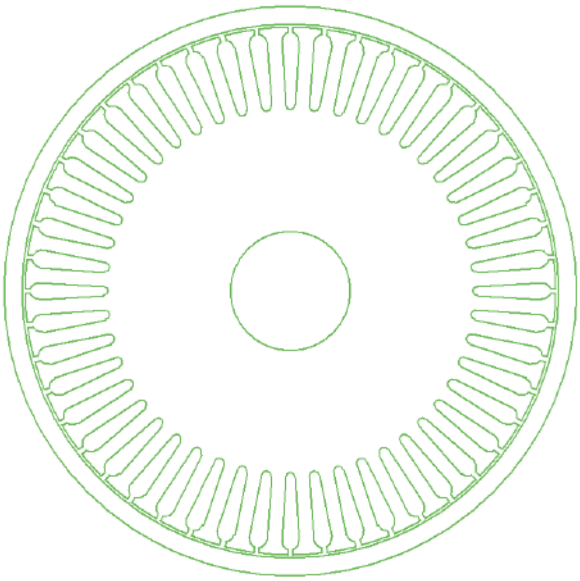

Figure 3. MFEC model in ANSYS RMxprt

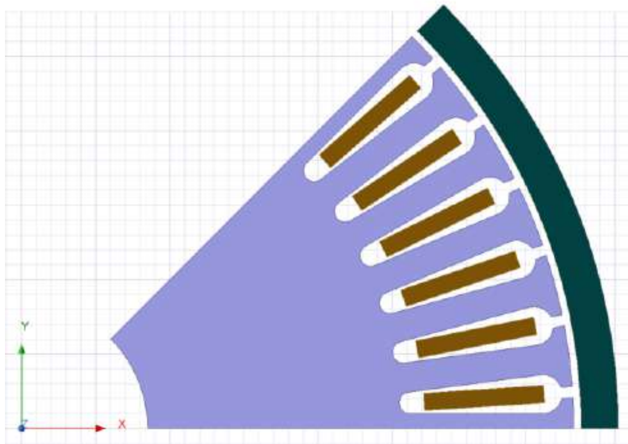

Figure 4. MFEC model in ANSYS Maxwell 2D (1/8 part)

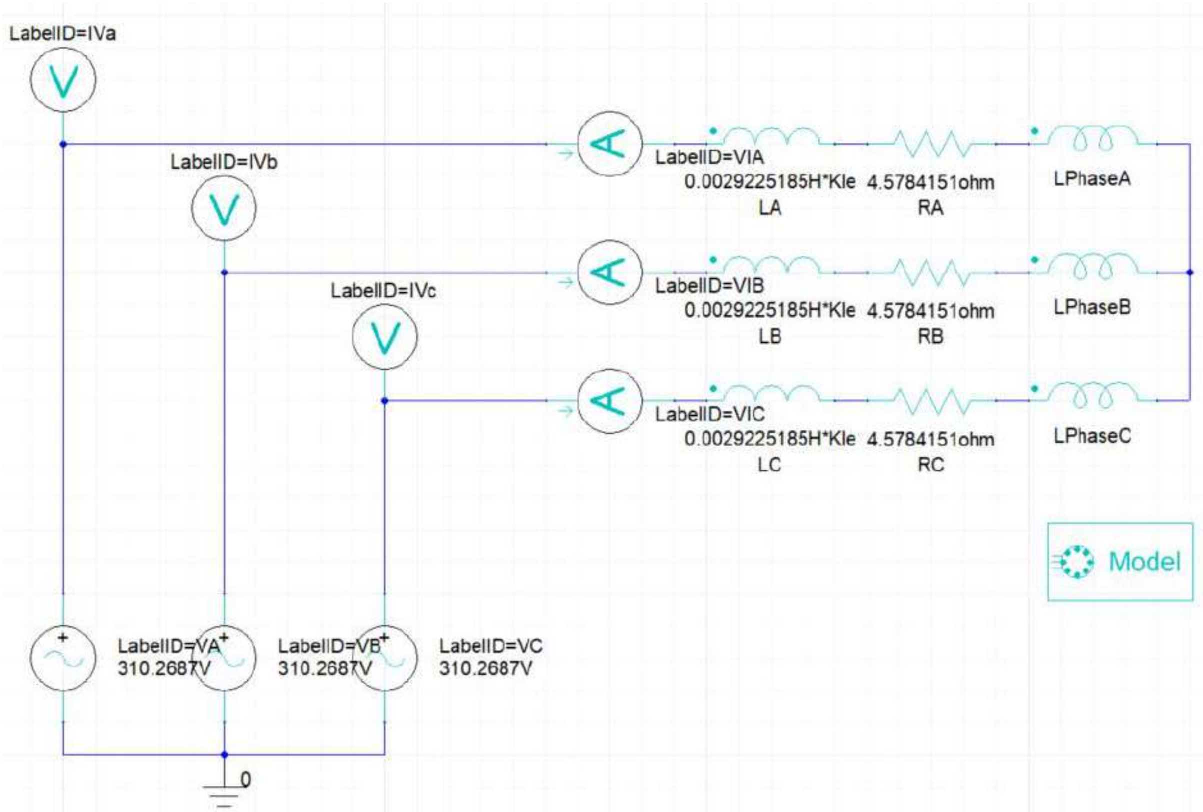

Figure 5. Scheme of MFEC power supply in ANSYS Circuit Editor

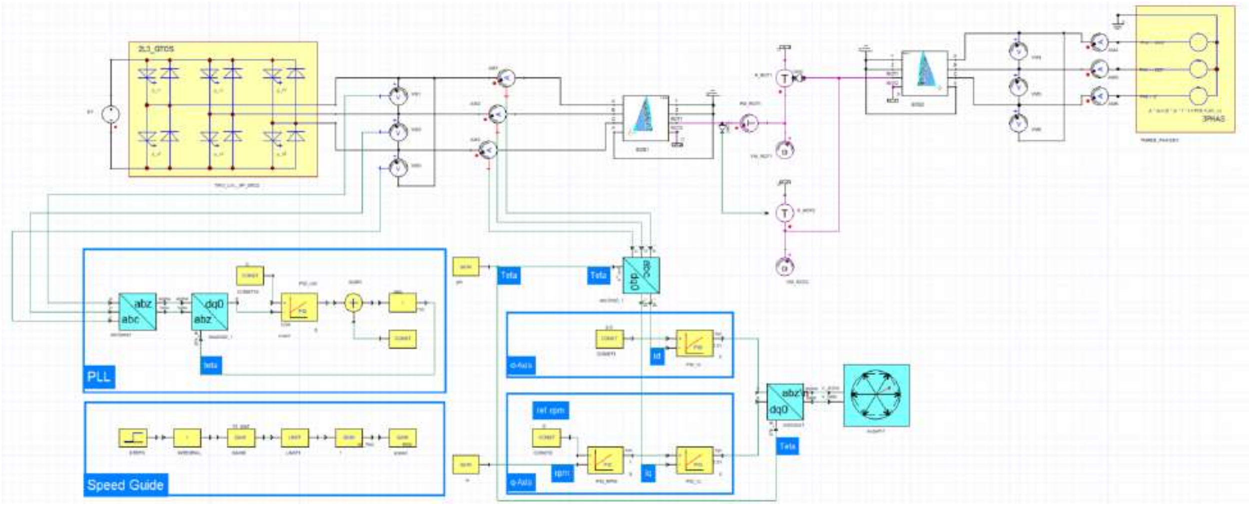

Figure 6. A complete scheme of the simulation model for frequency control of a two MFEC units

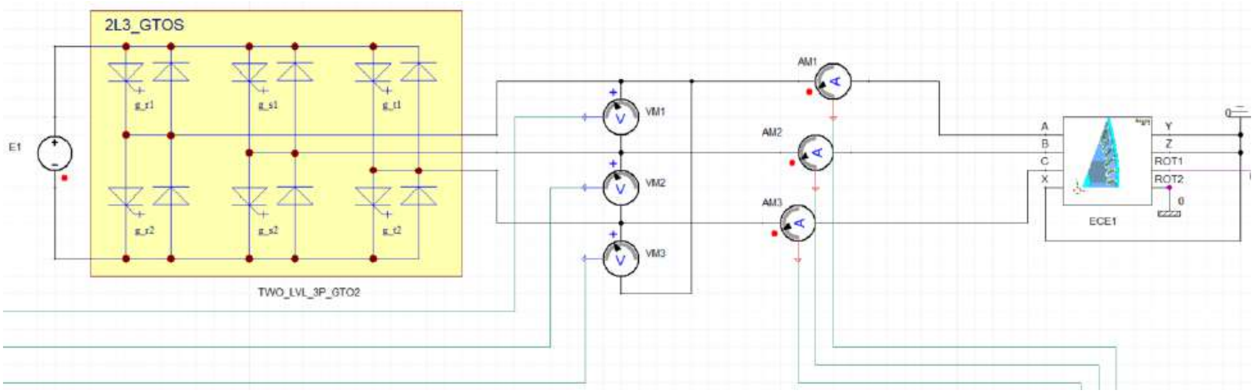

Figure 7. MFEC model: the power part of the control system

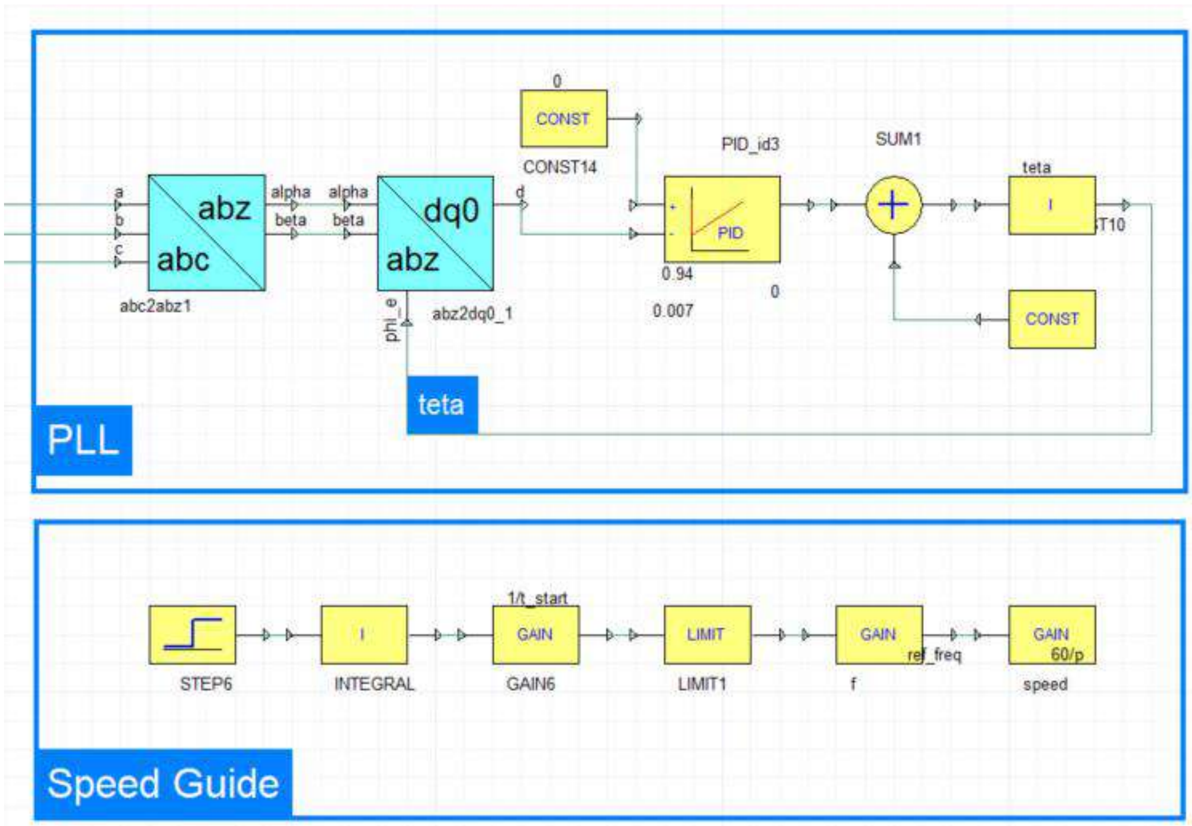

Figure 8. MFEC model: PLL (phase locked loop) scheme and run-up rate task

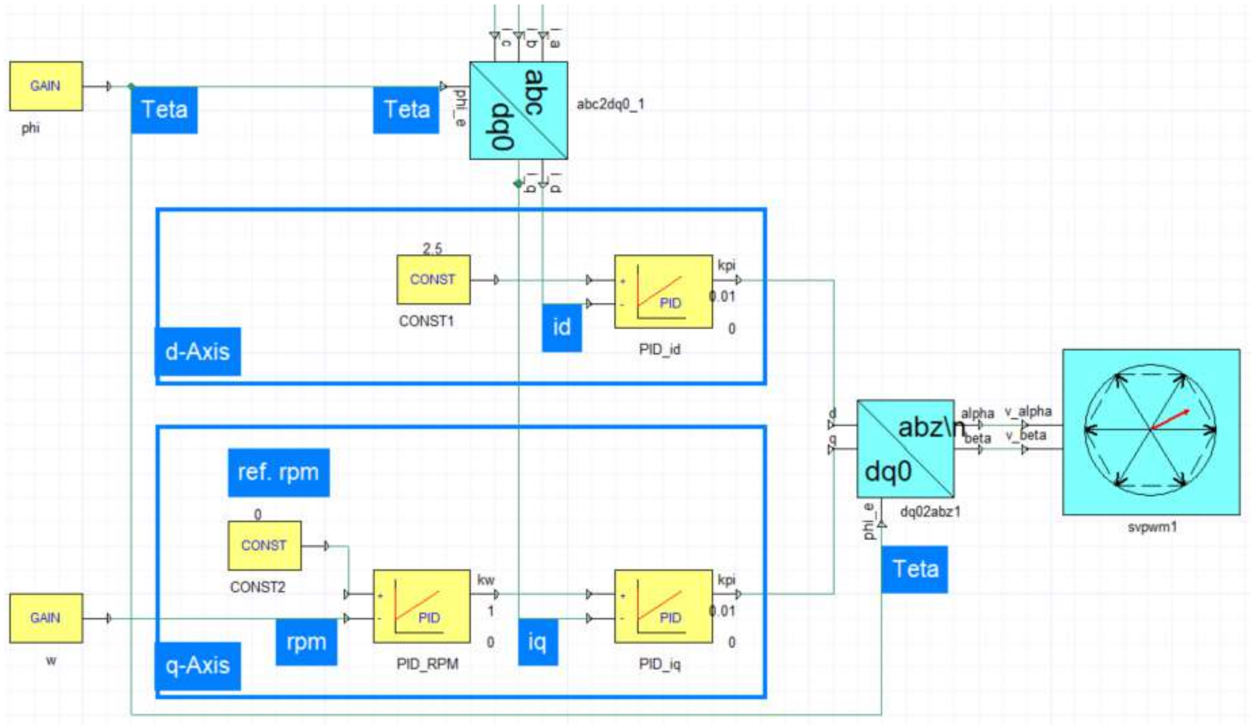

Figure 9. MFEC model: implementation of the FOC control system

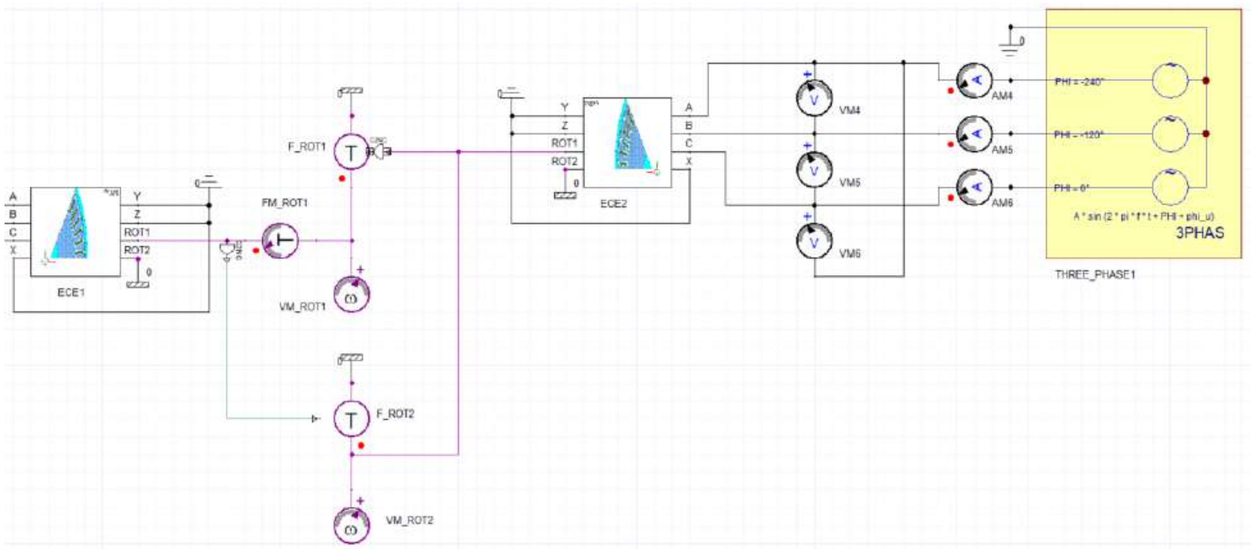

Figure 10. MFEC model: electromechanical part

In the parameters of the ECEIM module (Fig. 5) it was specified:

- currentSweeps: (0.3A, 10);
- poles: 8.

The line (0.3A, 10) is equivalent to a list of 0.3A current values; 0.6 A; 0.9A; 1.2A; 1.5A; 1.8A; 2.1A; 2.4A; 2.7A; 3.0A, where the last value is equal to the current of the MFEC winding at the nominal load.

The ECEIM model is used to set up the sweeping of currents in three-phase windings. A slip sweep is added together with the current sweep. The slip sweep is fixed (not user-configurable) with a list of the following 13 values: 0.01, 0.02, 0.04, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0.

To simulate the real operation of induction motors at a specified slip with Eddy Current solvers, the rotating rotor is treated as a locked rotor with equivalent rotor resistances and inductances.

If the specified conditions are met, it will be possible to import the object of the equivalent scheme of the MFEC from ANSYS Maxwell 2D into ANSYS Twin Builder. It should also be noted that such a procedure is possible if the Eddy Current project of the MFEC is fully calculated in Maxwell 2D. This calculation is parametric and creates reference points to which the simulation model in ANSYS Twin Builder is "pinned". Due to the large size of the simulation model (Fig. 6), it will be shown in separate parts (Fig. 7–10).

In Fig. 6 and on a larger scale in Fig. 10 blocks imported from ANSYS 2D of two identical MFEC modules are connected to each other through Torque Source task elements. Thus, it was possible to realize the connection of the rotors of the modules into a complete electromechanical system.

In Fig. 8, the reference speed of 60 rpm is indicated in the subsystem of the run-up tempo task.

In other figures (Figs. 7–9), the FOC vector control system was explained in detail in the previous works of the authors [19, 20].

It should be noted that the frequency control system is connected only to the first module of the MFEC. The second module of the MFEC, whose task is to resist the movement of the first module, is powered by an unregulated three-phase source with a reduced voltage (in the study, the voltage was reduced by 50% of the nominal). Under such conditions, namely anti-switching of the modules, full electromechanical loading of the modules is achieved, and as a result, heating of the rotors. Such a scheme is easier to implement and is suitable for the mode of transportation of loose materials of negligible viscosity, for example, for drying grain in storage [25, 26].

When the modules are turned on simultaneously, the control system also maintains a stable speed, but it will be more difficult and expensive to implement the "master-slave" motion control mode with work on the general external load. This mode occurs with significant auger loads and will be discussed in a separate article.

Practically, both the first and second modes can be combined in one control system and switched depending on the operating conditions.

SIMULATION RESULTS

The results of the simulation based on the simulation model given above are shown in Fig. 11–16.

The analysis of the simulation results allows to draw conclusions about the full achievement of the set goal of the research - the electromechanical control system works stably at a total speed of 60 rpm, while maintaining a high level of torque at the level of 30 Nm when rated currents flow through the stator windings (current values of the currents are 23 A for the first module and 25 A for the second). In this case, the constructed system provides stable power on the rotor at low rotation speed while maintaining intense heating.

CONCLUSIONS

In this paper, three problems are solved, which accompany the use of a screw two-module unit with a solid rotor. A simulation model of a two-module electromechanical system of induction motors with an external solid rotor, rigidly connected to each other in the anti-inclusion mode, was developed. Such a model is built due to the compatible modeling of two programs: ANSYS RMxprt (engine model) and ANSYS Twin Builder (control system). A high and stable torque value of 30 Nm of the solid rotor at low rotation speeds of 60 rpm is ensured. The condition of ensuring a high level of heating of the solid rotor at low rotation speeds is met by adjusting the power supply frequency of the stator windings and ensuring the flow through the stator windings of the modules with a nominal current of 23 A for the first module and 25 A for the second.

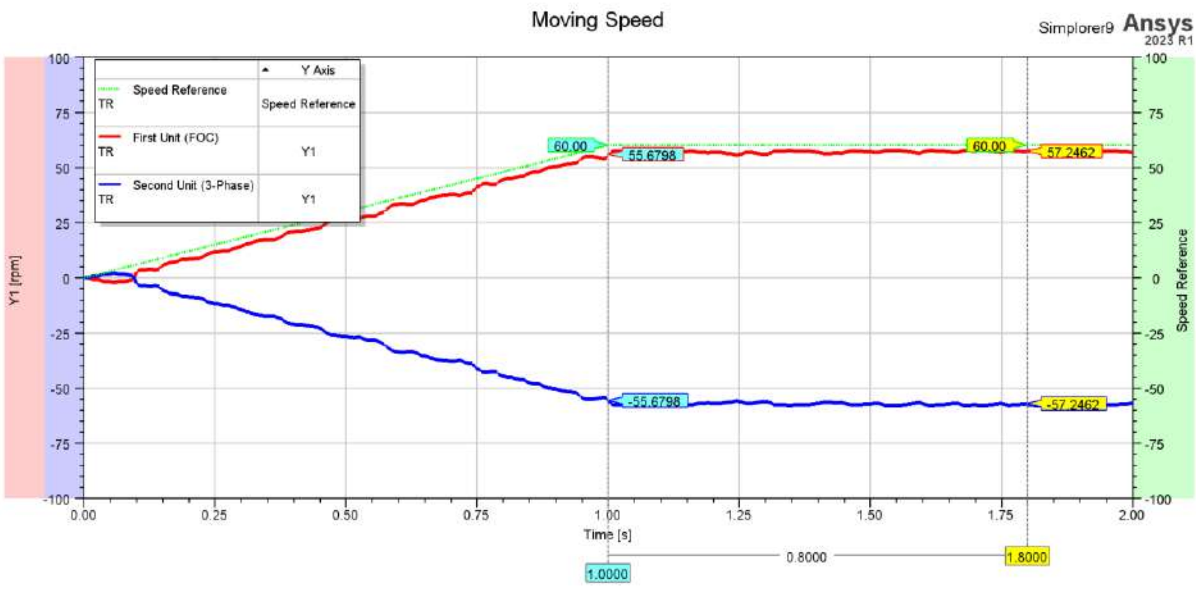

Figure 11. Rotation speed of two MFEC units

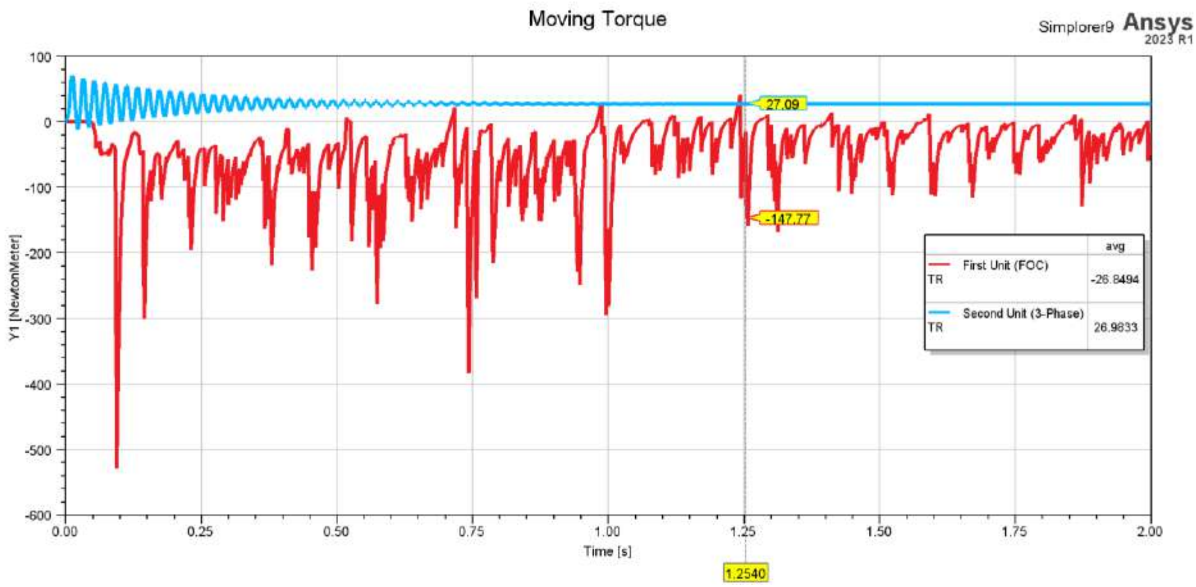

Figure 12. Moving torques of two MFEC units

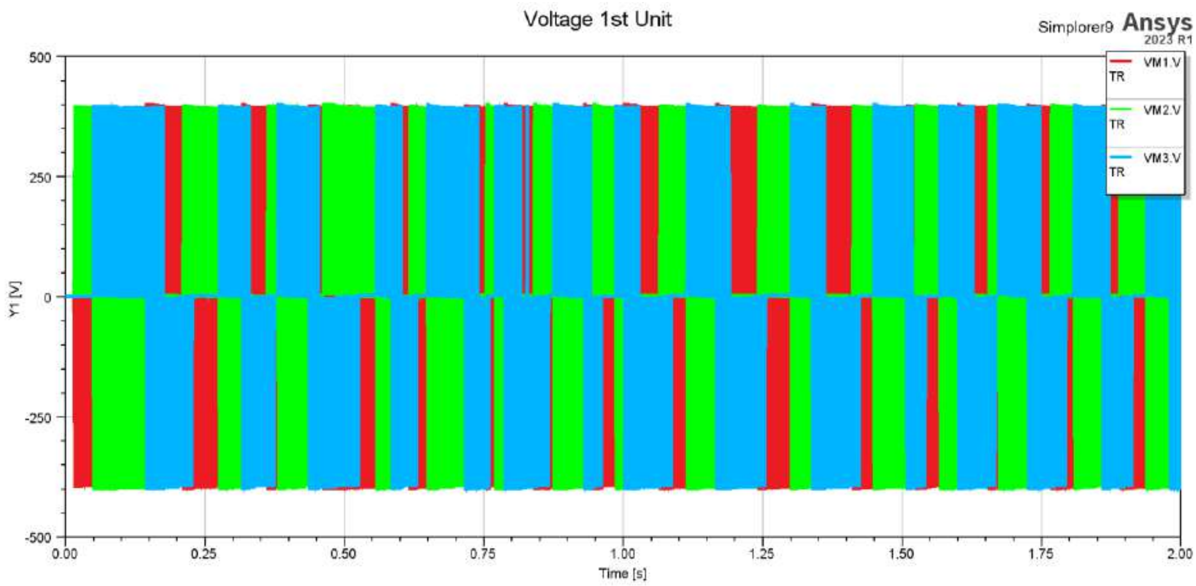

Figure 13. Modulated voltage of the first MFEC unit

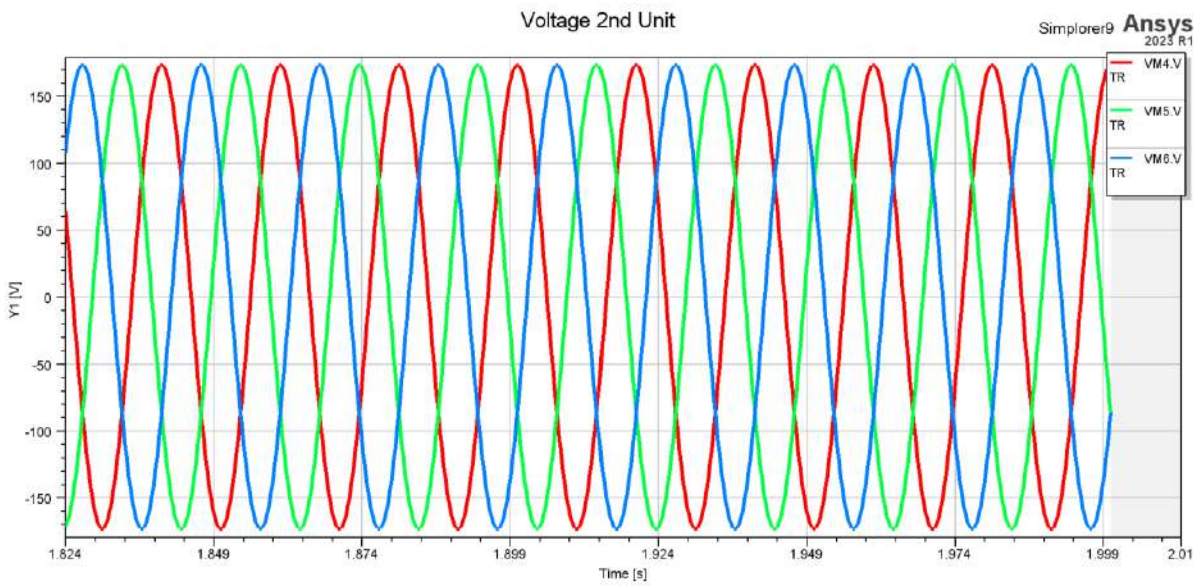

Figure 14. Voltage of the second MFEC unit (the last chart section is shown)

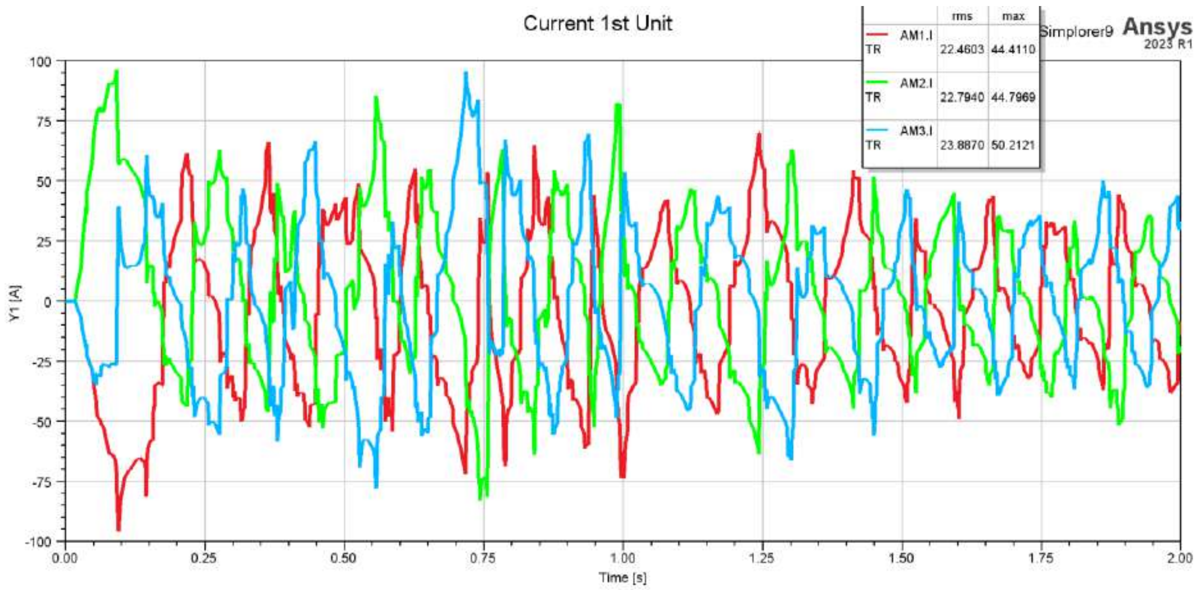

Figure 15. Modulated currents of the first MFEC unit

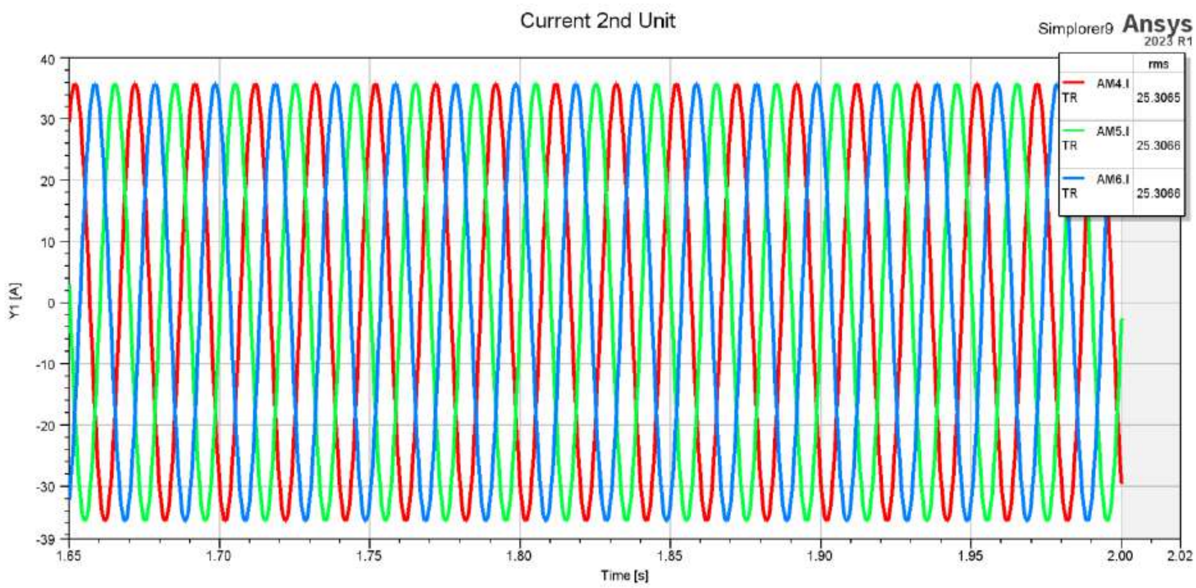

Figure 16. Currents of the second MFEC unit (the last chart section is shown)

The article shows in detail the construction of a vector control system for an induction drive using ANSYS Twin Builder without the involvement of third-party software. Unlike the authors' previous publications, this system is used for the simultaneous and compatible operation of two modules of a multifunctional energy converter. The results of simulation modeling gave positive results, so the authors' next research will be devoted to the hardware implementation of the control system based on the developed simulation model. In this case, in order to obtain more accurate characteristics, modeling will be performed according to the proposed scheme, but using the 3D model of the MFEC and the implementation of parallel (compatible) calculation of the field model in ANSYS Maxwell 3D and the control system in ANSYS Twin Builder.

DISCLOSURE STATEMENT

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

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Імітаційна модель подвійного гвинтового агрегату з суцільним ротором в ANSYS Twin Builder

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Анотація. Дана стаття присвячена вирішенню задачі імітаційного моделювання системи електроприводу двох асинхронних машин із зовнішнім суцільним ротором, жорстко з'єднаних між собою. Дана конструкція зумовлена дослідженнями, спрямованими на оптимізацію механічних характеристик та підвищення стабільності режиму змішування сумішей сипучих матеріалів різної дисперсності за допомогою багатофункціонального шнекового перетворювача енергії. Завдання представляє складність з точки зору забезпечення продуктивності сушіння вологого сипучого матеріалу. З одного боку, щоб забезпечити заданий відсоток зниження вологи при просуванні її по поверхні шнека, необхідна низька швидкість обертання ротора для збільшення часу контакту матеріалу з гарячою поверхнею. ротора. З іншого боку, зменшення швидкості обертання ротора призводить до зниження інтенсивності його нагріву, що негативно позначається на продуктивності агрегату в цілому. Третім завданням є забезпечення високого крутного моменту при низькій швидкості обертання, щоб запобігти прогину матеріалу високої щільності. У попередніх публікаціях авторів було проведено дослідження щодо вирішення подібних проблем за рахунок специфічного поєднання двигуна та гальмівного модулів шнека, але такий підхід не дав позитивних результатів. Вирішення зазначених проблем можливе завдяки відтворенню такої складної електромеханічної системи та системи електроприводу в програмному забезпеченні ANSYS Twin Builder. У статті показано детальну векторну систему орієнтованого на поле керування, застосовану до двох модулів гвинтової установки. Кожен із модулів представляє модель зменшеного порядку, яка працює в моделюванні зв'язків з електромеханічними процесами в ANSYS Twin Builder. Дана робота буде корисна як для фахівців в області електроприводу, так і для дослідників, які займаються розробкою цифрових двійників складних систем.

Ключові слова: перетворення енергії, електромеханічна установка, шнековий конвеєр, імітаційна модель, ANSYS Twin Builder.

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