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The Speed Stabilization System of Electromechanical Energy Converters in ANSYS Twin Builder

Vladyslav Pliuhin[1], Yevgen Tsegelnyk[1], Oleksii Slovikovskyi[2], Oleksii Duniev[3], and Andrii Yehorov[3]

[1] O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
[2] National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
[3] National Technical University “Kharkiv Polytechnic Institute”, Kharkiv, Ukraine

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Abstract
The paper is devoted to solving the problem of building a control system for a special electromechanical energy converter, which is due to the inverted structure of the stator and the presence of a solid hollow rotor made of ferromagnetic steel. The task of the control system is to ensure the speed of the rotor's run-up to a given value in a certain time and then maintain it regardless of load fluctuations. The task was solved due to the implementation of Field Oriented Control (FOC) vector control with speed and current controllers and a phase locked loop (PLL). Despite the fact that from the point of view of the electric drive theory, the given task is not new, its solution using only ANSYS Twin Builder blocks is being solved for the first time. The peculiarity of this work is that the electromechanical converter in ANSYS Twin Builder is not presented in the form of a mathematical model and electric machine blocks built into the Twin Builder library, but through the solution of the ANSYS Maxwell 2D/3D coupling project and the ANSYS Twin Builder solver with co-simulation, which significantly increases the quality of calculations. The obtained results will be useful for solving similar problems for other types of electric machines, not only for the considered electromechanical converter of the asynchronous type with a solid rotor.

INTRODUCTION

The speed stabilization system of electromechanical energy converters is an important component to ensure stable operation of the entire system. The speed of an electric motor can vary due to various factors such as shaft load, supply voltage change, temperature change, etc. Stabilizing the speed allows to avoid deviations in the system and ensure its stability.

One of the features of speed stabilization is the use of a closed control system. This means that measuring devices installed on the motor shaft transmit information about the speed of rotation to the controller. The controller compares this data with the set speed value and performs appropriate corrective actions based on the received information.

To fulfill the task of controlling and stabilizing the speed of an alternating current motor, the use of vector control was proposed, since vector control, in comparison with scalar control, has a higher performance.

Vector control is a method of controlling an electromechanical energy converter, which allows you to independently and practically inertialessly regulate the speed of rotation and the torque on the shaft of an AC electric motor [1–6]. The main idea of vector control is to control not only the magnitude and frequency of the supply voltage, but also the phase. In other words, the magnitude and angle of the spatial vector are controlled [7–12].

Field oriented control (FOC) is the most widely used among vector control [13–17]. FOC is a control method that controls a brushless AC motor in such a way that field and torque can be controlled separately. In polyoriented control, the torque and field are controlled indirectly by controlling the components of the stator current vector. The instantaneous value of the stator current vector is decomposed

Corresponding author: vladyslav.pliuhin@kname.edu.ua (Vladyslav Pliuhin)

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mathematically into two components: the longitudinal component of the stator current I_{sd}, which creates a field, and the transverse component of the stator current Isq, which creates a torque. Thus, AC motor control can be performed using an inverter with pulse-width modulation (PWM), a linear PI controller, and a space-vector voltage modulation.

Speed stabilization of electric motors using field-oriented control can be successfully analyzed in the ANSYS Twin Builder software [18–25]. Previous work was described AC motor scalar control system in ANSYS Simplorer (now it is known as Twin Builder) [26]. ANSYS Twin Builder is software that allows to model and analyze the behavior of electromechanical systems under various conditions. In addition, the ANSYS Twin Builder program in combination with ANSYS Maxwell allows the use of various control algorithms, which ensures the optimal operation of the electric motor under the given conditions.

In the previous paper, a co-simulation of the Multifunctional Energy Converter (MFEC) was performed in ANSYS Maxwell and Twin Builder [27]. In mentioned paper, the power supply of the MFEC was carried out from a static three-phase source without adjustment of the rotation speed.

Current paper continues and improves previous studies [26, 27] and is devoted to the implementation of the FOC control system of the MFEC with inverter and space vector PWM.

IMITATION MODEL

Previously, the problem of induction motor speed control was solved based on scalar control system with sinusoidal PWM [26], however, the accuracy of maintaining the speed and run-up rate was not high, significant fluctuations of the speed curve around the guide were observed. This especially applies to the MFEC, which has a heavy rotor with a large moment of inertia (in the study, the mass of the rotor is 250 kg, and the value of the moment of inertia is 7 kg·m^2). To solve this problem, a vector control system with field orientation, the so-called FOC control, was implemented [28, 29].

Such a problem from the point of view of the electric drive theory is not new and, in many works, it is solved using either purely ready-made Simulink blocks, or with coupling modeling in Ansys Twin Builder and Simulink, which is entrusted with FOC control [30-33]. In some works, there was an attempt to implement FOC control exclusively with Twin Builder tools, but they either contain an incomplete description of the model, or the run-up of the machine is uncontrollable in time.

The following tasks are set in this work:

- implement the power supply of the MFEC from a three-phase inverter;
- MFEC must reach a given speed in a given time;
- the speed curve should deviate as little as possible from the given trajectory;
- implement FOC control only with Twin Builder tools;
- perform modeling in Ansys Maxwell and Twin Builder coupling project, where the MFEC is imported into the Twin Builder sheet as a Maxwell 2D/3D object and is solved using the finite element method.

The complete scheme of the model in Twin Builder is shown in Fig. 1. In Fig. 1 power part consists of a connection of a three-phase inverter fed by an ideal DC voltage source (500 V), active resistances and inductances of the stator winding phases, a MFEC object imported from Maxwell 2D/3D, and a load represented by the torque block F_ROT1 and STEP1 module. The MASS_ROT1 block sets the moment of inertia of the rotor (7 kg·m^2). In the options of voltmeters and ammeters, the presence of an output port for connection to the control system is activated.

The control system consists of 3 main parts: the PLL (Phase Locked Loop), the Speed Guide run-up tempo assignment block, and the Decoupled Controller, which forms the switching signals of the inverter transistors using SVPWM (Space Vector Pulse and Width Modulation).

The basic idea of the PLL system is a feedback system with a PI-regulator tracking the phase angle. Input is the three phases of the grid voltage and output from the PLL is the phase angle θ (teta) of one of the three phases. In the power supply substation there will be one inverter leg for each of the three phases. There are two alternatives, either assuming the grid voltages are in balance and track only one of the phases and then shift with 120 degrees for each of the other two phases or having three PLL systems, one for each phase [33].

The PLL block is shown separately in Fig. 2. The input of the abc/abz coordinate converter (provides the calculation from a, b, c to alpha, beta, zero transform) receives signals from the voltmeters of the corresponding phases. Next, the following abz/dq0 transformation is performed (provides the calculation from alpha, beta, zero to d, q, z_dq transform, with corresponding electrical angle from the motor). The purpose of the feedforward frequency, w (coming from angular velocity sensor VM_ROT1), is to have the PI-regulator (for this task, KP = 0.94; KI = 0.007; KD = 0) control for an output signal that goes to zero. The resulting phase angle theta is connected to the phi_e port of the abz/dq0 coordinate converter, and to the coordinate converter of the Decoupled Controller block, which will be discussed in this paper below.

In Fig. 3 shown the structure of the Speed Guide run rate task block.

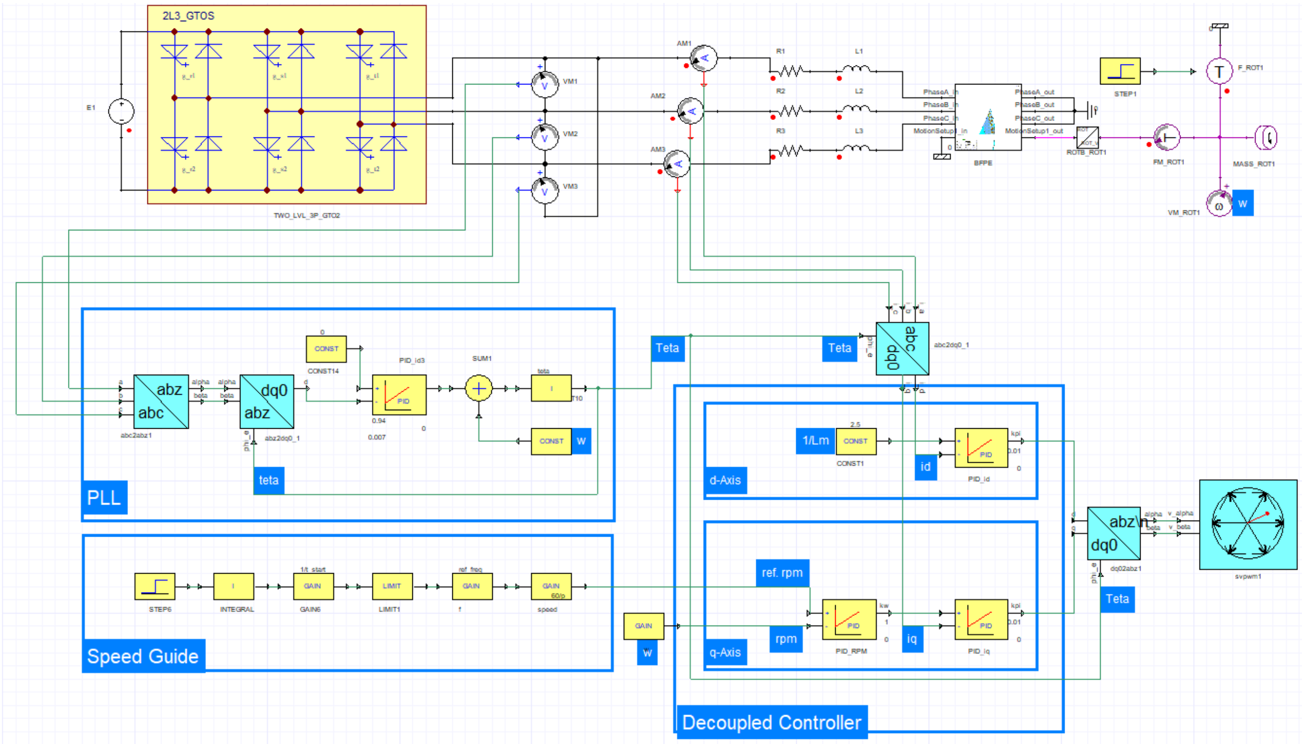


Figure 1. MFEC FOC control system in ANSYS Twin Builder

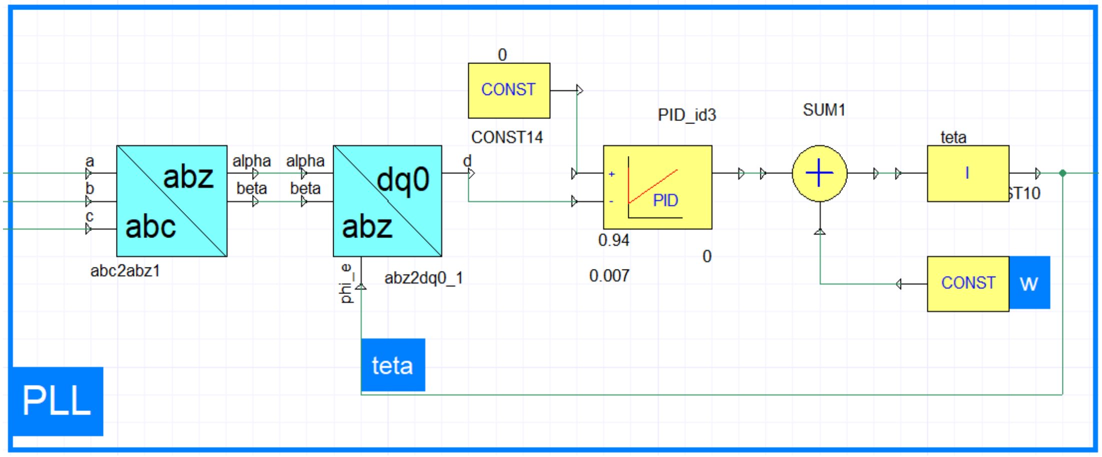


Figure 2. Structure of the PLL system in Twin Builder

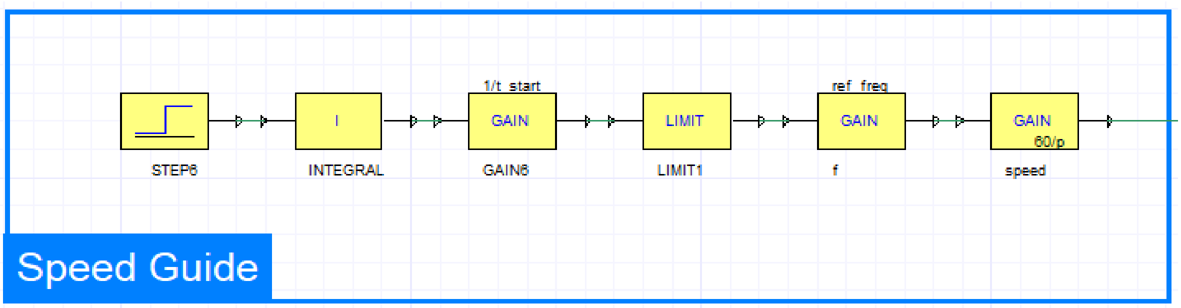


Figure 3. Speed Guide realization in ANSYS Twin Builder

Both STEP6 and INTEGRAL blocks forms time function (STEP6 block has Time Step value 0, Final Value 1 and Initial Value 1). GAIN6 block scales time value to starting time 1/t_start (time for motor run out from zero speed to the set value). LIMIT1 block limits a signal at the level ±1. GAIN block with the label f has a rated frequency value, defined by target final speed (speed in rpm × 60 / pole pairs) and calculates actual frequency value in Hz according to the modelling time step. GAIN block with the label speed converts speed frequency value from Hz to rad/s and has value 60/p.

Obtained speed value goes as a reference speed in Decoupled Controller. Decoupled controller realized current and speed control system (Fig. 4).
Signals from the ammeters of the corresponding phases and the phase angle theta calculated in the PLL block are fed to the input of the coordinate converter abc/dq0.

There are two given values and two closed-loop controller in the FOC system. The two given values are given rotor angular speed (comes from Speed Guide as reference speed) and given rotor flux (1/Lm).

The discrepancy between the given rotor angular speed and measured rotor angular speed feed the speed regulator PID_RPM (KP = 20; KI = 1; KD = 0), the output of the speed regulator is given torque current component for PID_iq.

The discrepancy between the given torque current component and the actual torque current component iq feed the current regulator PID_iq (KP = 6; KI = 0.01; KD = 0), the output of the current regulator is q input value for SVPWM.

The discrepancy between the given flux current component (1/Lm, flux value is equal to 1 Wb) and actual flux current component id feed the other current regulator PID_id (KP = 6; KI = 0.01; KD = 0), the output of this current regulator is d input value for SVPWM. The outputs of the current regulators PID_id and PID_iq are applied to the inverse park transformation module dq0/abz (provides the calculation from d, q, z_dq to alpha, beta, zero transform, with corresponding electrical angle from the motor). The phase angle theta calculated in the PLL block is supplied to the phi_e port of the coordinate converter. The outputs of this projection are ud and uq which are the components of the Space Vector PWM. The outputs of SVPWM block are the signals that drive the inverter.

SIMULATION RESULTS

The whole FOC system simulation model is built, and the parameters of MFEC for simulation are as follows: rated voltage 380 V; target speed 300 rpm; number of pole pairs 4; Lm = 0.02 H; moment of rotor inertia 7 kg·m^2; time to reach target speed from zero 3 s.

The given rotor flux is 1Wb. MFEC is starting with load 10 Nm and in time 4 s raised up to 120 Nm. The whole time of the simulation is 6 s and the simulation time step is 10 us. The all-simulation results are shown in Fig. 5–8.

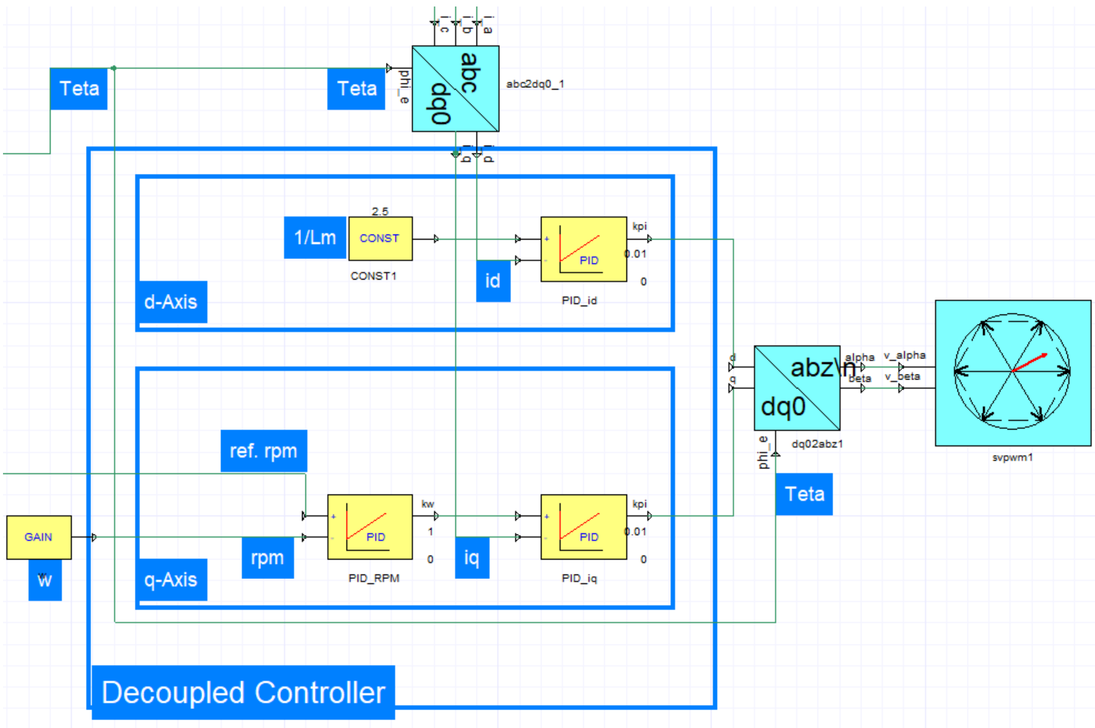
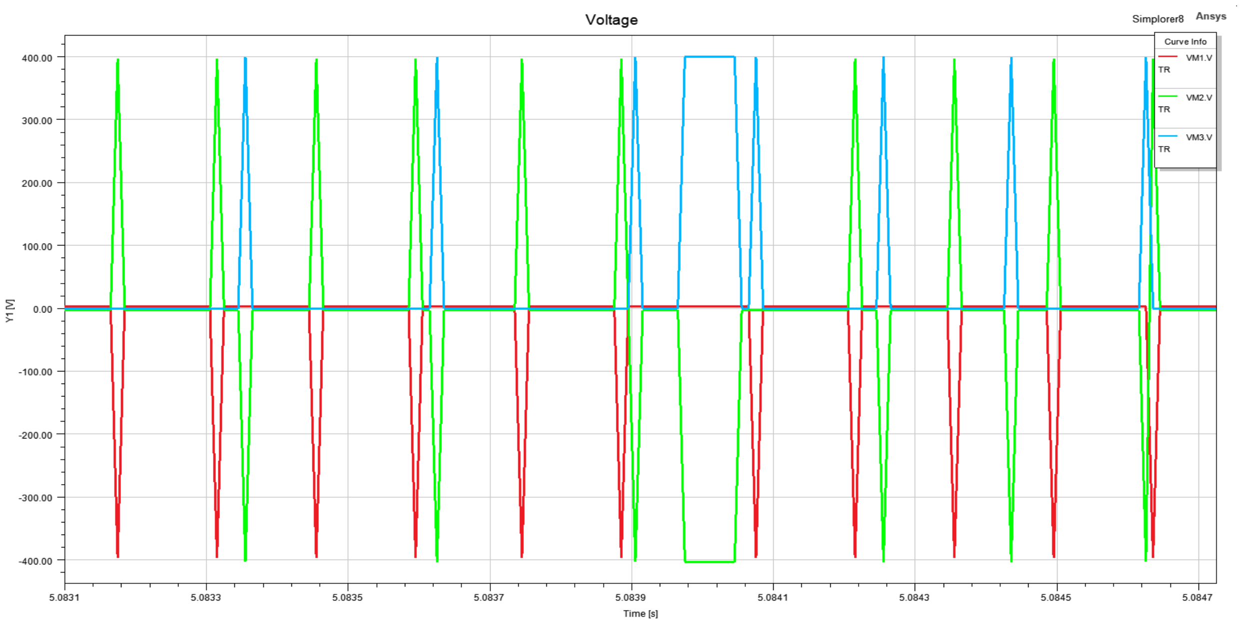
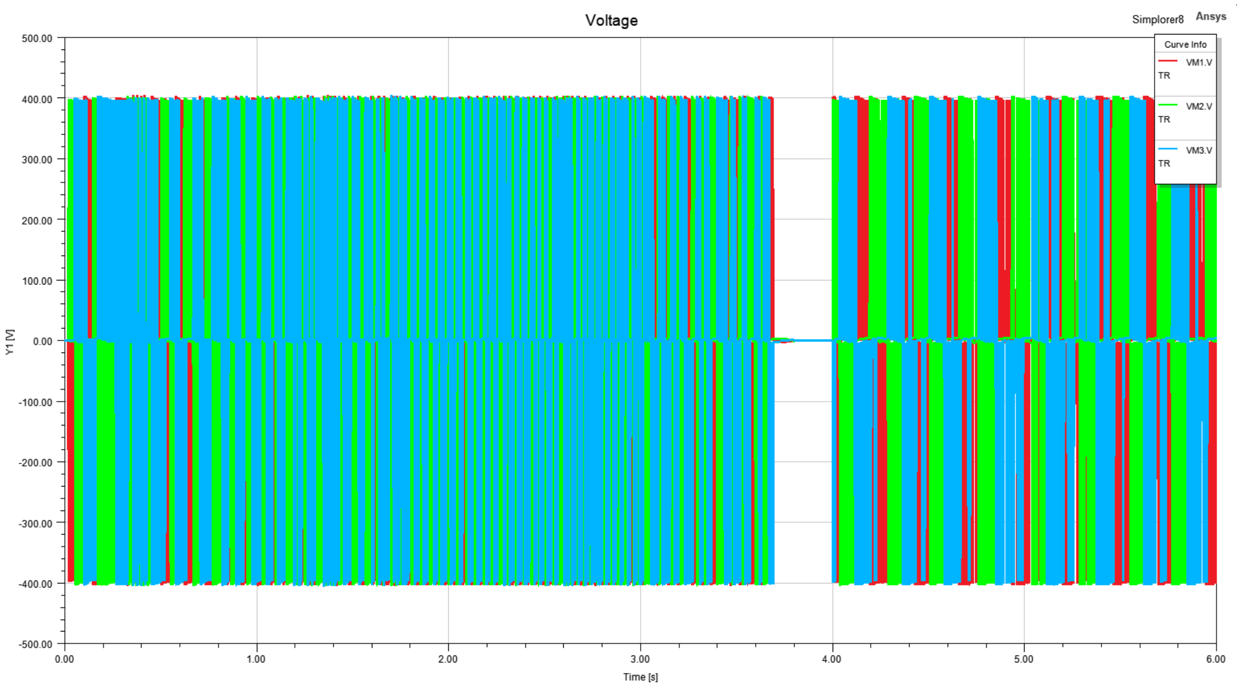


Figure 4. Current and speed control system in ANSYS Twin Builder

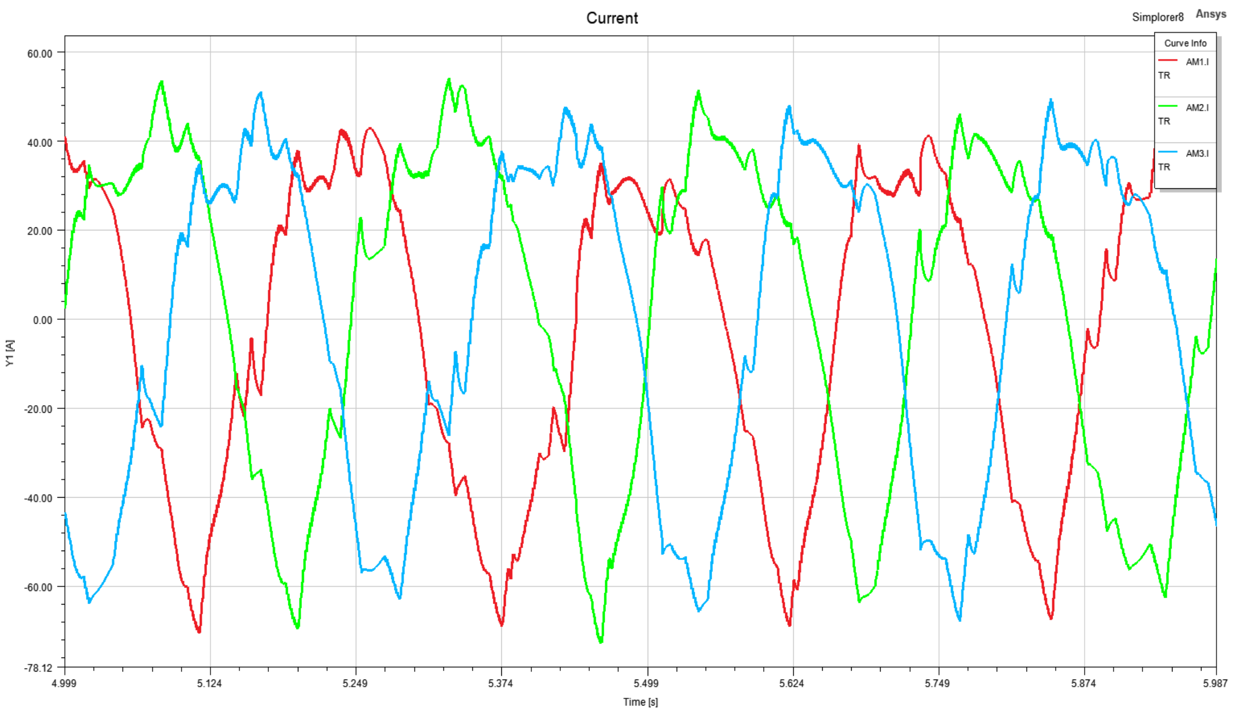


(*a*)

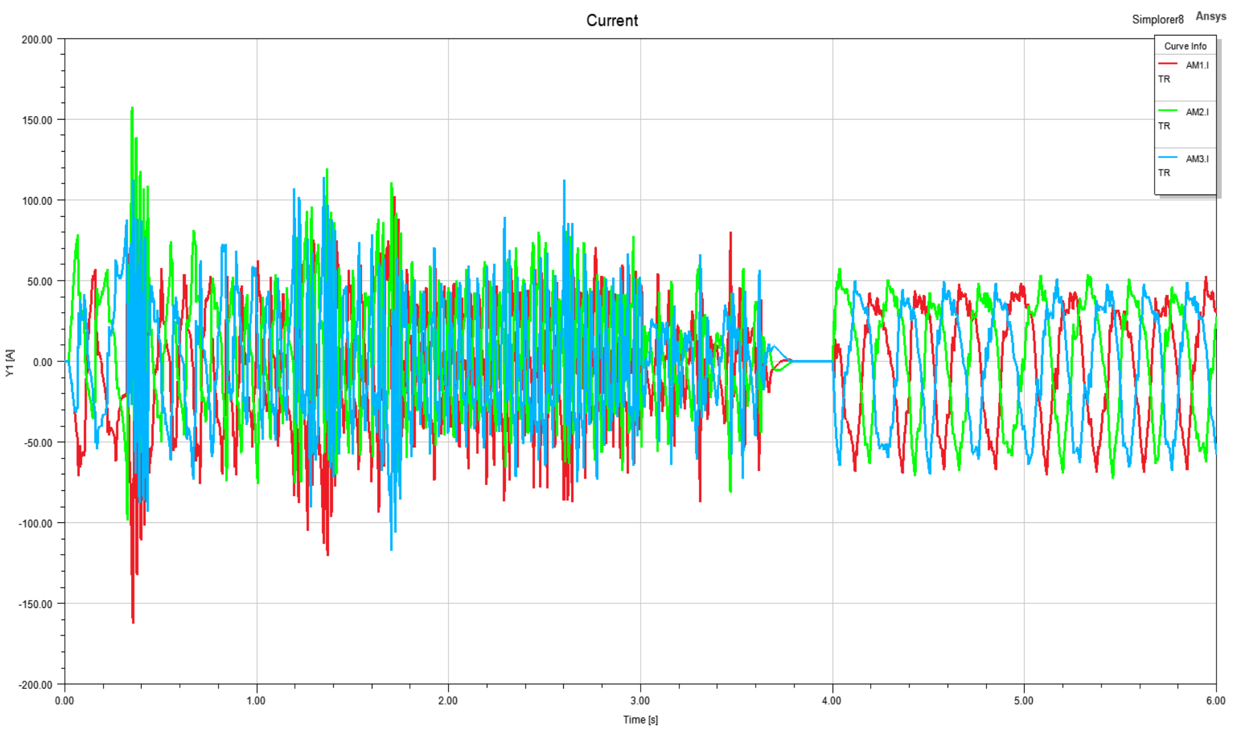


(*b*)

Figure 5. Three-phase voltages: (*a*) scaled fragment after 5s; (*b*) full time



(*a*)



(*b*)

Figure 6. Three-phase currents: (*a*) scaled fragment at time interval from 5s to 6 s; (*b*) full time

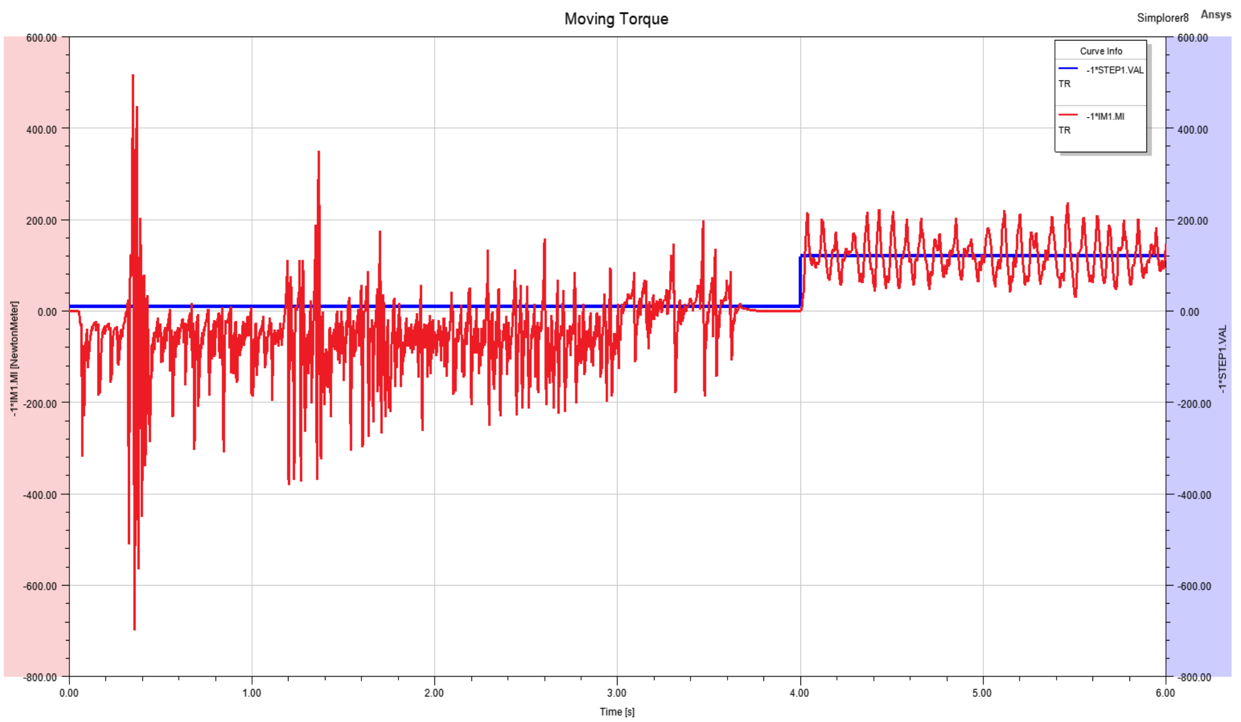


Figure 7. Moving and load torque (blue line)

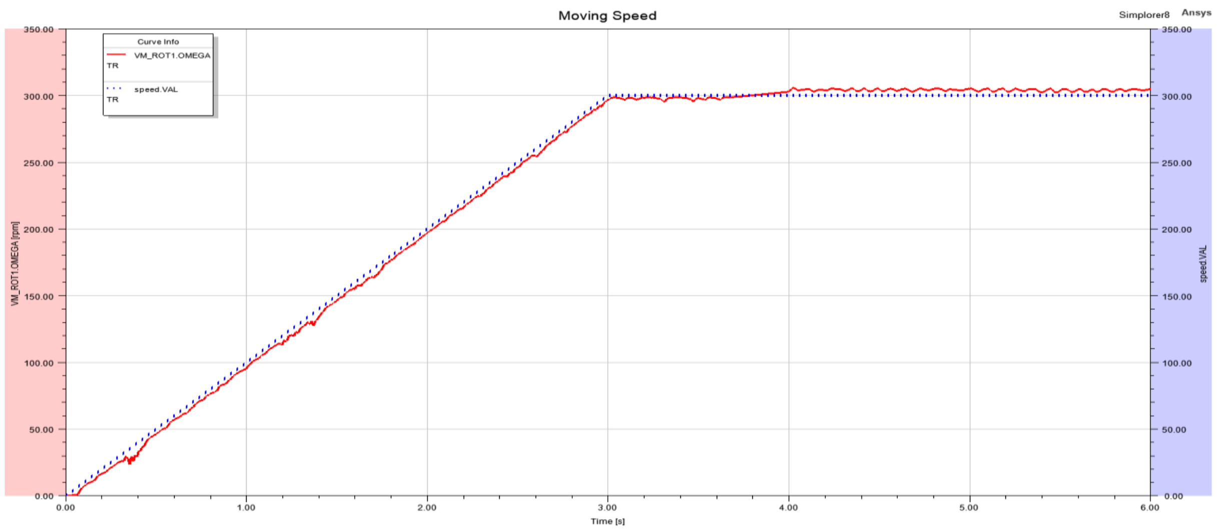


Figure 8. Moving speed and speed guide reference (dotted line)

CONCLUSIONS

During the research, the task was set to implement the control system of the MFEC, which allows the rotor to run under load from zero speed to the specified speed in a certain time. The task was accomplished due to the implementation of a vector control system only using Ansys Twin Builder library tools. A feature of the solved problem was the coupling modeling of the electric machine in Ansys Maxwell 2D/3D and the control system realized in Ansys Twin Builder.

The simulation results showed high accuracy of speed maintaining on the given trajectory, full compliance with the run-up trajectory in accordance with the given time and speed.

The solved problem can and has been successfully applied not only to the MFEC, which is an induction motor with a solid rotor, but also to an induction motor with a squirrel-cage rotor and a synchronous motor with permanent magnets.

The following studies will be related to the optimization of MFEC parameters and obtaining coefficients of PID controllers.

DISCLOSURE STATEMENT

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

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Система стабілізації швидкості електромеханічних перетворювачів енергії в Ansys Twin Builder

Владислав Плюгін, Євген Цегельник, Олексій Словіковський, Олексій Дунєв, Андрій Єгоров

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 об'єкту, 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.

NOTES ON CONTRIBUTORS

Vladyslav Pliuhin
vladyslav.pliuhin@kname.edu.ua

D.Sc., Professor
Department of Urban Power Supply and Consumption Systems
O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
https://orcid.org/0000-0003-4056-9771
https://www.webofscience.com/wos/author/record/F-4627-2018/
https://scopus.com/authid/detail.uri?authorId=57204286328

Yevgen Tsegelnyk
y.tsegelnyk@kname.edu.ua
Ph.D., Senior Researcher
Department of Automation and Computer-Integrated Technologies
O. M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine
https://orcid.org/0000-0003-1261-9890
https://www.webofscience.com/wos/author/record/J-1570-2015/
https://scopus.com/authid/detail.uri?authorId=57192961558

Oleksii Slovikovskyi
slovikovskyi@nubip.edu.ua
Postgraduate Student
Department of Automation and Robotic Systems named by I. Martynenko
National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine
https://orcid.org/0000-0001-8912-6256

Oleksii Duniev
oleksii.duniev@khpi.edu.ua
Ph.D., Associate Professor
Department of Electrical Machines
National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine
https://orcid.org/0000-0001-8196-7077
https://www.webofscience.com/wos/author/record/G-3310-2016/
https://scopus.com/authid/detail.uri?authorId=57497865000

Andrii Yehorov
andrii.yehorov@khpi.edu.ua
Ph.D., Associate Professor
Department of Electrical Machines
National Technical University "Kharkiv Polytechnic Institute", Kharkiv, Ukraine
https://orcid.org/0000-0001-6643-4256
https://www.webofscience.com/wos/author/record/G-3960-2016/
https://scopus.com/authid/detail.uri?authorId=57200639200