



International conference on High Technology for Sustainable Development

HiTECH 2022

PROGRAMME

**6 – 7 October 2022
Sofia**

General Programme

Day	Hour	Event
Wednesday 5 October	<i>16.00 – 18.00</i>	Online Registration of participants
Thursday 6 October	<i>09.00 – 12.00</i>	Registration of participants - MS Teams - https://teams.microsoft.com/l/team/19%3aTSPxaxtc6QB2v_AeXll6R_TrdsauTrAdgw1VsKjt9t01%40thread.tacv2/conversations?groupId=fb7bc74-72a8-499f-a304-2d33f877606e&tenantId=7feeb5c0-34f4-4a4b-8cc0-e59f06920156
	<i>14.00 – 14.15</i>	Opening Session FNTS
	<i>14.15 – 15.00</i>	Invited Papers FNTS
	<i>15.00 – 17.00</i>	Session 1 FNTS
	<i>17.30 – 19.30</i>	Session 2 FNTS
Friday 7 October	<i>09.00 – 12.00</i>	Session 3 https://teams.microsoft.com/l/team/19%3aTSPxaxtc6QB2v_AeXll6R_TrdsauTrAdgw1VsKjt9t01%40thread.tacv2/conversations?groupId=fb7bc74-72a8-499f-a304-2d33f877606e&tenantId=7feeb5c0-34f4-4a4b-8cc0-e59f06920156
	<i>12.00 – 13.30</i>	Lunch Break
	<i>13.30 – 16.30</i>	Session 4 https://teams.microsoft.com/l/team/19%3aTSPxaxtc6QB2v_AeXll6R_TrdsauTrAdgw1VsKjt9t01%40thread.tacv2/conversations?groupId=fb7bc74-72a8-499f-a304-2d33f877606e&tenantId=7feeb5c0-34f4-4a4b-8cc0-e59f06920156
	<i>16.30 – 17.00</i>	Closing Session

Opening Session

Tuesday 6 October, 14.00 - 14.15

14.00 - Opening Session

Invited Papers

Tuesday 6 October, 14.15 - 15.00

1. ENERGY PLANNING IN BULGARIA

Dimo Stoilov, Dimitar Tonev, Kiril Anguelov, Kristina Hadzhiyska

2. IMPLEMENTATION OF EUROPEAN STANDARDS FOR THE BENEFIT OF ENGINEERING TRAINING IN CAMEROON

Kiril Anguelov

3. APPROPRIATION OF INTERNATIONAL STANDARDS FOR THE STRUCTURING OF ENGINEERING TRAINING IN WEST AFRICA

Kiril Anguelov, Ludmil Stoyanov

Session 1

Tuesday 6 October, 15.00 - 17.00

Chairpersons: Nikolay HINOV, Dimo STOILOV

1. THE OUTPUT PREDICTION OF A BOOST DC-DC CONVERTER USING MACHINE LEARNING APPROACHES

Mirjana Kocaleva, Zoran Zlatev, Nikolay Hinov

2. SYNCHRONIZATION OF A DEVELOPING MECHANISM VIA A PID CONTROLLER

Goran Goranov, Petar Panaiotov

3. MODELING, DESIGN AND CONTROL SYNTHESIS OF CUK DC-DC CONVERTER

Nikolay Hinov, Tzvety Hranov, Krasimir Tonev

4. MODELING, DESIGN AND PROTOTYPING OF A SYNCHRONOUS BUCK DC-DC CONVERTER

Nikolay Hinov, Valeri Ivanov

5. SIMULATION OF A SINGLE-PHASE INDUCTION MOTOR FOR EDUCATIONAL PURPOSES

Ludmil Stoyanov, Ivan BACHEV

6. SIMULATION OF TRANSFORMERS' CHARACTERISTICS IN LABORATORY EXERCISES FOR ELECTRICAL ENGINEERS

Ludmil Stoyanov, Ivan BACHEV, Vladislav Petrov

7. MATLAB IMPLEMENTATION OF INDUCTION MOTOR EXERCISES FOR CHARACTERISTICS ESTIMATION

Ludmil Stoyanov, Ivan BACHEV, Vladislav Petrov, Emilia Hadjiatanasova Deleva, Gabriela Nacheva

Matlab Implementation of Induction Motor Exercises for Characteristics Estimation

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Abstract—The paper presents the implementation in Matlab Simulink of different laboratory exercises with induction motors, aiming at their digitalization. The created models follow the students' operations in the real exercises to determine the main characteristics of induction motors, which are a basic knowledge for specialists in the field of electrical engineering for their application in different industrial sectors.

Keywords— Induction motors, mathematical models, Matlab simulations

I. INTRODUCTION

The COVID-19 pandemic in the past two-three years caused several closures of secondary schools and universities over the world [1]. This stimulated the digitalization of the educational content to ensure an educational process without significant losses to the trainee's knowledge. The digitalization in the field of the engineering requires specialized software, especially for the laboratory exercises, which hindered the spread of the distance learning in this field.

Different authors apply different approaches [2]-[7], according to the aimed discipline with her specificities and the available and familiar software. This paper presents the use of Matlab Simulink to digitalize the laboratory exercises on induction motors at the Technical University of Sofia. These exercises are mandatory for electrical engineers because the induction motors are largely used in human life. Their effective application requires good knowledge of different basic characteristics, which are the subject of the mentioned laboratory works.

II. SIMULATED EXPERIMENTS

The digitalized experiments are mandatory to obtain the basic characteristics of the induction motors.

A. Load variation [8]

The load variation gives the opportunity to determine two different characteristics – the mechanical characteristic and operational characteristics. The mechanical characteristic is the variation of the torque as a function of the speed or of the slip. To obtain it, the load varies in such a manner that the speed varies from almost the synchronous speed to 0. This dependance gives information for some specific points – maximal and starting torque, critical slip and speed etc. The decreased speed is accompanied by an increase in the stator current and, most importantly, the starting current. The

operational characteristics are the dependance of many variables, such as the torque, the active and reactive powers, the speed and respectively the slip, the stator current, the efficiency and the power factor, in function of the load power. The load variation maintains the speed between the synchronous and the speed that corresponds to the maximal torque. This means that the load values are smaller and it is appropriate to separate both cases in two experiments, which is the case in the real experimental benches.

B. Open circuit (OC) experiment [8]

The aim of this experiment is to determine the open-circuit characteristics of the induction motor. These characteristics represent the variation of the stator power, the stator current, and the induction motor's power factor in function of the supplying voltage. The input voltage varies from 0 to the rated value.

On the real experimental bench, this experiment allows the separation of the mechanical and iron losses. In the case of digitalization this is not possible because of the induction motor model's assumptions and the neglected mechanical losses [9].

C. Short circuit (SC) experiment [8]

This experiment allows the determination of the short-circuit characteristics of the induction motor. They are again the variation of the stator power, the stator current, and the induction motor's power factor in function of the supplying voltage, which is reduced to maintain the current equal or lower than the nominal one. Another specific condition for this experiment is the blocked rotor, which means that the speed is equal to zero.

D. Frequency control of induction motor [10]

The supply of the induction motor with a power converter is a very modern approach and this suggests the interest in it. The aim of this laboratory work is the determination of the mechanical characteristics and the regulation characteristics. In the first case, the supply voltage and frequency are constant and the load varies. To improve the understanding of the frequency control, it is recommended to use several values of the frequency, which implies the respective voltage value. The regulation characteristics are the variation of the voltage and the speed in function of the frequency. This variation is realized for two values of the load torque.

Along with the determined characteristics, it is interesting to study the operation of the closed loop control, which maintains the speed of the motor at a given reference. For this purpose, a speed reference is set and the frequency of the supplying voltage is changed. The reference is respected if the load of the motor is smaller than the maximal one for the given frequency.

III. LABORATORY EXERCISES MODELLING

The real laboratory program regroups the previously described experiments in 4 laboratory works. Thus, the laboratory works for digitalization are:

- Lab 1: Load variation to obtain the mechanical characteristic;
- Lab 2: Load variation to obtain the operational characteristics;
- Lab 3: Open circuit and short circuit experiments;
- Lab 4: Frequency control.

The Matlab Simulink environment is used for the digitalization of the laboratory works. In the realized models, the induction motor is the main object, while the other elements have secondary function. Thus, the model of the motor, according to the generalized theory of the electrical machines, is presented below [11]. This model contains two equation systems with 4 equations each – on the base of the Kirchoff's law and for the flux linkages and the currents:

$$\begin{cases} u_d = r_1 \cdot i_d + \frac{d\Psi_d}{dt} - \omega_s \cdot \Psi_q \\ u_q = r_1 \cdot i_q + \frac{d\Psi_q}{dt} + \omega_s \cdot \Psi_d \\ 0 = r_2 \cdot i_{dr} + \frac{d\Psi_{dr}}{dt} - (\omega_s - \omega_r) \cdot \Psi_{qr} \\ 0 = r_2 \cdot i_{qr} + \frac{d\Psi_{qr}}{dt} + (\omega_s - \omega_r) \cdot \Psi_{dr} \end{cases} \quad (1)$$

$$\begin{cases} \Psi_d = L_s \cdot i_d + L_m \cdot i_{dr} \\ \Psi_q = L_s \cdot i_q + L_m \cdot i_{qr} \\ \Psi_{dr} = L_m \cdot i_d + L_r \cdot i_{dr} \\ \Psi_{qr} = L_m \cdot i_q + L_r \cdot i_{qr} \end{cases} \quad (2)$$

where u_d and u_q are the stator voltages in d-q reference frame, r_1 and r_2 – the stator and referenced rotor resistances, Ψ_d , Ψ_q , Ψ_{dr} and Ψ_{qr} – the stator and rotor flux linkages in d-q reference frame, i_d , i_q , i_{dr} and i_{qr} – the stator and rotor currents in d-q reference frame, ω_s and ω_r – the reference frame and rotor speeds, L_s , L_r and L_m – the stator, the referenced rotor and the mutual inductances.

The implementation in Matlab Simulink of Lab 1 is presented on Fig 1, while Fig. 2 shows the models of the other three laboratory works. In Lab 1 the mathematical model uses the rotor speed as an input variable, and the user can variate it using the slider to obtain the mechanical characteristic. It is interesting to illustrate the influence of the input voltage and the rotor referenced resistance on this characteristic. Those parameters are changed using dialog boxes in the model. The necessary measurements are shown on displays on purpose.

In Lab 2 the interest of the students is attracted to two experiments – the direct starting and the operational characteristics. The first experiment requires the switching on of the motor by the round switch in the left upper corner. The transient process of the currents can be visualized on a scope. The mechanical power is varied by the slider aiming at the operational characteristics of the induction motor. The points of the characteristics are obtained by the measurement displays.

In Lab 3, the user can choose the experiment to be performed (open circuit or short circuit) by a round switch. This choice influences the rotor speed of the motor respectively from almost synchronous speed to zero and the range of the variation of the stator voltage (the SC requires significantly lower voltage). The larger slider is used for the voltage variation in the case of an open circuit, while in the case of a short circuit, the smaller slider is used. Measurement displays are also available in the model.

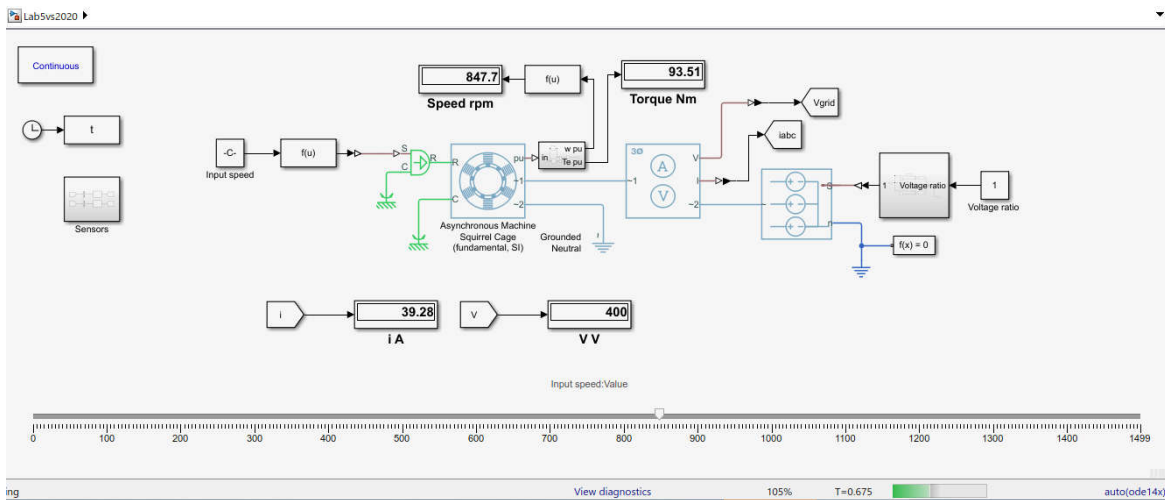


Fig. 1. Matlab Simulink implementation of Lab 1

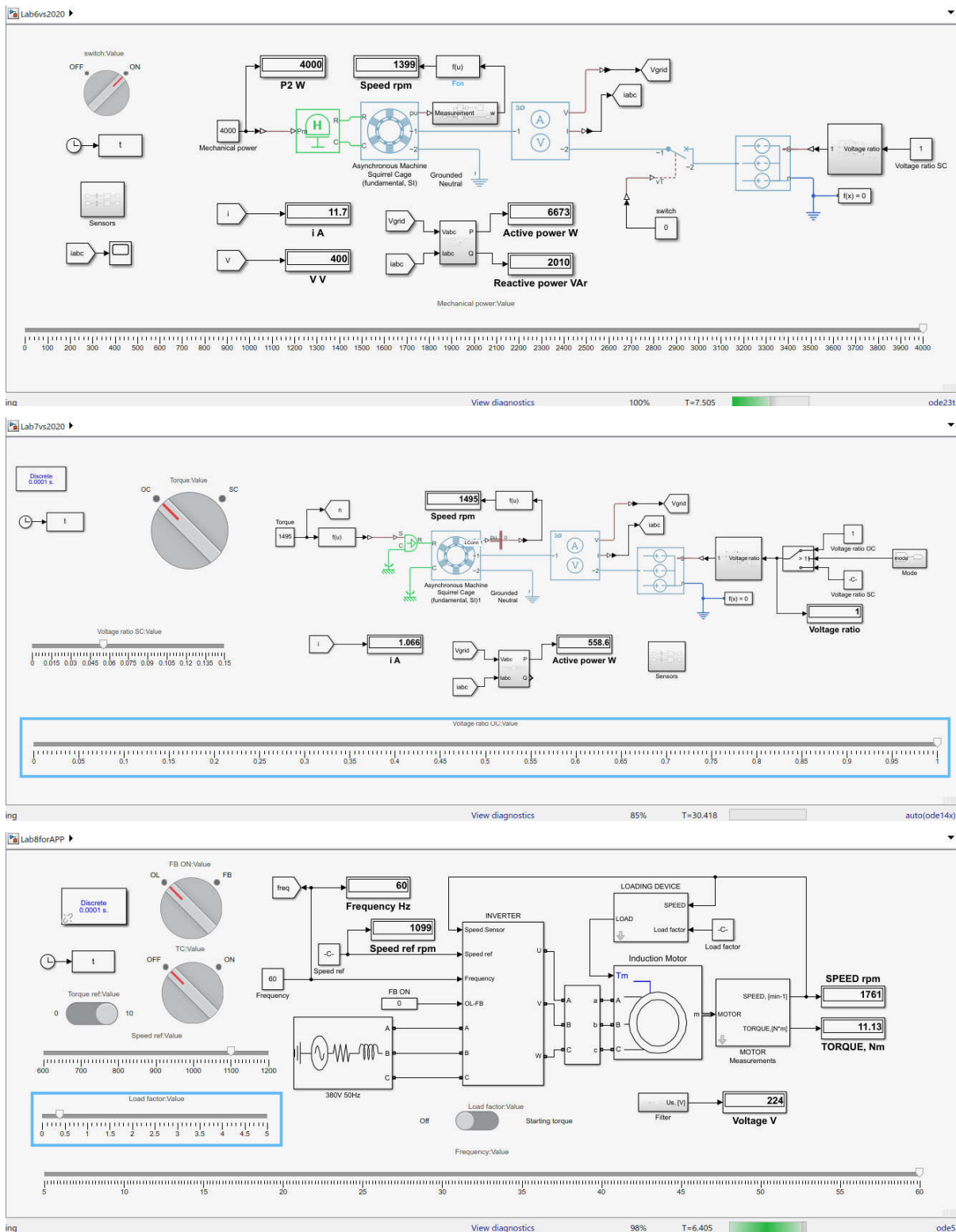


Fig. 2. Matlab Simulink implementation of Lab 2 (up), Lab 3 (middle) and Lab 4 (down)

Lab 4 contains several experiments, and the control devices are numerous. The mechanical and regulation characteristics are obtained in open loop control. For this purpose, the OL position of the round switch should be active. The frequency of the mechanical characteristic is chosen by the large slider, while the load is changed by a smaller slider (named "load factor"). To obtain the starting torque, a switch is used to impose a very high value of the load factor (in the low middle of the model). The regulation characteristics are

measured for two values of the load torque. The load should be maintained constant and the torque control (TC) is switched on by the respective round switch. Then the reference values of the torque are changed by a switch (in the left part of the model). To obtain the characteristics, the frequency is changed in the already mentioned manner. For the last experiment, the speed feedback (FB) is switched on and the speed reference is set by a small slider. The needed measurements are available on different displays.

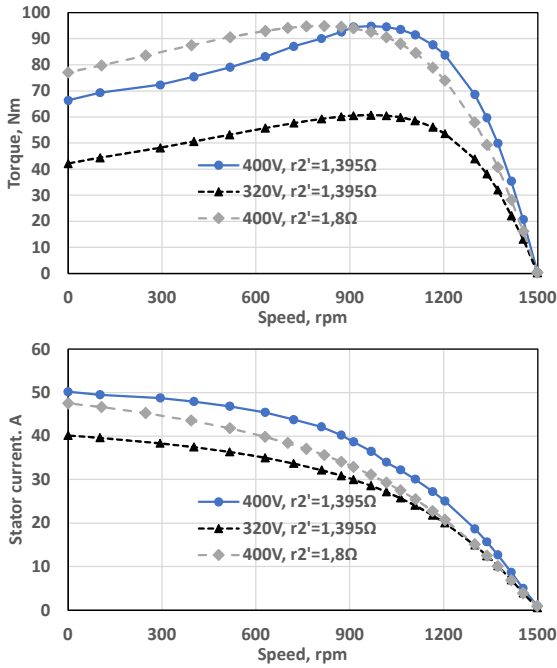


Fig. 3. Mechanical characteristics (up) and currents variations (down)

IV. SIMULATION RESULTS

The above-described models are used to obtain the required results. They are presented in this section. The experiment for the mechanical characteristic is realized for three combinations of two voltage values and two resistance values. The results are shown on Fig. 3 for 400V and 320V and 1.395Ω and 1.8Ω. The obtained mechanical characteristics (up) and current variations (down) correspond to the theory – the voltage influences the values of the obtained torque, while the rotor resistance moves the critical speed to the left. The currents increase with the speed decrease.

The first experiment in the second laboratory work is the direct start-up of the motor. The result on the stator currents, presented on Fig. 4, illustrate the high obtained values of the currents during the starting process. Thus, they are aware of the danger to the equipment in the stator circuit. The operational characteristics are shown on Fig. 5 for variation of the load from 0 to 4000W. The active power and the stator current increase following the quadratic function. The consumed reactive power is almost constant during the load variation, with smaller values for high loads. The rotor speed decreases linearly with the load increase. In the same time, the torque and the slip increase linearly, while for the other

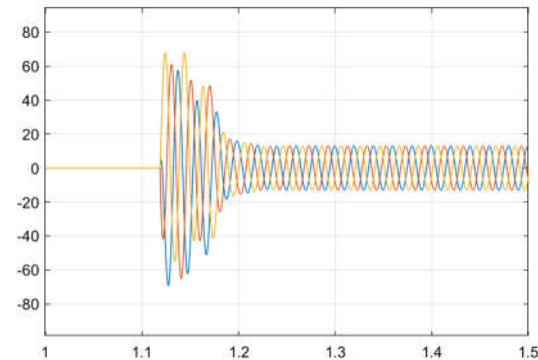


Fig. 4. Transient process of the stator currents (in A).

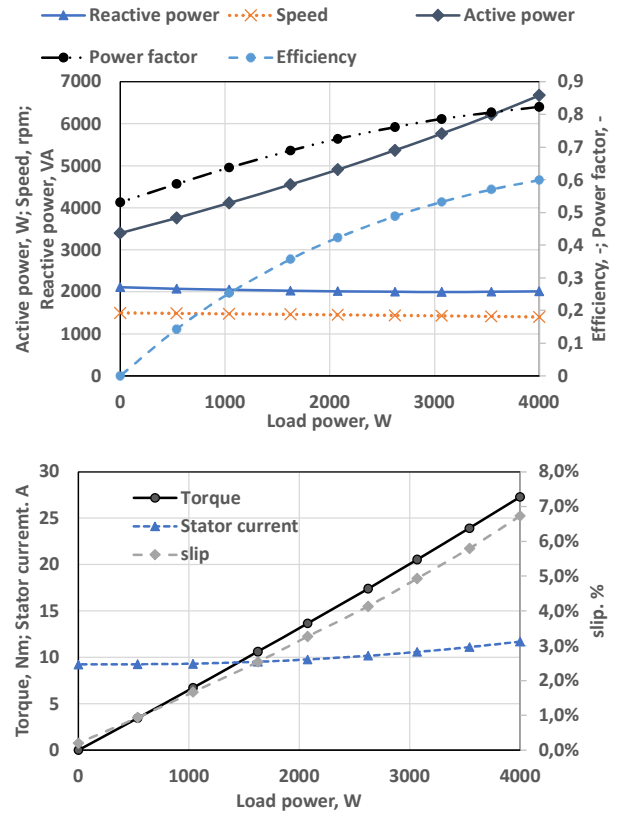


Fig. 5. Operational characteristics of the induction motor.

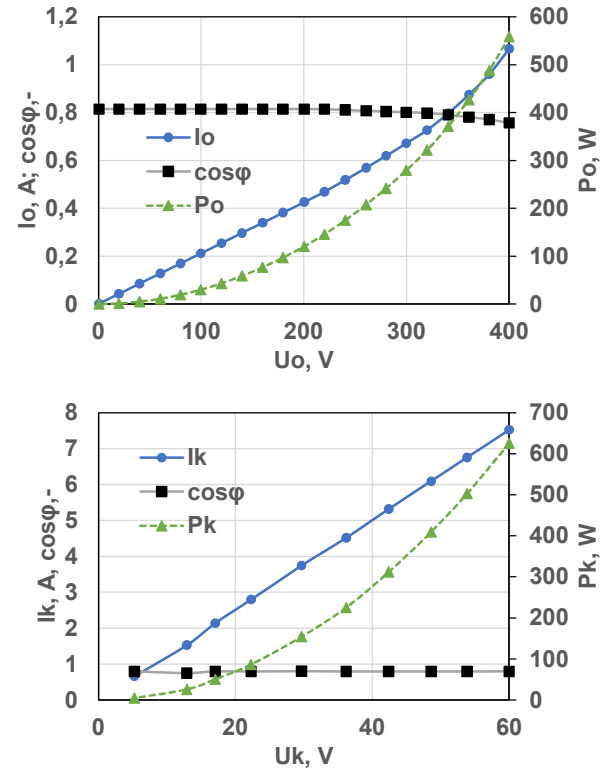


Fig. 6. Open circuit (up) and short circuit (down) characteristics of the induction motor.

variables (the power factor and the efficiency), the augmentation is non-linearly. The variations of the variables correspond to the theory, taking into account the mathematical model's assumptions.

The results for the open circuit and short circuit experiments of the induction motor are shown on Fig 6. For OC the voltage varies from less than 1% to 100% of the rated stator voltage, while for SC the variation is from about 1% to 15%. In the first case, the variable change is marked by the iron saturation for high voltage values. This saturation is not present in the short circuit experiment. Thus, the current increases linearly, the stator power follows a quadratic law, and the power factor is almost constant. The described variations correspond to the theory. The only difference is due to the mechanical losses neglect in the model. Thus, the power in the simulation crosses the ordinate axis in the zero.

The results from the last laboratory work are presented on Fig. 7. The mechanical characteristics for three different frequencies (30Hz, 50Hz, and 60Hz) are presented on the upper figure. For the lowest frequency, the envisaged change of the load is not sufficient to reach the maximal torque and the only point on the left side of the graphic is the starting torque. For 50Hz, this maximum is achieved and several points are possible in the instable part of the characteristic. The highest frequency value gives the opportunity to draw the entire mechanical characteristic. From the experiment for the regulation characteristics, two graph families can be extracted. The first one is the voltage control law, while the second one is the speed variation, both in function of the frequency change. For frequencies from 5Hz to 50Hz, the voltage increases linearly, while for higher values, the voltage remains constant. The presence of load torque shifts down the curve for higher frequencies. The speed increases linearly for the entire range of frequency augmentation. The load torque shifts down the curve for all frequencies.

V. CONCLUSIONS

This paper presents the digital models of the laboratory works, dedicated to the induction motor at the Technical University of Sofia. The experiments are separated in four laboratory works. The Matlab Simulink environment is used to model each of them, keeping a maximal analogy to the real experimental benches and the required students' manipulations. Different results from the performed simulations in each laboratory work are shown. A good correspondence between the theory and the real laboratory results is observed, keeping in mind the mathematical model's assumptions, especially the mechanical losses neglect. Thus, the education on the digitalized laboratory works can be considered as a good equivalent with sufficient quality of the real laboratory exercises for the purposes of the distance learning or in the case of emergency situation as the lockdowns due to the COVID-19 pandemic in the recent years.

ACKNOWLEDGMENT

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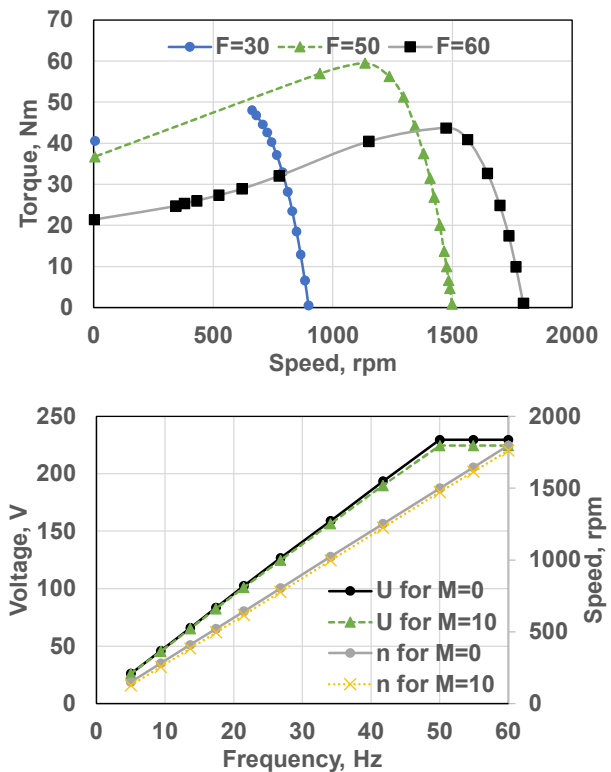


Fig. 7. Mechanical (up) and regulation (down) characteristics of the induction motor for frequency control.

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