International conference on High Technology for Sustainable Development

HiTECH 2022

PROGRAMME

6 – 7 October 2022
Sofia

General Programme

Day	Hour	Event
Wednesday 5 October	*16.00* – 18.00	**Online Registration of participants**
Thursday 6 October	*09.00* – 12.00	**Registration of participants - MS Teams -** https://teams.microsoft.com/l/team/19%3aTSPxaxtc6QB2v_AeXll6R_TrdsauTrAdgw1VsKjt9t01%40thread.tacv2/conversations?groupId=fbb7bc74-72a8-499f-a304-2d33f877606e&tenantId=7feeb5c0-34f4-4a4b-8cc0-e59f06920156
	14.00 – 14.15	**Opening Session** **FNTS**
	14.15 – 15.00	**Invited Papers** **FNTS**
	15.00– 17.00	**Session 1** **FNTS**
	17.30 – 19.30	**Session 2** **FNTS**
Friday 7 October	*09.00* – 12.00	**Session 3** https://teams.microsoft.com/l/team/19%3aTSPxaxtc6QB2v_AeXll6R_TrdsauTrAdgw1VsKjt9t01%40thread.tacv2/conversations?groupId=fbb7bc74-72a8-499f-a304-2d33f877606e&tenantId=7feeb5c0-34f4-4a4b-8cc0-e59f06920156
	12.00 – 13.30	**Lunch Break**
	13.30 – 16.30	**Session 4** https://teams.microsoft.com/l/team/19%3aTSPxaxtc6QB2v_AeXll6R_TrdsauTrAdgw1VsKjt9t01%40thread.tacv2/conversations?groupId=fbb7bc74-72a8-499f-a304-2d33f877606e&tenantId=7feeb5c0-34f4-4a4b-8cc0-e59f06920156
	16.30 – 17.00	**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

Simulation of a single-phase induction motor for educational purposes

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***Abstract*—The paper presents the development of a mathematical model of a single-phase induction motor for laboratory works. The experimental test bench that is used in the real exercises is represented by a mathematical model, created in the Matlab/Simulink environment. The created model is used for simulation of different main characteristics with high importance for the education of electrical specialists and engineers and studies the behavior of the single-phase motor with different kinds of run-capacitors, which is not possible in the real experimental bench at the Technical University of Sofia.**

Keywords—single-phase induction motor, mathematical models, Matlab simulations, distance learning

I. INTRODUCTION

The present work is aimed at creating a mathematical model of a single-phase induction motor, that will be used in distant laboratory exercises by the students of the Electrotechnical Faculty of the Technical University of Sofia. The need for online laboratory exercises has been driven by the recent COVID-19 pandemic, which has shown the world the benefits of the distance learning process for foreign students for example [1], [2], [3], [4], [5], [6].

The single-phase induction motor is one of the most commonly used types of electrical machines in our everyday life. This is why its work principles must be adequately taught to the students in electrical engineering specialties. To do this in virtual environment, a mathematical model of a single-phase induction motor based experimental bench is developed [7] which is later built as an online tool for the students, as proposed in a recent study for other electrical machines by the authors [8]. The model is created in the Matlab/Simscape environment and is then exported as a Matlab Web App, which does not require the installation of the full software product or the acquirement of software licenses [9].

II. OPERATING PRINCIPLES OF THE SINGLE-PHASE INDUCTION MACHINE

The considered electrical machine is in fact a two-phase motor with a single-phase power supply. It consists of two stator windings *A* (main winding) and *B* (auxiliary winding), which are positioned in the stator's slots at 90° electrical from each other – Fig. 1. To obtain a rotating magnetic field in the machine the current in one of the two stator phases must be dephased. The most common way to do this is by the use of a start-capacitor and/or a run-capacitor.

To obtain a circular rotating magnetic field in the stator one must accomplish two conditions:

1. The coefficient of transformation *k* between the two stator windings *A* and *B* must be:

$$k = tg\varphi_A \qquad (1)$$

2. The capacitance of the run-capacitor C_r must be equal to:

$$C = \frac{\cos^2\varphi_A}{2\pi f_1 x_A} \qquad (2)$$

Here φ_A is the angle between the vectors of the voltage and current of the phase A, f_1 is the frequency of the stator voltage and x_A is the reactance of winding A.

When one of the two conditions is not met the magnetic field in the stator is rotating elliptical. From (1) and (2) it is evident, that to obtain a circular rotating field in the machine it is necessary to change the coefficient of transformation between the two stator windings, because the angle φ_A changes with the load of the motor. This change of the coefficient *k* is impossible due to the fact that it requires change of the winding turns in the stator phases. Thus the capacity of the run-capacitor should be calculated in such a way, that the circular magnetic field is obtained for the rated load. This leads to worsened starting torque of the single-phase motor, due to the elliptic magnetic field. This gap can be overcame with the use of additional capacitor, switched-off at steady state operation mode.

As shown, the capacity of the run-capacitor plays an important role in the single-phase induction motors. This is why the developed model permits the students to change the capacity and to study the motor's performances in different

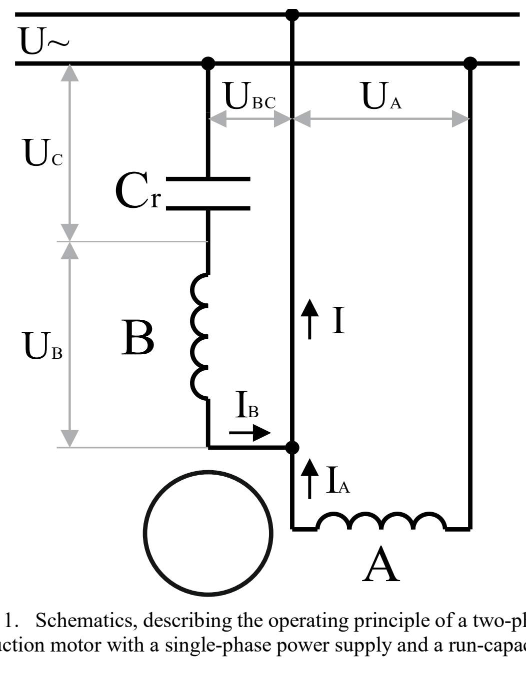

Fig. 1. Schematics, describing the operating principle of a two-phased induction motor with a single-phase power supply and a run-capacitor

operating conditions. This is an improvement over the real laboratory test bench, which uses only one capacity of the run-capacitor and will permit the students to learn how to calculate and determine the required capacitance and obtain the characteristics of the studied machine in different cases of operation.

III. Modelling of the single-phase induction machine

The single-phase induction motor can be represented by the schematics at Fig. 2. The upper schematic represents the circuit for the phase winding *A* and the lower one – for the phase winding *B*. The principles of operation of the single-phase induction motor are described by the following equations (here the index 1 describes the stator parameters, the index 2 describes the rotor parameters and *A* and *B* denote the stator windings) [7]. The inductances are represented by:

$$L_{m1} = L_{mA1} = \frac{1}{k^2} L_{mB1} \quad (3)$$

Here the L_{m1} is the mutual inductance, which is equal to the inductance of the phase *A* L_{mA1}. L_{mB1} is the inductance of the phase *B* and *k* is the transformation coefficient between the two phases and is calculated by:

$$k = \frac{w_A}{w_B} \quad (4)$$

Here w_A is the number of turns of the phase winding *A* and w_B is the number of turns of the phase winding *B*.

The active resistances of the rotor windings of both phases are linked by:

$$R'_{A2} = \frac{1}{k^2} R'_{B2} \quad (5)$$

The leakage inductances of the rotor are:

$$L'_{\sigma A2} = \frac{1}{k^2} L'_{\sigma B2} \quad (6)$$

The Kirchhoff's equations for the stator's and the rotor's voltages in d-q coordinate system are expressed by the following equations:

$$v_{q1} = R_{A1} i_{q1} + \frac{d\psi_{q1}}{dt} \quad (7)$$

$$v_{d1} = R_{B1} i_{d1} + \frac{d\psi_{d1}}{dt} \quad (8)$$

$$0 = R'_{A2} i'_{q2} + \frac{d\psi'_{q2}}{dt} - \frac{1}{k}\omega_2 \psi'_{d2} \quad (9)$$

$$0 = k^2 R'_{A2} i'_{d2} + \frac{d\psi'_{d2}}{dt} + k\omega_2 \psi'_{q2} \quad (10)$$

Here v_{q1} and v_{d1} are the stator voltages on the direct (d) and quadrature (q) axes of the single-phase motor, i_{d1} and i_{d2} are the stator currents on both axes and ψ_{d1} and ψ_{d2} are the flux linkages, expressed by:

$$\psi_{q1} = (L_{\sigma A1} + L_{m1}) i_{q1} + L_{m1} i'_{q2} \quad (11)$$

$$\psi_{d1} = (L_{\sigma B1} + k^2 L_{m1}) i_{d1} + k^2 L_{m1} i'_{d2} \quad (12)$$

$$\psi'_{q2} = (L'_{\sigma A2} + L_{m1}) i'_{q2} + L_{m1} i_{q1} \quad (13)$$

$$\psi'_{q1} = k^2 (L'_{\sigma A2} + L_{m1}) i'_{d2} + k^2 L_{m1} i_{d1} \quad (14)$$

The electromagnetic torque of the single-phase induction motor is represented by:

$$T = p\left(k\psi'_{q2} i'_{d2} - \frac{1}{k}\psi'_{d2} i'_{q2}\right) \quad (15)$$

Here *p* represents the number of pole pairs in the motor.

The mechanical equation for the model is represented by:

$$J\frac{d\omega_m}{dt} = T - T_L - B_m \omega_m \quad (16)$$

Here *J* is the moment of inertia of the rotor and the load, T_L is the mechanical torque of the load of the motor, B_m is the

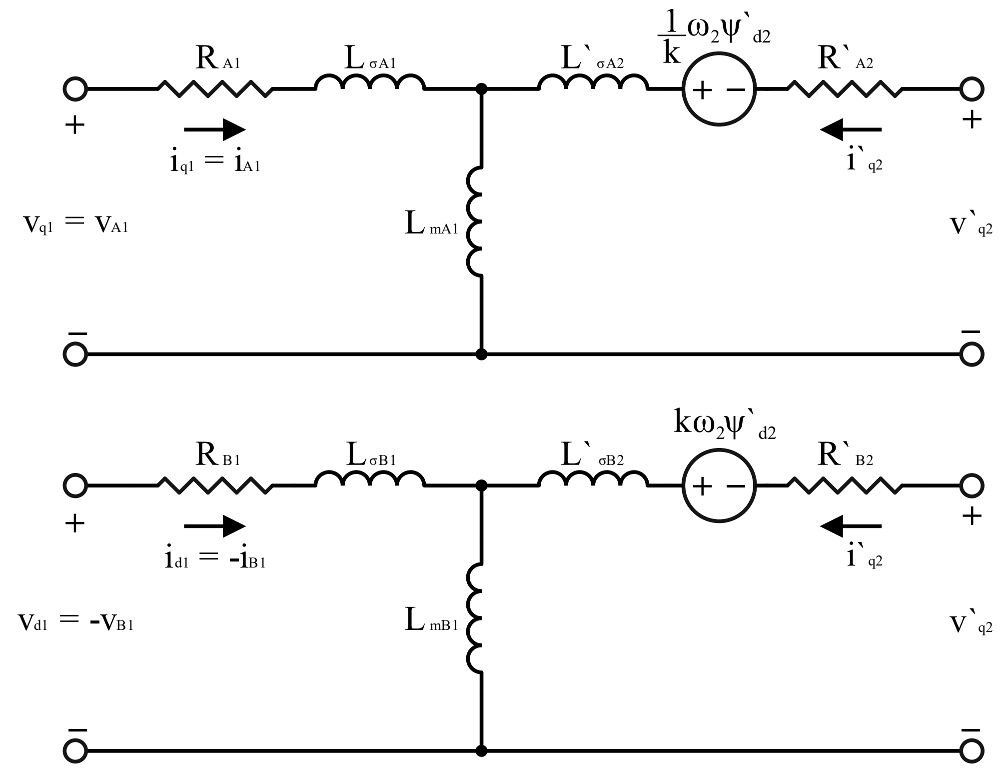

Fig. 2. Equivalent electrical circuits of phase winding A (top) and B (bottom).

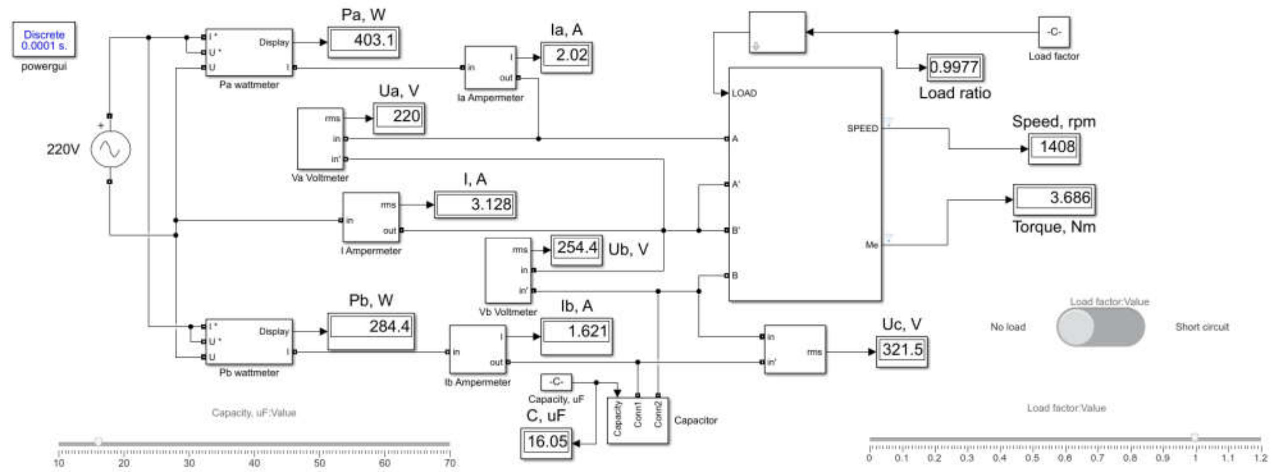

Fig. 3. Matlab Simulink implementation of the developped laboratory exercise.

friction coefficient of the rotor and the load and ω_m is the angular velocity of the rotor of the machine.

The laboratory exercises are simulated in the Matlab Simulink environment. The developed model is presented at Fig. 3. The model permits to the user to change the values of the run-capacitors of the single-phase induction motor with the bottom left slider, thus encouraging the students to determine the required capacitance for the modelled machine.

The value of the run-capacitor can be calculated using the following equation:

$$C_r = \frac{P\,\eta}{U^2 f_1} \tag{17}$$

Here C_r is the capacity of the run capacitor in nF, P is the rated power of the motor, η is the motor's efficiency (in %), U is the rated voltage and $f1$ is the electrical frequency of the stator voltage.

A practical criterion for the selection of the run-capacitor's capacitance is presented by the authors of [5].

IV. Simulation Results

The laboratory exercise has been modelled in the Matlab/Simscape environment. The appropriate capacity of the run-capacitor is determined by variation of its value from 10μF to 70μF and recording the values of the starting and the nominal torques. The result of this variation is presented on Fig. 4. The black line (with triangle marks) represents the starting torque of the motor, which is highly influenced by the value of the run-capacitor. To augment the starting torque high values of the capacitor's capacitance should be used. This on the other hand is costly and leads to greater losses in the machine, thus requiring an adequate compromise while choosing the run-capacitor, or as mentioned above to use a start capacitor and a run capacitor with different capacitances. The variation of the torque at nominal speed is presented with blue line and round markers. According to this variation it is obvious that the run capacitor should be around 34 μF to maximize the torque at nominal speed and this value is used in the simulations of the operation characteristics, presented below. To obtain them, the load of the single-phase induction motor is varied using the slider presented in the bottom right side of Fig. 3. Thus, we are changing the load factor of the motor. Load factor of 1 corresponds to the rated load in N.m and load factor of 0 corresponds to no-load.

The operational characteristics of the single-phase induction motor are measured using the proposed simulational setup. These characteristics are presented on Fig. 5. The top graph represents the speed n, the mechanical power at the shaft of the motor P_2, the electrical power, consumed by the stator P_1 and the efficiency of the single-phase motor, all measured for different loads. The lower graph represents the rest of the operational characteristics – the stator current I and the power factor of the motor $cos\varphi$.

The operational characteristics of the laboratory machine are presented at Fig. 6. The behavior of the simulated single-phase induction motor corresponds to the comportment of the real one, used in the laboratory exercises.

Some differences in the measured values can be perceived, which are due to the fact that the goal of this work was not the exact modelling of the motor used in the laboratory works, but the correct representation of the principles of operation and the method for obtaining the operational characteristics of the single-phase induction motor trough tests. Apart from these differences in the values, the nature of the operational characteristics in both the simulation and the laboratory test bench is the same.

An interesting observation can be made, by looking at the power factor graphs at Fig. 5 (bottom) and Fig. 6 (bottom), respectively for simulation and experiment. In the experimental test bench, the maximum attained power factor $\cos\varphi$ is 0.411, and in the simulation, the maximal attained

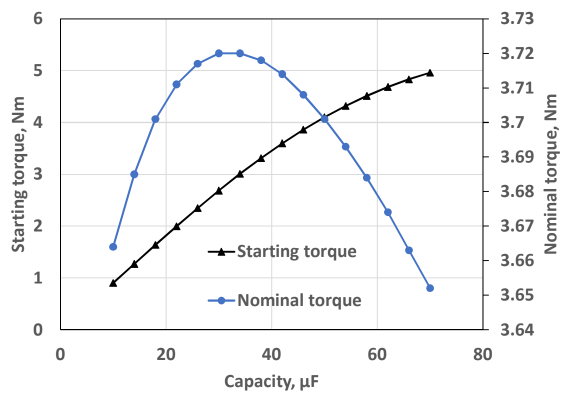

Fig. 4. Starting and nominal torque in dependance of the chosen capacity of the run-capacitor used in the modelled single-phase induction motor.

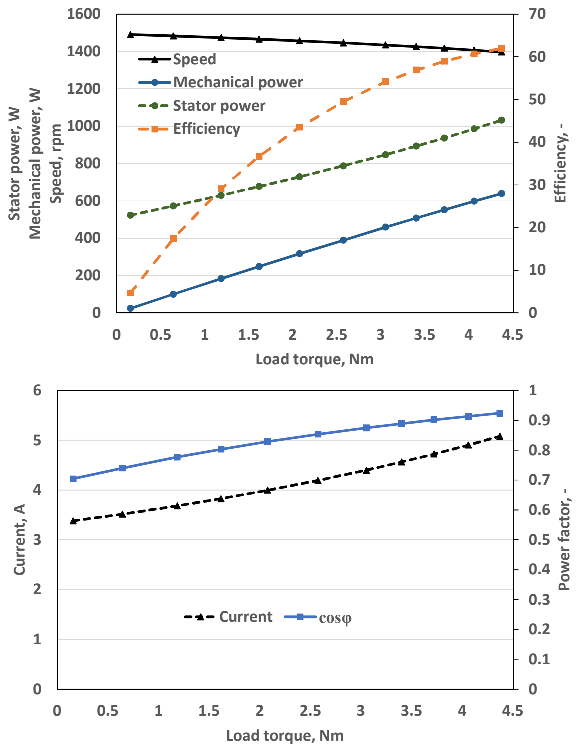

Fig. 5. Operational characteristics of the modelled single-phase induction motor.

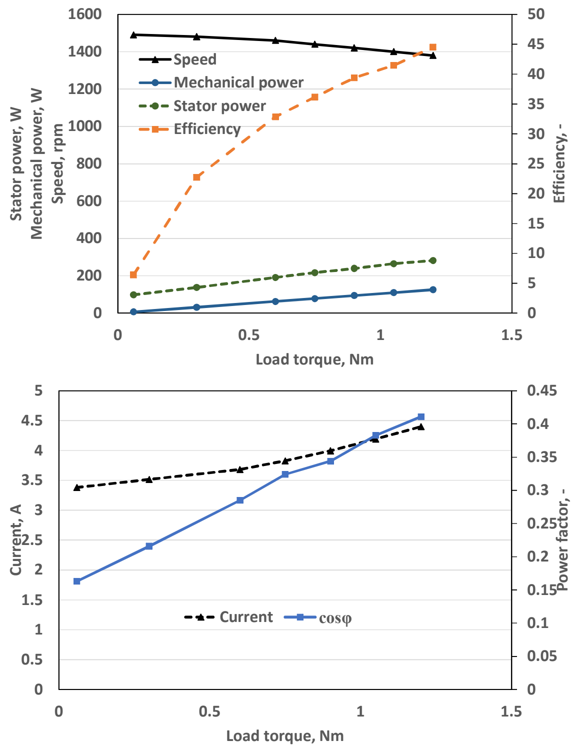

Fig. 6. Measured operational characteristics of the laboratory used single-phase induction motor.

value of the power factor cosφ is 0.924. This is due to the chosen value of the capacitance of the run capacitor. In the laboratory test bench, the single-phase induction motor is started with no load, and thus requires less starting torque. This permits the use of a capacitor with a lower capacitance, which can lead to a reduction in the price of the system. On the other hand, the choice of inappropriate capacitance can lead to deformation of the rotating magnetic field in the single-phase motor from circular to elliptical for the point of the nominal load, which leads to a reduction of the power factor and higher consumption of reactive energy. The capacity value in the simulation is chosen appropriately to increase both the torque and the power factor.

V. Conclusions

The paper presents the created model of the laboratory works for single-phase induction motor in the Technical University of Sofia. The modelling of the motor in the Matlab/Simscape environment is presented. Simulation results are compared to experimentally acquired characteristics of the real machine, used in the laboratory works. The realized model corresponds to the real experimental bench and the manipulations of the students are as close as possible to the real laboratory work. The developed model permits the digitalization of the laboratory work, which permits the students to participate in the event of distance learning.

Acknowledgment

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