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 Transformers' Characteristics in Laboratory Exercises for Electrical Engineers

Ludmil Stoyanov
Department of Electrical machines,
Faculty of Electrical engineering,
Technical University of Sofia
Sofia, Bulgaria
ludiss@tu-sofia.bg

Ivan Bachev
Department of Electrical machines,
Faculty of Electrical engineering,
Technical University of Sofia
Sofia, Bulgaria
iv.bachev@tu-sofia.bg

Vladislav Petrov
Department of Electrical machines,
Faculty of Electrical engineering,
Technical University of Sofia
Sofia, Bulgaria
vlep@tu-sofia.bg

***Abstract*—The paper presents the creation of models of different laboratory works aiming the simulation of transformers' characteristics. The real experimental benches are represented by mathematical models in Matlab-Simulink environment. The created models are used for simulation of different main characteristics with high importance for the education of electrical specialists and engineers.**

Keywords—Transformers, mathematical models, Matlab simulations

I. Introduction

The past years demonstrates the importance of the digitalization of the education [1]. This digitalization can be driven by the will of the education institutions for distance learning [2] or, unfortunately, forced by external factors as pandemical restrictions [3], what is the current case with the COVID-19 pandemic in the last years.

The transformers are basic electrical machines in the human life and the electrical grid. Thus, their investigation is very important for the electrical engineers or other specialists in this field. Technical University of Sofia, as a leader in the technical high education in Bulgaria, forms basic or specialized knowledge in this field of the students and this paper presents the digitalization of the laboratory exercises, dedicated to the power transformers. This digitalization follows the trend [4]-[9], caused by the COVID-19 pandemic, but is useful for the implementation of engineers' distance learning.

II. Considered Experiments, Characteristics and Parameters

Different characteristics and parameters are aimed by the digitalized laboratory works. They are obtained by different experiments, detailed below.

A. Open circuit (OC) experiment [10]

This experiment allows the determination of the transformation ratio of the transformer and open circuit characteristics. The first parameter represents the ratio of the primary and secondary voltages, or the ratio of the number of turns of the primary transformer's winding and the respective turns of the secondary winding. The open circuit experiment allows the measurement of the voltages and this is used in the laboratory work. The open circuit characteristics represent the variation of the primary power, the primary current, and the power factor of the transformer in function of the primary voltage. Those characteristics are obtained by varying the input voltage from 0 to the rated value.

This experiment allows also the determination of iron losses, magnetizing current and equivalent scheme's parameters of the magnetizing circuit, but they are not aimed by the digitalization.

B. Open circuit starting and operation particularities [11]

This experiment is used to illustrate the particularities of the starting process of three-phase transformers, the magnetic asymmetry, and the source of harmonics for high values of the operation voltage. Those particularities are important for the sizing of protection equipment.

C. Short circuit (SC) experiment [10]

This experiment is performed with reduced input voltage and aims at the determination of the short-circuit characteristics of the transformer, which are, again, the variation of the primary power, the primary current, and the power factor of the transformer in function of the primary voltage.

The copper losses and the equivalent scheme's parameters of the windings, which are also determined with this experiment, are not considered in the modelled laboratory works.

D. Transformer's hour index [10]

The transformer's hour index is a very important parameter, which influences the possibility for parallel operation of numerous transformers. Thus, its knowledge and understanding are crucial for electrical engineers in the field of power systems. The aim of the experiment is the visualization of the phase difference between the primary and secondary line-to-line voltages.

E. Output characteristics and parallel operation of transformers [10]

This experiment illustrates the influence of the load on the transformer's output voltage, called an external characteristic, and allows the study of the influence of the parallel operation of transformers on this characteristic.

III. Laboratory Exercises Modelling

The experiments described in the previous section are grouped into 4 laboratory works, as in the real laboratory program, to keep the analogy between the real and the digital exercises. The laboratory works are:

- Lab 1: Open circuit and short circuit experiments;
- Lab 2: Transformers hour index;
- Lab 3: Parallel operation of transformers;
- Lab 4: Open circuit starting and operation.

The laboratory exercises are simulated using the Matlab Simulink environment. Each model contains a transformer or two (in the case of the parallel operation) and auxiliary equipment. As the transformer is the main machine in the labs, only its model is considered. The transformer's model is presented by the system below of two voltage and one current equations, which describe the equivalent scheme, presented on Fig.1 [12].

$$\begin{cases} u_1 = r_1 i_1 + L_{l1}\dfrac{di_1}{dt} + \dfrac{d\Phi}{dt} \\ u_2^{'} = -r_2^{'} i_2^{'} + L_{l2}^{'}\dfrac{di_1}{dt} + \dfrac{d\Phi}{dt} \\ i_1 = i_2^{'} + i_m + i_{r_m} \end{cases} \quad (1)$$

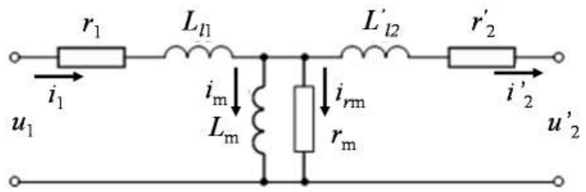

Fig. 1. Equivalent scheme of the transformer

where: u_1 and u'_2 are the transformer's primary and its referred to the primary side secondary voltages, i_1 and i'_2 are the primary and the referred to the primary side secondary currents, r_1 and r'_2 are the primary winding's and the referred to the primary side secondary winding's resistances, L_{l1} and L'_{l2} are the primary winding's and the referred to the primary side secondary winding's leakage inductances, and Φ is the magnetic core flux, which depends on the inductance of the magnetizing branch (L_m) and the core loss resistance (r_m).

Fig. 2 presents the implementation of Lab 1 (up) and Lab 2 (down), while Fig. 3 – of Lab 3 (up) and Lab 4 (down). In Lab 1, the user can choose the experiment to be performed by a round switch. This choice influences the "load", connected on the transformer's secondary terminals from no load to short circuit, and the voltage supply range, because the SC requires a smaller input voltage. The determination of the OC and SC characteristics needs the variation of the primary voltage. In the first case, the larger slider is used, while the smaller slider controls the voltage in the second case. The model offers the needed measurements of the variables to determine the characteristics.

In Lab 2 the user can vary the phase order of the secondary winding (abc, cab and bca) from the left round switch. The right round switch is used to change the type of connection (star or delta) and the starts and ends of the windings. Thus, all possible connections can be performed. The model shows the primary and secondary line-to-line voltages with a scope

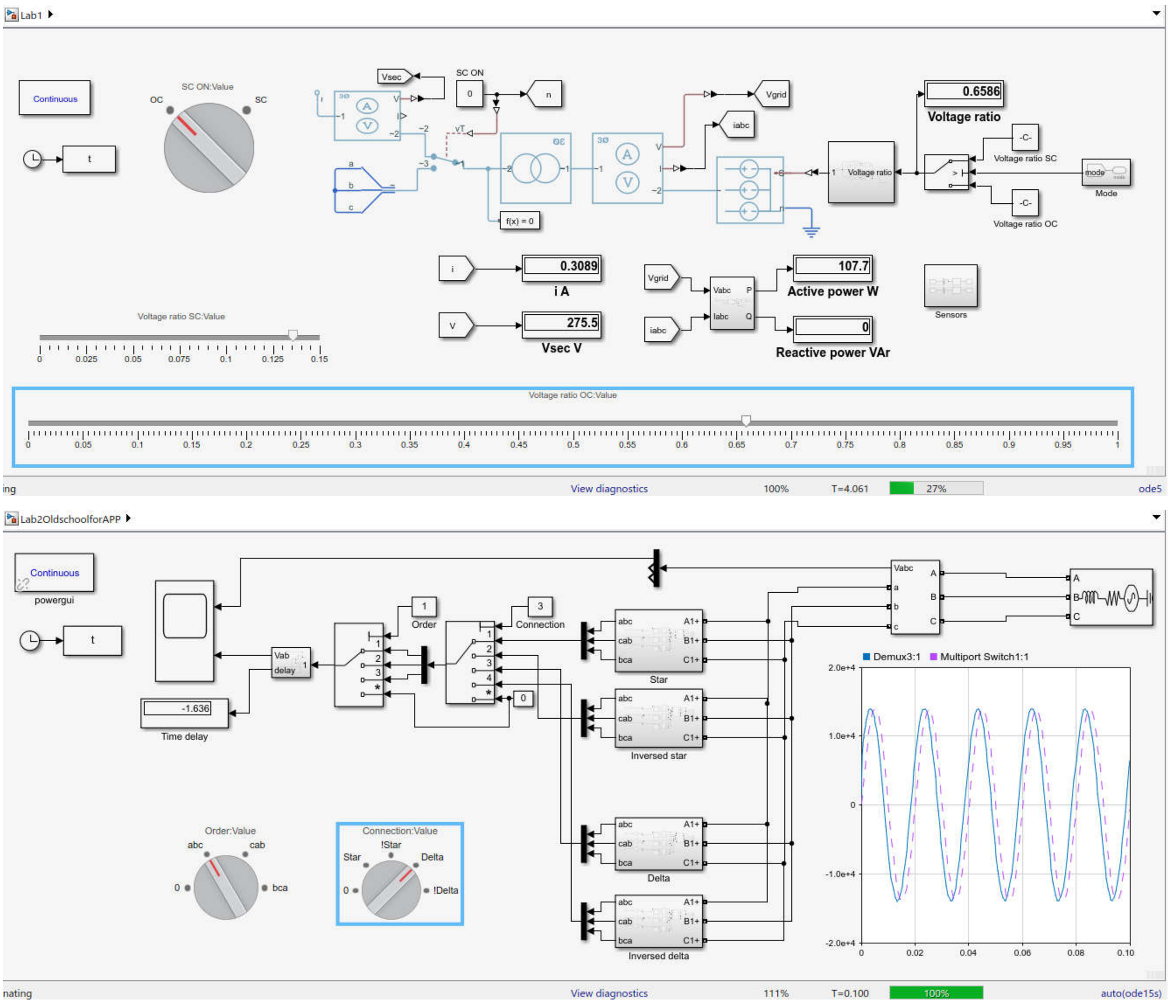

Fig. 2. Matlab Simulink implementation of Lab 1 (up) and Lab 2 (down)

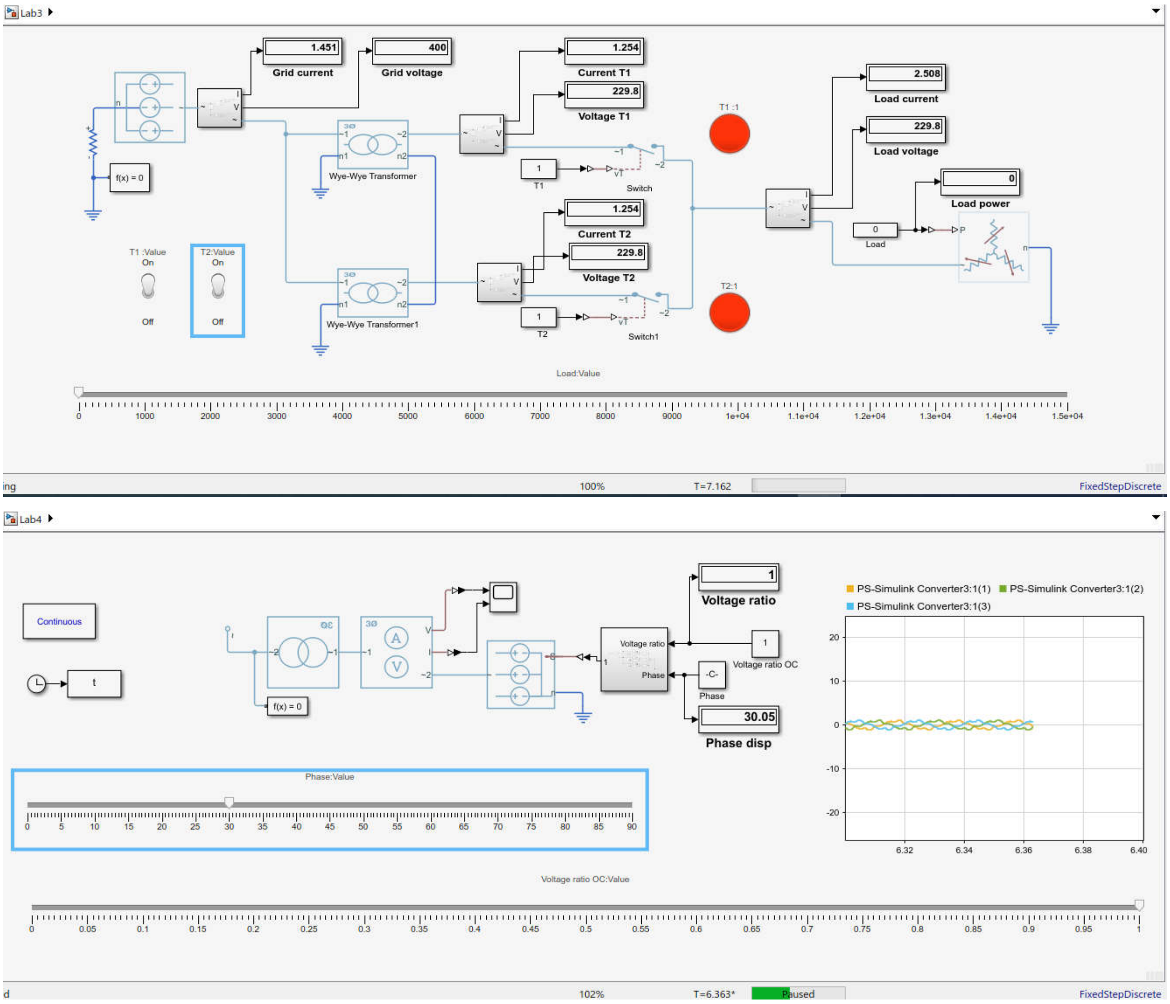

Fig. 3. Matlab Simulink implementation of Lab 3 (up) and Lab 4 (down)

in real time. Thus, the students understand the hour index influence. Moreover, the time delay is measured to quantify the phase difference and determine the hour index.

In Lab 3 the transformers can operate separately or in parallel. The connection is controlled by one switch per transformer and indicated by light (red for ON and green for OFF). The aim of the laboratory exercise is to determine the influence of the load on the external characteristic of one transformer separately and of two transformers in parallel. The load is variated with the slider in the lower part of the model. The needed measurements are also indicated with several displays.

The experimental part of Lab 4 is simpler and aims to illustrate the influence of the input voltage on the current's harmonic distortion and the phase on the starting transient process. The primary voltage is changed by the larger slider, while the voltage initial phase is varied with the smaller one. A real-time scope illustrates the transformer's currents. Another scope is used for detailed analysis.

IV. Simulation Results

This section will present some graphical results obtained with the presented Matlab models. In the first laboratory exercise, the open circuit and short circuit characteristics of the transformer are both obtained by variation of the input voltage. In the first case, the variation is from 100% to around 10%, while in the second case the variation is between 15% and 1%. The obtained characteristics are presented on Fig. 4. Their variation corresponds to that expected by the theory. We

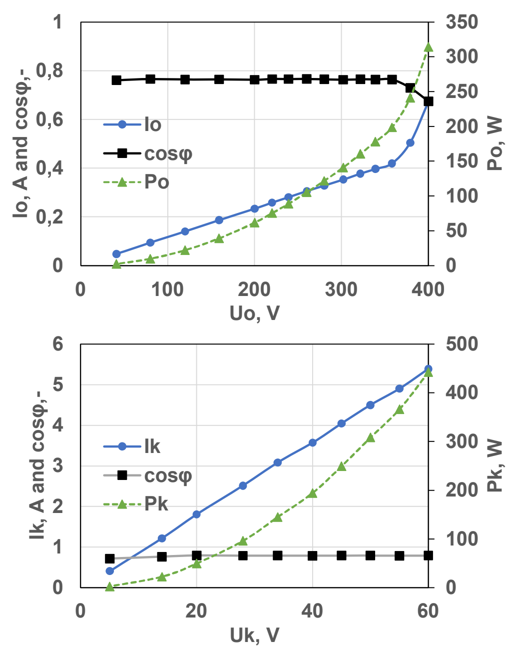

Fig. 4. OC (up) and SC (down) characteristics

observe the main difference between both operation modes – the influence of the magnetic circuit saturation for high voltages, which is observed in the OC experiment where the voltages are significantly higher.

In the second laboratory work, the students measure the time delay between the primary and secondary line-to-line voltages. The delay is then transformed into a phase difference and the transformer's hour index is determined. The results are presented graphically on Fig. 5, where the variations of the time delay and of the phase delay in function of the transformer's hour index are illustrated. For each hour index, the voltage oscillograms are considered and analyzed.

The simulation results from the third laboratory exercise are presented on Fig. 6. The illustrated external characteristics for one transformer separately are identical because both transformers in the model have the same parameters. We observe that the increase in the load power decreases significantly the output voltage of the transformer when it operates alone – almost 50V. In the case of parallel operation, the voltage drop is reduced to about 15V. This result corresponds to the theory and justifies the parallel operation of the transformers.

In the last laboratory exercise, the students have two tasks. The first one is to observe the harmonic distortion of the transformer's currents when the magnetic circuit is saturated at high voltages. A digital oscilloscope is used for this purpose. An example of the results is presented on Fig. 7 and Fig. 8. The first figure illustrates the case for low voltage, where the magnetic core is not saturated and the currents are sinusoidal. In the second case, the voltage is near the nominal one and the magnetic circuit is saturated. This causes harmonic distortion of the currents, which is well simulated by the model of the laboratory work.

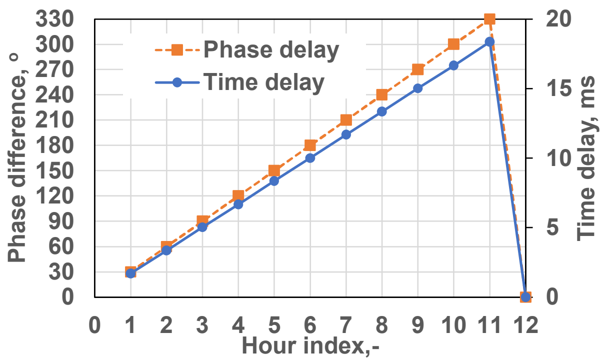

Fig. 5. Variations of the phase and time delays for different hour indexes.

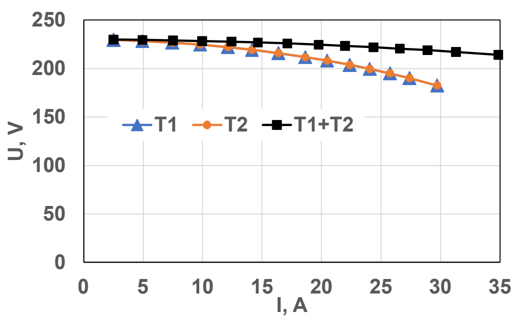

Fig. 6. External characteristics of one transformer separetely (T1 or T2) and in parallel (T1+T2).

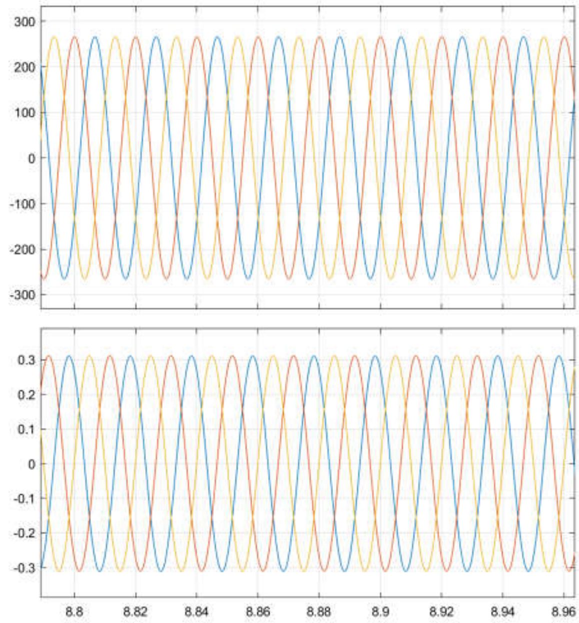

Fig. 7. Voltages' (up) and currents' (down) variations for non saturated magnetic core.

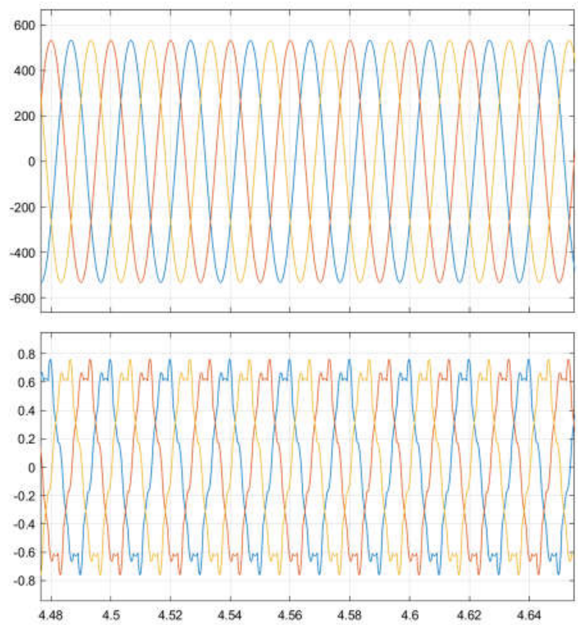

Fig. 8. Voltages' (up) and currents' (down) variations for saturated magnetic core.

The second task of the laboratory exercise is to illustrate that the startup transient process for a three-phase transformer changes with the initial phase of the voltages. To illustrate the operability of the model in this aspect, two starting processes are presented on Fig. 9. The first one is for the initial phase of line A equal to zero (up), while in the second case, this phase is about 30° (down). The difference between them is well visible – a difference in the obtained amplitudes during the transient process and a different order of the amplitudes' values. In the first case, the maximal amplitude is about 20A, versus 25A in the second case. On the upper figure, the yellow phase follows the blue one with high current amplitude, while on the lower figure, this role is taken by the red phase. This difference accomplishes the required task.

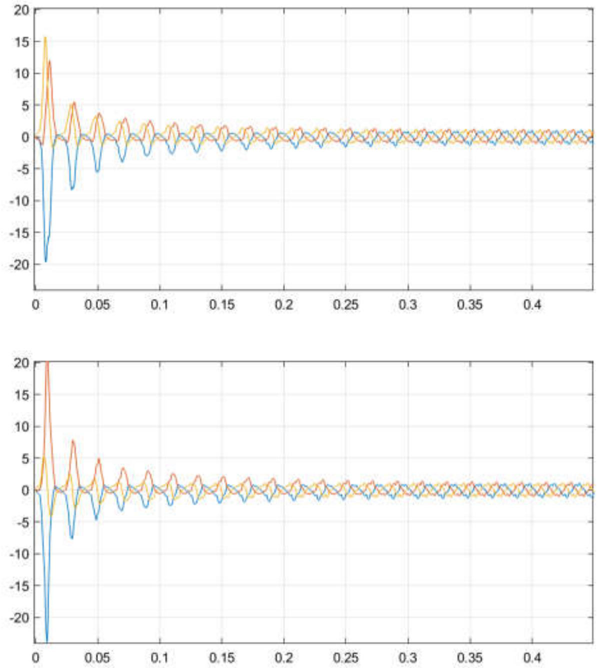

Fig. 9. Transient processes of the transformer's currents for initial phase zero (up) and 30° (down).

V. CONCLUSIONS

The paper presents the created library with models of the laboratory works for transformers at the Technical University of Sofia. Five main experiments are regrouped into four laboratory exercises. They are modeled in the Matlab Simulink environment. Each model corresponds to the real experimental bench, and the manipulations of the students are as close as possible to the real laboratory work. The presented simulation results show good correspondence to the theory, which allows the models' use in the educational process without concerns about their quality. The digitalization of the laboratory exercises in the field of electrical engineering is a good solution to the problems caused by the COVID-19 pandemic and allows the application of distance learning, which can favor international exchanges.

ACKNOWLEDGMENT

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