USING MATLAB-SIMULINK AS TOOL FOR STUDYING INDUCTION MOTOR

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Abstract: *The needed models and procedures for simulating induction motor tests are presented in the paper. The induction motor model is one from Simulink library and students can use it in simulation. Measured quantities and necessary relations for parameter determination are shown. In addition to laboratory tests, an attempt is made to find a solution for operation at low load, so that the efficiency is maintained as high as possible. The main purpose is to show students the possibilities of using Simulink in the study of the induction motor and through similarity to the study of any electrical equipment or systems.*

1. INTRODUCTION

Matlab-Simulink is well-known as one of the most performant software package used for physical phenomena simulation. The ease of programming, the suggestive logic and easy understandable, the way of working similar to the laboratory one, are just some of the many benefits. The libraries with different models, grouped by specializations, the possibility of coupling models from different library, etc., have imposed the worldwide use of Matlab, both in research work and industry and also in educational activity.

Regarding the field of electrical engineering, this package offers the possibility to model and simulate most of the equipment and systems encountered in practice. In this context, the use in the educational field of electrical engineering is more than justified, especially considering the attractive possibilities regarding the way of working and those of visualizing the results, very suggestive [1]-[4].

Last but not least, has to be highlighted the open policy of the MathWorks team, which offers free licenses to students and academic staff.

There are mainly two different ways of working in Simulink. First, it is based on the mathematical equations corresponding to the physical model, and the realization of the numerical model is done using mathematical operators (simple but also those of integration and derivation) and mathematical functions predefined or defined by the user. The necessary parameters for solving the integro-differential equations must be known and could be constants or functions of different variable, which in turn are calculated iteratively during the simulation process, in established initial conditions. The quantities of interest can be visualized in different stages, as instantaneous values, or transformed into other values (as RMS) defined by the programmer. The great advantage of this way of working is the fact that it is possible to simulate practically any desired situation, not necessarily ordinary (for example, defects in different equipment or electrical systems can be studied) [5].

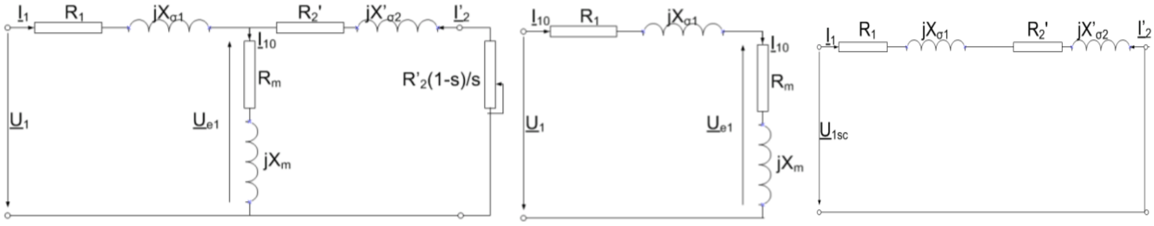
The second way involves the use of special libraries, in which we find the necessary models of the desired equipment/system. Thus, modeling in this way is very suggestive and it is close (as a working way) to the practice. For example, if we want to study a power transformer, we find in libraries different models (single-phase or three-phase, with or without saturation), we set the materials, the number of turns, the voltages, etc., then will connect the transformer to a single or three-phase power source whose parameters we can set as needed. Different operation regimes it is possible to study, being able to determine or visualize the quantities of interest in transient or stationary regime [6] - [9].

The paper is addressed mainly to electrical engineering students, but also to those who want to use Simulink in the study of the induction motor. The main contribution of this study is the presentation of some Simulink models, on which the students from electrical engineering specialization can use to model and simulate the different tests that have to perform in the laboratory. A second purpose is showing a way of operating this motor type in the industry. It is desired to highlight a simple method of operation, possible to be used so that the efficiency is maximum, depending on the motor load. Inclusion in a certain efficiency class has also been studied.

2. METHODOLOGY

The studied motor is three-phase squirrel cage induction motor. The equivalent one phase diagrams, used in this study, are shown in *fig. 1*. Index 1 is for stator winding parameters, 2 for the rotor, *m* is for magnetizing and σ stand for leakage. The ' index means referred to the stator. *R* and *X* represent resistance and reactance respectively.

The induction motor block has been selected from Simulink Library as shown, *Simscape/ Electrical/ Specielized Power Systems/Fundamental Blocks/ Machines*. In this section are many types of electrical machines.



a) b) c)

Fig. 1. Induction motor equivalent diagrams: a) normal operation; b) no load; c) locked rotor

Different types of electrical machines there are also in *Simscape/ Electrical/ Electromechanical* library. The models from *.../Machines* are different by models from *.../Electromechanical*, the latter can be coupled with a model corresponding to a mechanical equipment, while the former allow the definition of the input quantity, torque [Nm] or speed [rad/s], as a function. We worked with the model from the library, but also it can be done based on motor's equations [10], [11].

Of course, once a motor of a certain power is chosen, it has all the characteristic parameters defined, both the electrical ones consisting of a number of poles, resistances and inductances, but also the mechanical ones as inertia and friction factor, just like a real motor. In addition, the initial conditions regarding the values of some parameters at the time of starting simulation can also be defined. The problem that we want to resolve is to determine these parameters by simulating tests, just like in the laboratory. This is what we achieved next. The data that were taken into account are the rated ones such as line voltage and phases connection (Y / D 400 / 230V), frequency (50Hz), rotor speed (1430 rpm), mechanical power (4 kW), stator current (7.9 A) and stator winding resistance (1.405 Ω), which is relatively easy to measure in the laboratory. Among the mechanical parameters, friction factor (0.002985 Nms) has been used. The other electrical parameters have to be identified by tests: the no-load operation and locked rotor. Operation curves have been obtained from the load operation test.

2.1. No-load test

For no-load test, the chosen input mechanical quantity has been the load torque, and zero value was imposed. In *fig*. 1 the carried out model and the measured quantities are shown. The motor is connected to a three phase power source through a measuring kit. The instant currents and voltages are measured, and also active and reactive power. The rms values are determined and displayed. From the motor model, all electrical and mechanical instant quantities and also electromagnetic torque are obtained.

The friction factor *(F)* and the pole pairs number (*p*), have been used in order to obtain the mechanical losses in the no-load regime (negligible) knowing that,

$$p_m = F\Omega^2 = F\left(\frac{2\pi n}{60}\right)^2 \tag{1}$$

Magnetising resistance, in terms of the measured power, *P*, and average value of the stator currents, I_1, is,

$$R_m = \frac{P-p_m}{3I_1^2} - R_1 \tag{2}$$

No-load reactance also can be determined,

$$X_0 = X_m + X_{\sigma 1} = \frac{Q}{3I_1^2} \tag{3}$$

No-load power factor is,

$$cos\varphi_0 = \frac{P}{\sqrt{3}U_1 I_1} \tag{4}$$

Obtained values in no-load operation: Ω=156.97rad/s; p_m=0.468W; R_m=1.44Ω; X_{10}=55.9Ω; $cos\varphi_0$=0.051.

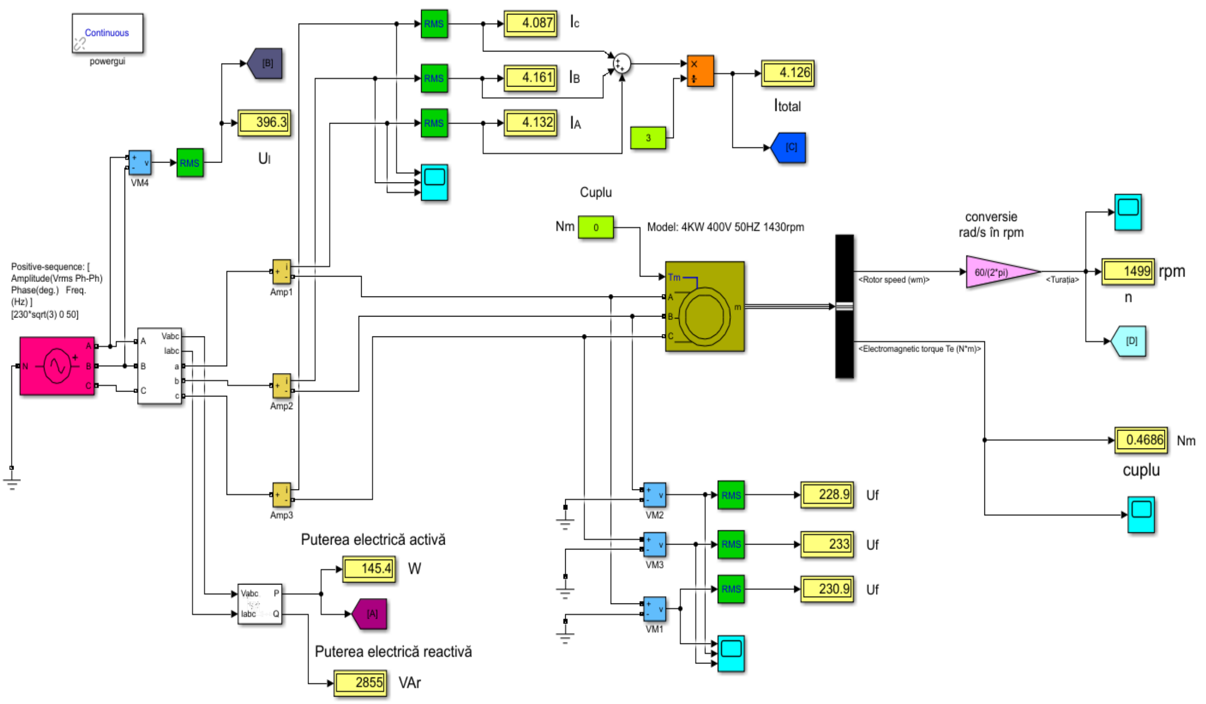


Fig. 2. Carried out model for the no-load test

2.2. Locked rotor test

The realized model and the measurements are shown in *fig*. 3. In this case, the mechanical input has been set the speed, and the imposed value was zero.

The rotor resistance referred to the stator is,

$$R_2' = \frac{P}{3I_1^2} - R_1 \tag{5}$$

The stator leakage reactance and rotor leakage reactance referred to the stator have been considered equals, and they are half of the short circuit reactance,

$$X_{\sigma 1} = X_{\sigma 2}' = \frac{X_{sc}}{2} = \frac{1}{2}\frac{Q}{3I_1^2} \tag{6}$$

Short circuit power factor is determined with the same formula as in no-load regime. Obtained values are: $R_2' = 1.29\Omega$; $X_{\sigma 1} = X_{\sigma 2}' = 1.81\Omega$; $cos\varphi_{sc}$=0.595.

Now, having the stator leakage reactance, the magnetizing reactance can be obtained, and the value is X_m=54.1Ω.

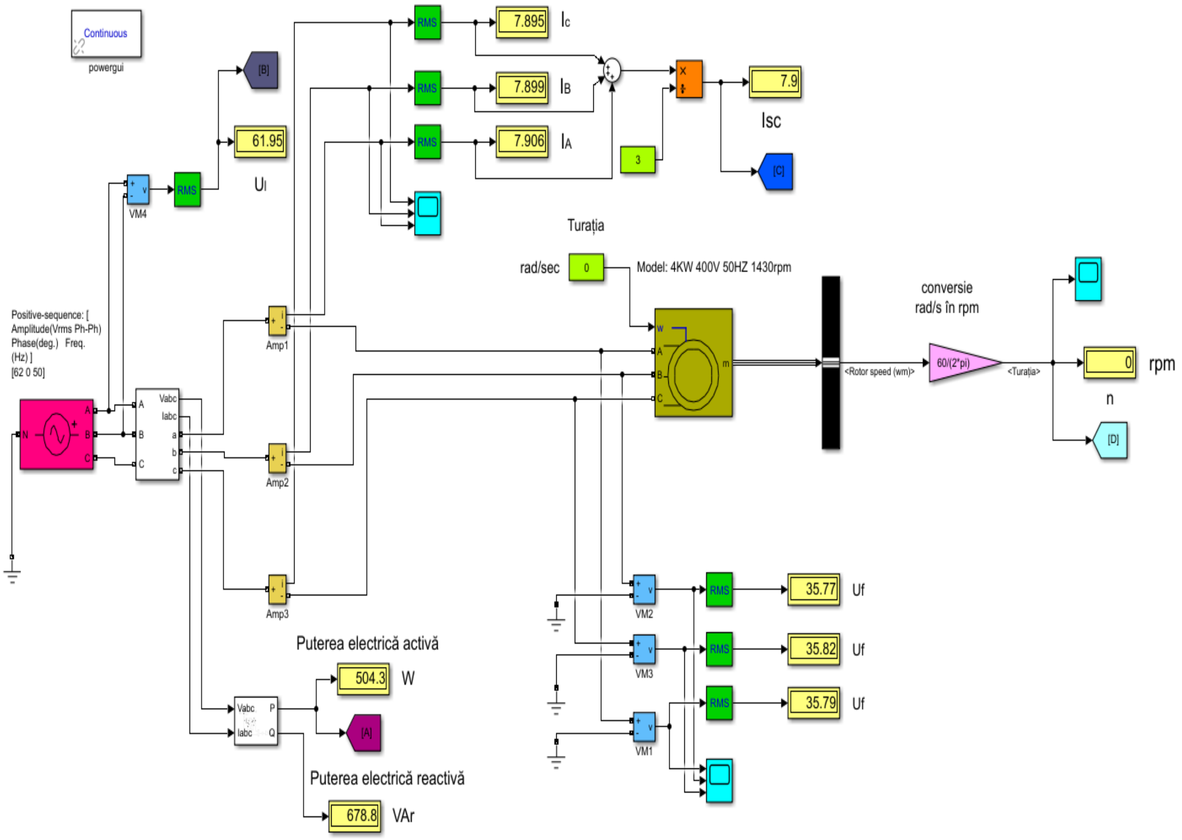


Fig. 3. Model for the locked rotor test test

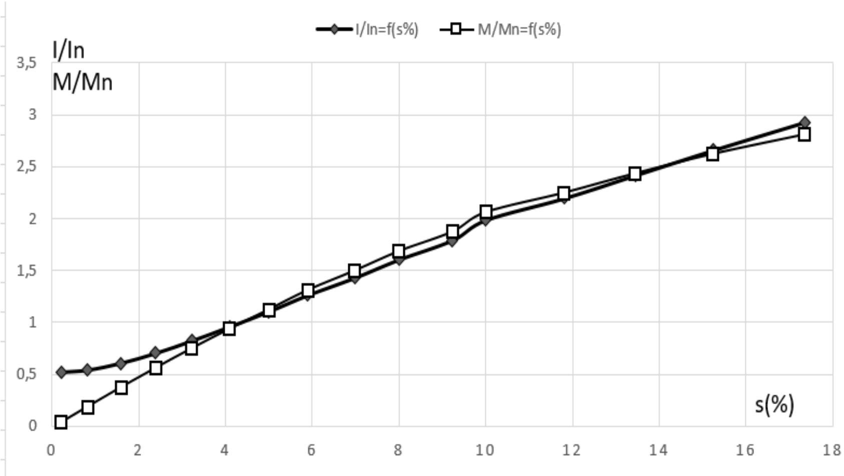
2.3. Load operation

For testing the motor with load, the model from *fig*. 2 has been used, but the imposed torque values was set from very low to more than 150% load. All operation characteristics are obtained, as: I=f(s), η=f(P_2/P_n), *fig*. 4 and Ω=f(M), *fig*. *5*.

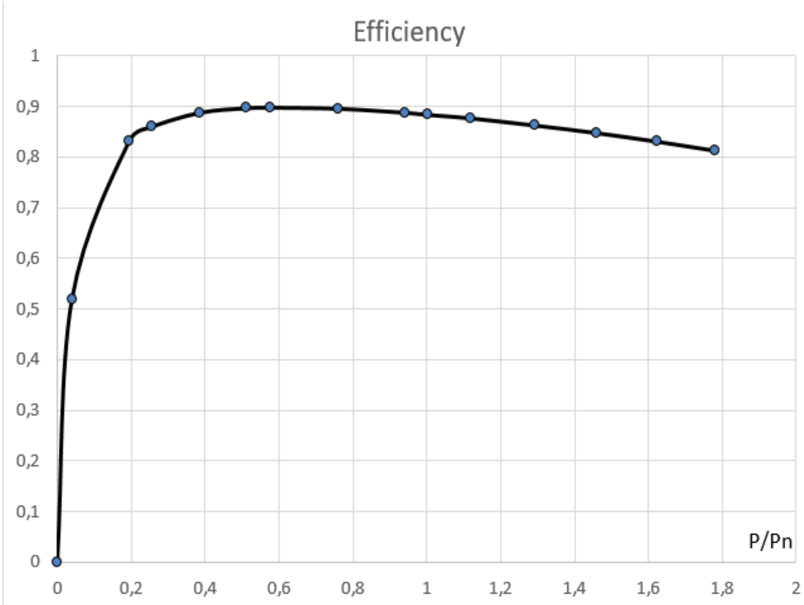
Were noted: s for slip, P_2 for motor mechanical power and P_n for motor rated power, I for stator current and M for electromagnetic torque.

2.4. Mechanical charateristics

In order to obtain the entire natural characteristic M=f(s) (or Ω=f(M)) , the model from *fig*. 3 has to be used, imposing rotor speed so that the slip is in 0…1 range.



a) I/I_n and M/M_n



b) Efficiency

Fig. 4. Load operation characteristics

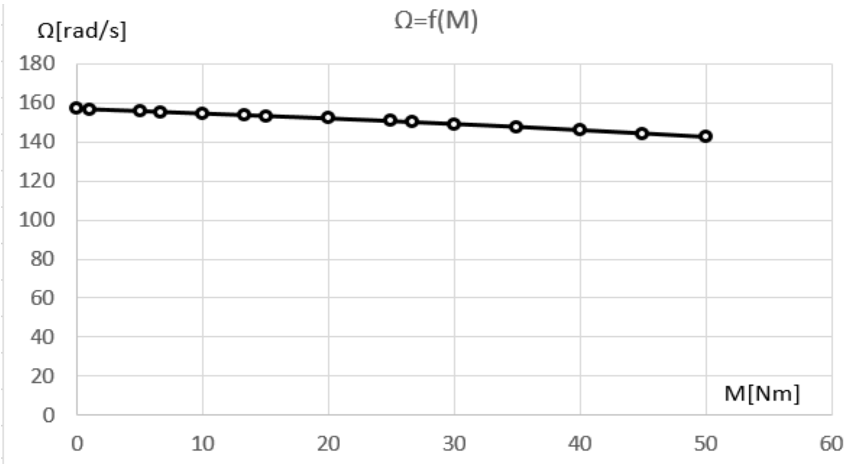


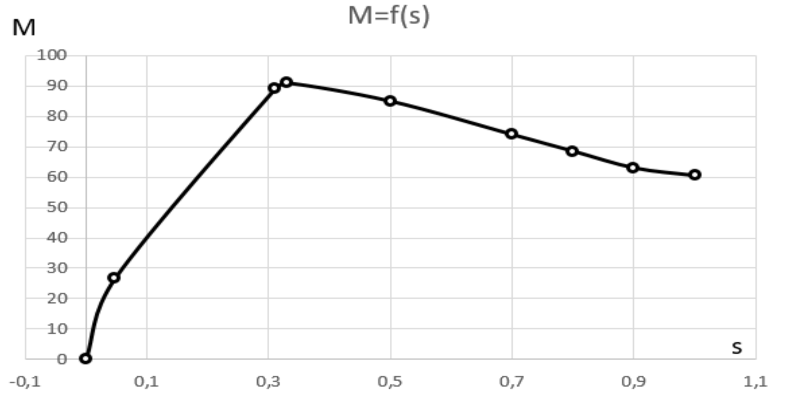
Fig. 5. Natural characteristic Ω=f(M)

The voltage and frequency characteristics are obtained also, varying the voltage amplitude (the frequency being constant) and the voltage frequency (the amplitude kept constant) respectively. *Fig*. 6 shows these characteristics.

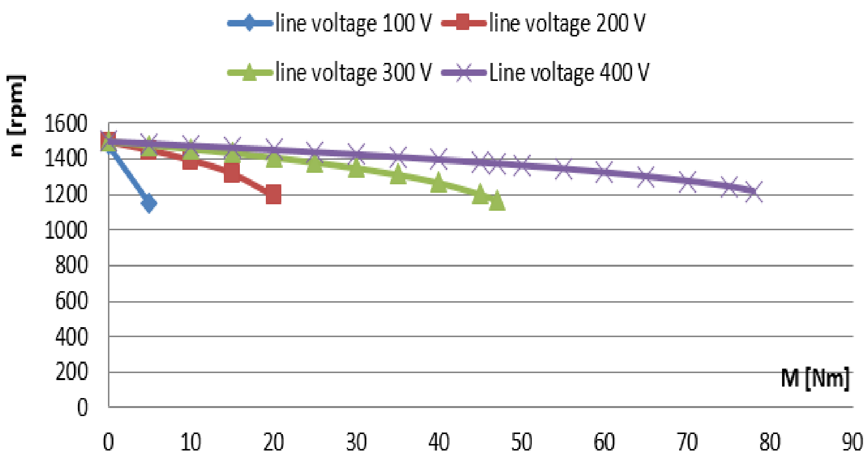
2.5. Optimal operation

Looking to the *fig*. 5, b), it is observed that the rated motor efficiency is 88.4%, so it is in IE3 efficiency class (premium) according to the standard IEC 60034-30-1. But this efficiency is the rated one, so when the motor is underload (lower than 20%), the efficiency decrease rapidly. In order to improve the efficiency when the motor is low loaded, a simple possible solution have been studied, consisting in changing phases connection (from D to Y), resulting a lower phase voltage. This is easy to apply, changing connection in relation with the stator current. So, for D and Y connection, for reduced load torque, the efficiency has been compared, *fig*. 7.

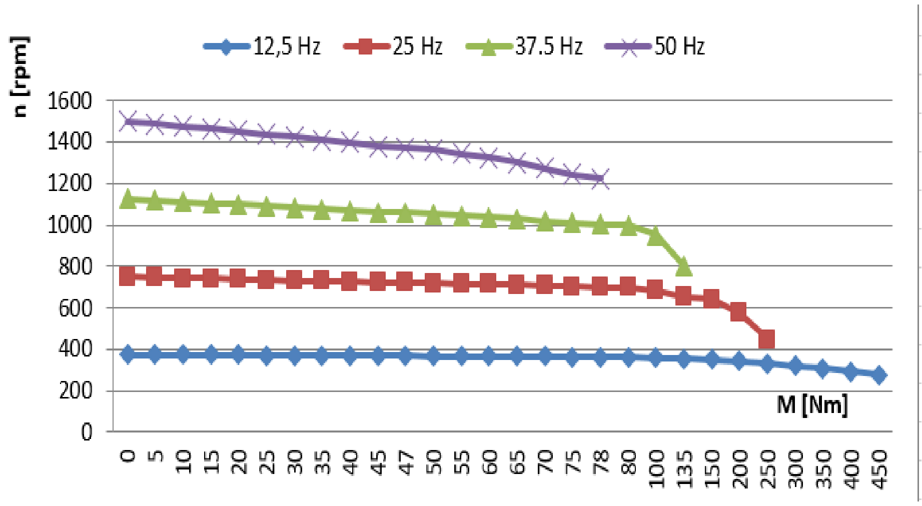
For the studied motor, when the load torque is lower than 22.5% by rated torque, the efficiency is greater when Y connection is chosen. This is generally true for all induction motors, of course the torque percentage may be different.



a)Natural characteristic M=f(s)



b) Voltage characteristics



c) Frequency characteristics

Fig. 6. Mechanical characteristics

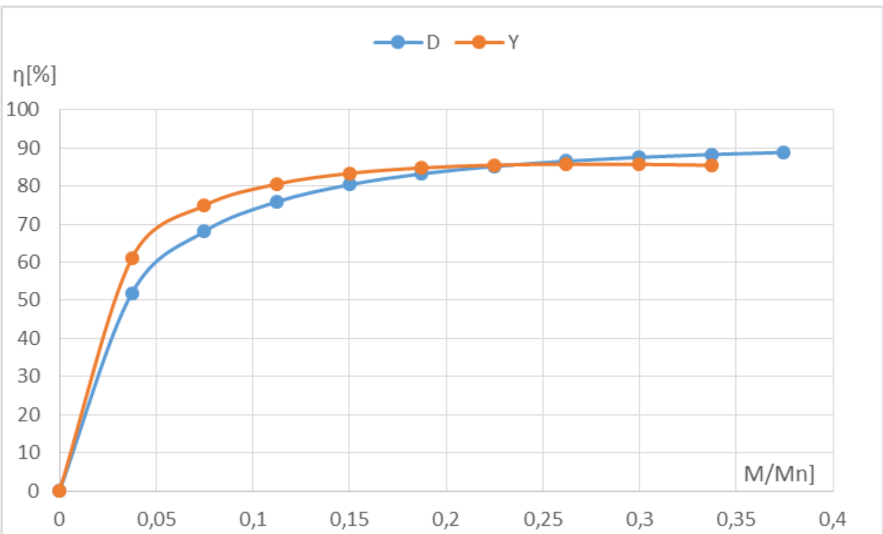
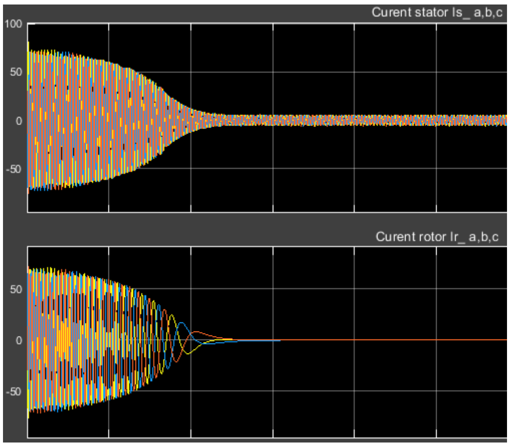
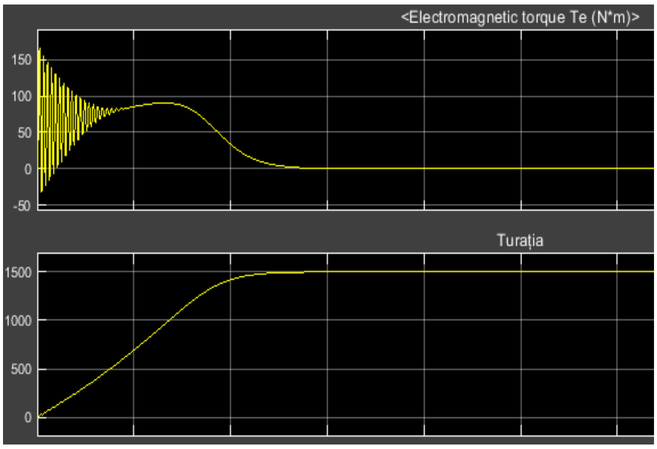


Fig. 7. Efficiency as function of the load torque for D and Y connection

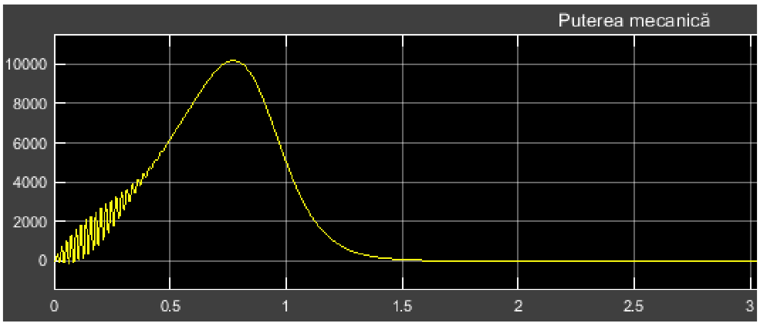
But unlike laboratory tests, where special equipment is needed, in the case of simulations, it is very easy to record transient quantities. In fact, Simulink always works with instant quantities. For example, the variations of some quantities during the starting process of induction motor, are show in *fig*. 8.



a) Stator and rotor currents;



b) Torque and rotor speed (rpm)



c) Mechanical power

Fig. 8. The strating process

3. CONCLUSION

Utilization of Matlab-Simulink for simulation of laboratory tests of induction motor has been presented in this paper. The corresponding models are shown including the measured quantities, and the used formulas are presented. Also, the measured quantities correspond to those from the laboratory tests.

Given that the possibilities of working in the laboratory with the students, considering the global pandemic situation, are very difficult to achieve, we believe that such an approach is very necessary. We are aware that practice cannot be replaced, but in its absence, theory, tests, working methods, and results can be more easily understood by modeling. And the Simulink environment offers unlimited possibilities for modeling and simulating electrical equipment and systems.

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