Graphical User Interface to Plot the Torque Speed Curves of Multiples Cage Induction Motor

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Abstract – **The aim of this paper is to propose an interdisciplinary approach in study of asynchronous machine with multiple cages rotor. There were two reasons to choose as subject of studying the asynchronous motor with multiple/double cages rotor: firstly, because of its large application in fans and water pumps for various industrial and irrigation systems, as well as in lathe and drilling machines, and secondly, because the theoretical background of this subject is a very complex one. Because the torque-speed curve has a crucial importance in improving the performances of a system, the final results of this study is to propose a Graphical User Interface in Matlab which could be used to calculate the characteristics of an asynchronous motor with multiple /double cages rotor. After a brief introduction about the constraints of systems with multiple cage asynchronous motors, paper propose a short review on theoretical background of these machines. The next step will be to underline the designing aspects of the machine and finally to models in Matlab its characteristics. The importance of this work is bringing in attention usual aspects which could be improved by revising in learning process and in new industrial technologies. The results of this work could be used to design a virtual laboratory in area of electrical machine.**

Cuvinte cheie: caracteristica cuplu viteza, rotor cu colivii multiple,rotor cu dubla colivie, pompe, ventilatoare.

Keywords: *torque speed curve, multiple cage rotor, double cage rotor, pumps, fans.*

I. INTRODUCTION

The asynchronous motor with multiple/double cages rotors has a large application in water pumps for various industrial and irrigation systems, as well as in lathe and drilling machines. The most disadvantageous aspect of a normal squirrel cage asynchronous motor is a low starting torque at a relatively high starting current. A response of this weakness is the multiple/double cage induction machine. This is a part of the category of electrical machines where the currents skin effect of the bars manifests, itself, as basic phenomena. The advantages offered by a double cage/multiple cage induction machine are: simple and robust construction, long life expectancy, low investments, low service costs, minimum maintenance, minimum service demand and supervising characteristics and advantageous starting conditions.

A. Performance characteristics

As an important part of the whole system, the induction motor of a pump or fan (for example), must response at a series of their requirements. Between these requirements we can enounce: variable load of the machines; the torque

change as a squared function of speed; the power changes as a cubed function of speed; the developed torque is reduced when the speed is under rated level and increased when speed grows; the precision of pump speed regulation at variation of load depends on the control strategy of the motor and the speed accuracy of the pump/fan has a great impact in its efficiency. The maximum efficiency of the pumps/fans is considered to be when the motor load torque is about 75% of the rated value [3]. To optimize the energy consumption, the pumps/fans must operate at its Best Efficiency Point (BEP).

In every scenarios of optimizing the operation of the system, the characteristic torque-speed curve of the squirrel cage induction motor is very important for its configuration. At the moment of starting, when the sleep is zero, we have the breakaway torque (M_a –figure 1). When speed increase, the torque is reduced up to a minimum value called pull up torque (M_s –figure 1). Then, the speed increase up with the torque respectively, to a maximum value called maximum torque or breakdown torque (M_k – figure 1). From this point, the torque decrease and becomes zero at the synchronous speed.
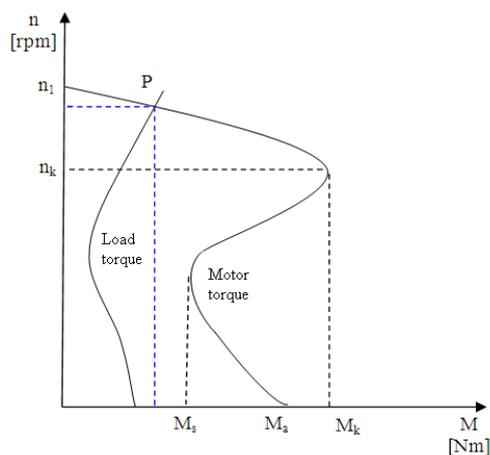

Fig. 1. Characteristic torque-speed curve of the squirrel cage induction

Regarding the mechanical overload limit of the motor, according with IEC 34-1, induction motor must be able to deliver an output power of up to 1.6 time their rated power at rated voltage and frequency for 15 seconds without breaking or any sudden speed drop'[4]. Concerning the allowable minimum torque of three phase induction motors, in accordance with IEC 34-1, for motors of rated power <100kW, is 0.5 times the rated torque, but no lower than the 50% of the starting torque and for motors of rated

power ≥100kW, is 0.3 times the rated torque, but no lower than the 50% of the starting torque [4].

For an appropriate selection of the motor, must be defined, as accurately as possible, the power, torque and the speed of the motor at rated conditions and take account the requirements of the system. When is calculated the torque speed characteristic of a squirrel cage induction motor, is obviously that, the rotor resistance has a significant impact on critical slip, the speed at which maximum torque occur. Due the combination of better features both start and operation, the double cage will be preferred at higher power

II. DESIGN CONSIDERATIONS

A. Construction constraints

Because the needs of various applications impose different characteristics from asynchronous motor, in practice of design, the standards proposed different classes for the induction motor according with its particularities. Designing a double cage induction machine comport a common part of general designing of a squirrel cage induction machine (stator calculus and principles of application of the analytical expressions) and a customize part, regarding the use of appropriate parameters of the rotors in accord with the studied regime of operating. A difficult problem, to be considered in designing process is the influence of magnetic saturation and skin effect of current on rotor's parameters. The presence of two cage impose to be take into consideration this particular aspect.

Double cage rotor has two windings: starting windings with high resistance and low leakage reactance and working windings with low resistance and high leakage reactance. The most usually shapes of these windings are [9] shown in figure 2. The shape of figure 2c is used when the bars are cast aluminum.
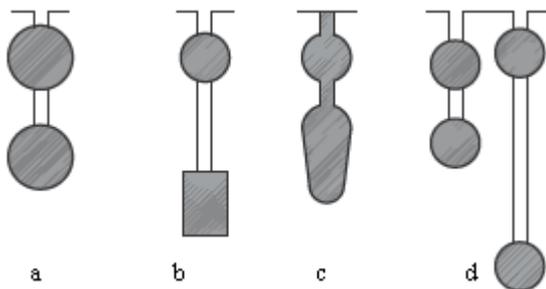
Fig. 2. Slots of multiples cages shape: a-c double cage, d-triple cage

The upper part of the slot, those in which is introduced the starting bars, usually has a circular shape, as shape of minimal resistance, but could be also rectangular. Bottom part, with working bars, could be rectangular or circular. Upper and bottom parts of the slots are linked be a narrow canal named intermediary isthmus. The different value for leakage reactance among the two parts of the slots is assured through the skin effect of currents between the two cages.The two cages could be short-circuited with a common short-circuit ring or an individual short-circuit rings for each cage. Regarding the torque – speed characteristics of the machines the influence of this aspect is neglected because the difference is not a significant one.

This aspect is important when is discussed the mechanical resistance of the cage because of the different heating of two cages. The upper cage is heating more than the bottom cage and the dilatation of this cage is higher. That is way the separate rings of short-circuit is preferred.

B. Aspects of skin effect

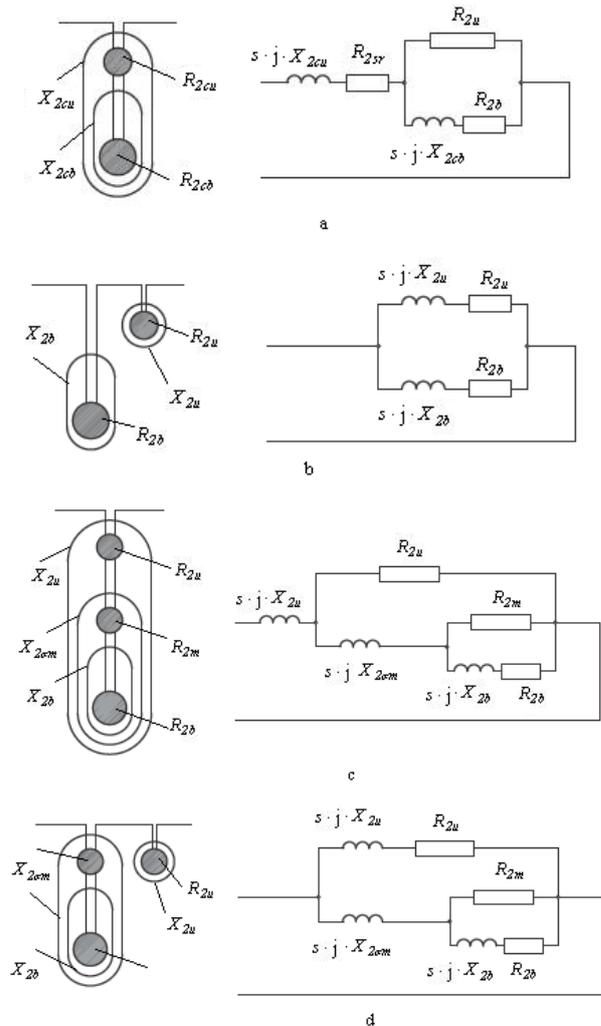The situation of leakage magnetic field is shown in figure 3.

Fig.3. Slots and equivalent schemas of multiples cages rotors: a-b double cage, c-d-triple cage

In figure 3.a is configured a double cage rotor with a single short-circuit ring with resistance R_{2sr}. In figure 3b, 3c and 3d, there are two short circuit rings. Can be easily observed that, the bottom part of the slot, are mostly surrounded with the magnetic field of upper slot, which is closing on the way of the minimum reluctance around the rotor.

At high rotor's frequency, because of leakage inductance, the currents of bottom cage could be neglected while, the currents of upper cage are important. At low frequency, when the leakage inductances could be neglected, the currents in bars are influenced by the bar resistances. For this, the currents in upper bars could be neglected and the currents of bottom bars are important.

III. CALCULATING THE CHARACTERISTICS OF A DOUBLE CAGE ASYNCHRONOUS MOTOR

To calculate the characteristics of a double cage induction motor must be use the equivalent schemas and their parameters definitions. Figure 4 shows the equivalent schema in T for a double cage rotor with separate short-circuits rings. This solution is used to avoid the different dilatation of rotors bars.

The parameters of cage are: $\underline{I}_1$, $\underline{U}_1$ - phase stator current and voltage; R_1,X_1- phase resistance and reactance of stator; R'_{2u} is the phase resistance of starting bars and X'_{2u} is the phase leakage reactance of starting bars when the rotor is reported to the stator, associated to the starting current I'_p, R'_{2b} is the phase resistance of operating/working bars and X_{2b} is the phase leakage reactance of working bars, when the rotor is reported to the stator, associated to the working current I'_b.

R'_{2sr} is the common phase resistance and X'_{2cu} is the common reactance which correspond with the leakage magnetic flux which surrounded the two cages of the rotor; associated to the total current of rotor $\underline{I}'_2$ ($\underline{I}'_2 = I'_p + I'_b$).
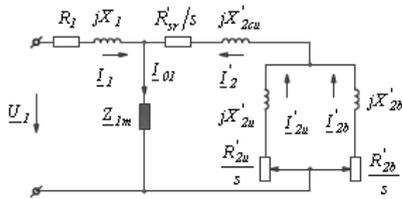

Fig.4. Equivalent schema in T for a double cage rotor with separate short-circuit rings

The equations of multiple cage rotor are wrote in accord with the configuration of the machine (shape of slots and short-circuit ring).

$$R_{sr} = \frac{R_r}{2 \cdot sin^2\left(\dfrac{\pi \cdot p}{Z_2}\right)}$$

$$R_u = \rho_b \cdot \frac{L_u}{S_u} \tag{1}$$

$$R_b = \rho_b \cdot \frac{L_b}{S_b}$$

Common resistance R_{sr} and phase resistances R_u and R_b are influenced by the construction of short-circuit rings of the rotor (equation 1 for common short circuit ring and equation 2 for separate short circuit rings).

$$R_{sr} = 0$$

$$R_u = \rho_b \cdot \frac{L_u}{S_u} + \frac{R_{ru}}{2 \cdot sin^2\left(\dfrac{\pi \cdot p}{Z_2}\right)} \tag{2}$$

$$R_b = \rho_b \cdot \frac{L_b}{S_b} + \frac{R_{rb}}{2 \cdot sin^2\left(\dfrac{\pi \cdot p}{Z_2}\right)}$$

In 1 ρ_u, ρ_b are the resistivity of starting bar, respectively working bar at θ=75°C, for B class of isolation of the stator and θ=115°C, for F class of isolation of the stator [1]. For copper, are those used to find the resistance of stator [1]. In equation 2, the resistances of short-circuit rings are R_{ru} and R_{rb}. The presence of common or separate short-circuit rings have an influence on the expressions of the reactance (equation 3 for common rings and 4 for separate rings).

$$\begin{aligned} X_{2cu} &= X_{\sigma d2} + X_{\sigma co} + X_{\sigma f2} \\ X_{2u} &= X_{\sigma cu} \\ X_{2b} &= X_{\sigma cb} \end{aligned} \tag{3}$$

$$\begin{aligned} X_{2cu} &= X_{\sigma d2} + X_{\sigma co} \\ X_{2u} &= X_{\sigma cu} + X_{\sigma fu} \\ X_{2b} &= X_{\sigma cb} + X_{\sigma fb} \end{aligned} \tag{4}$$

where: $X_{\sigma d2}$ is the reactance of differential leakages of the rotors, $X_{\sigma co}$ is the leakage reactance of the common isthmus for both slots, $X_{\sigma f2}$ is the leakage reactance in frontal parts of cages with common short-circuit rings, $X_{\sigma cu}$, $X_{\sigma cb}$ is the leakage reactance of the upper parts of the cage, respectively of the bottom parts, and $X_{\sigma fu}$, $X_{\sigma fb}$ are the leakages reactance in frontal parts of upper and respectively bottom parts of the cage (according with figure 5).
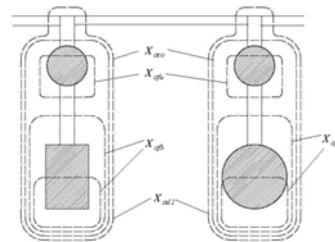

Fig.5. Reactance for a double cage rotor

In the case of machines with constant parameters, the characteristics of operating could be calculated through two methods: analytical method and graph-analytical method (or circle diagram [2], figure 6).
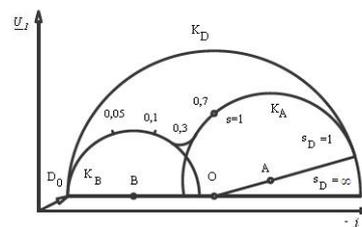

Fig.6. Circle diagram for a double cage rotor

The circle diagram could be obtained by calculating the expression of current $\underline{I}_1$, and varying the slips. Analyzing figure 6, could be seen that the operation of the machine at small slips is made on circle K_B. For slips with values near 1, the machine operates on curve K_A, and for slips between small slips and 1, the machine will operate on an intermediary curve. The circle diagram is preferred in practice, especially in experimental tests, to plot the characteristics of the machines.

To calculate the characteristics for the double cage rotor using the same analytical method as that used for the normal cage and high bars rotors, the equivalent schema in T must be transpose in equivalent schema with the magnetization circuit taken out to the terminals (figure 7) [1]. In this case, in figure 7, between point A and B, will be calculated the equivalent reactance of the rotor reported to the stator (5).
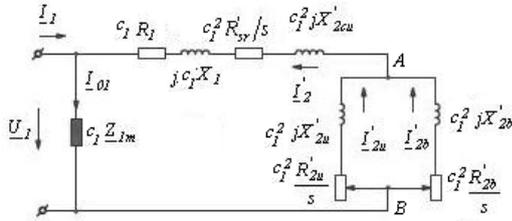

Fig.7. Equivalent schema with the magnetization circuit taken out to the terminals for a double cage rotor

The equivalent schema became those from figure 8 and the impedance of the rotor is 5. To calculate the parameters of machine we start with those equivalent schemas [10], [13], [14].
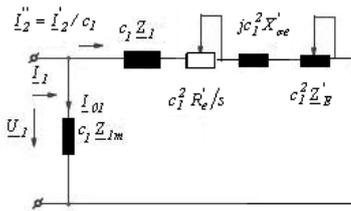

Fig.8. Equivalent schema with the magnetization circuit taken out to the terminals for a double cage rotor

$$\underline{Z}'_E = \frac{R'_E}{s} + jX'_E \qquad . \qquad (5)$$

In 5 could be separated the real part from imaginary parts and will be used a similar expression for the total impedance of the double cage rotor as in the case of a normal cage rotor (8).

$$R'_E = \frac{R'_u \cdot R'_b \cdot R' + s^2 \cdot \left(R'_u \cdot X'^2_b + R'_b X'^2_{pp} \right)}{R'^2 + s^2 \cdot X'^2} \qquad (6)$$

$$X'_E = \frac{\left(R'_u \cdot X'_{\sigma b} + R'_b \cdot X'_{pu} \right) \cdot R' - R'_u \cdot R'_b \cdot X'}{R'^2 + s^2 \cdot X'^2} +$$

$$+ \frac{s^2 \cdot \left(X'_{\sigma u} \cdot X'^2 - X'^2_{pu} \right) \cdot X'}{R'^2 + s^2 \cdot X'^2} \qquad (7)$$

$$\underline{Z}'_2 = \frac{R'_2}{s} + jX'_{\sigma 2} \qquad (8)$$

where:

$$R'_2 = R'_e + R'_E \qquad (9)$$

and

$$X'_{\sigma 2} = X'_{\sigma e} + X'_E . \qquad (10)$$

IV. PROBLEM STATEMENT

To illustrate the theoretical aspects presented above will be considered two kind of asynchronous motors: with single cage and with double cage. In terms of design, those motors have a same stator and the rotors are calculated differently. The equivalent schema with the magnetization circuit taken out to the terminals for the single cage rotor is shown in figure 9.
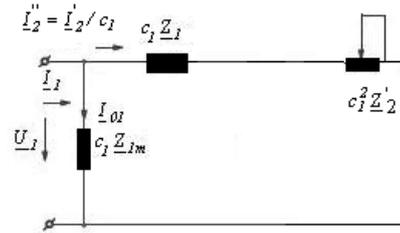

Fig.9. Equivalent schema with the magnetization circuit taken out to the terminals for the single cage rotor

The parameters of the common stator will be: R_1, stator resistance on phase, X_1, stator reactance on phase and X_{1m} reactance of the magnetization circuit. The rotor parameters for the single cage induction motor are: R_2, rotor resistance on phase and X_2, rotor reactance on phase.

The equivalent schema with the magnetization circuit taken out to the terminals for the double cage rotor is shown in figure 7. The rotor parameters for the double cage induction motor are the resistances: R_{2u} is the rotor resistance for upper/outer cage and R_{2b}, is the rotor resistance for bottom/inner cage; and the reactance: X_{2u}, is the rotor reactance for upper/outer cage and X_{2b}, is the rotor reactance for bottom/inner cage.

The problem request is to calculate and plot the torque speed characteristics in two cases of rotor design: for single and double cage.

V. SIMULATIONS AND RESULTS

The paper proposes to use Matlab Software package to calculate and plot the characteristics of a double cage induction motor. To optimize the interaction between script and users was used Graphical User Interface in Matlab to create a graphical interface.

As in [5], the objectives of the simulation are to exploit the full power of GUIDE of Matlab for building characteristics calculator of the asynchronous motor with double cage rotor; to implement data, manipulation, analysis and display; to create full featured graphical interfaces and interactive content and to optimize performance for multi-parameter systems and designs.

The stages of solving the problem are: 1. Introducing the parameters of the motor for two design formulation: double cage and single cage; 2. Generating a vector of speeds for motor operation (0<s<1); 3. Calculating the rotor impedance (resistance and reactance) in two design formulation: single cage rotor and double cage rotor; 4. Calculate the induced torque in two design formulation:

single cage rotor and double cage rotor; 5. Plot the torque speed curves (figures 12, 13); and 6. Create the interface.

To design the interface to calculate the characteristics of the asynchronous generator with a double cage rotor will be used the same steps as in [5]: define the model; discompose the system; laying out the GUI components; programming the GUI components; create a scenario to use the interface in PBL (Project Based Learning) units. For continuity, the background of the interface will be the same as in [5], [6] and [7]. In our example, the finality of laying out the background of the interface is shown in figure 10.

As in [5], the data are separate in two areas on the interface: input data and graphics 'Comparison of speed torque curves for single and double cage induction motor' (figure 11).
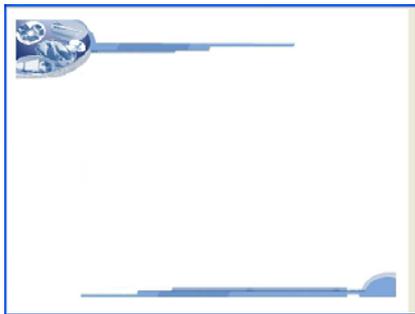

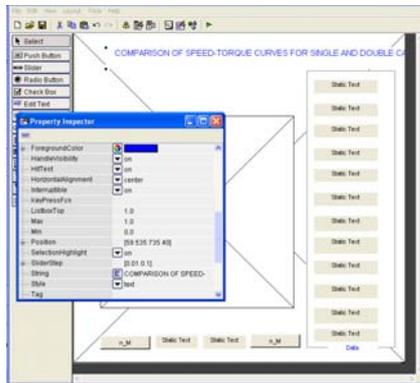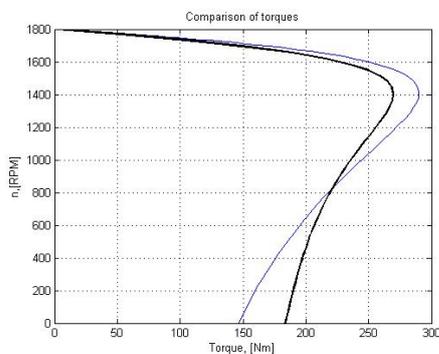Fig.10. Interface background

Fig. 11. Interface designing

Fig. 12. Speed- torque curves for double (black line) and single cage rotor

Esthetical reasons impose to put a 'Data' panel to introduce data and two buttons: M(n) and M(n) to call the graphics: speed-torque curve (figure 12) and torque-speed curve (figure 13).
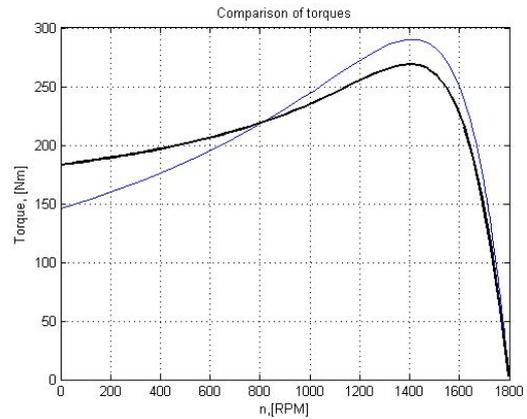

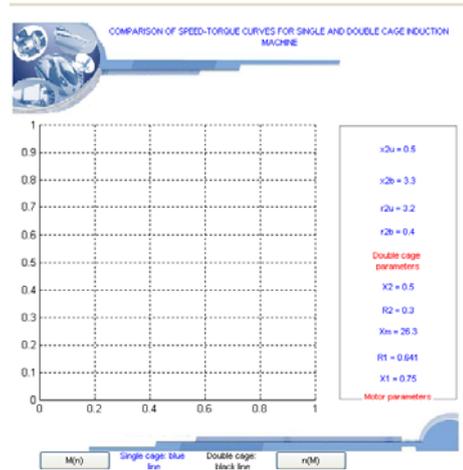Fig. 13. Torque-speed curves for double (black line) and single cage rotor
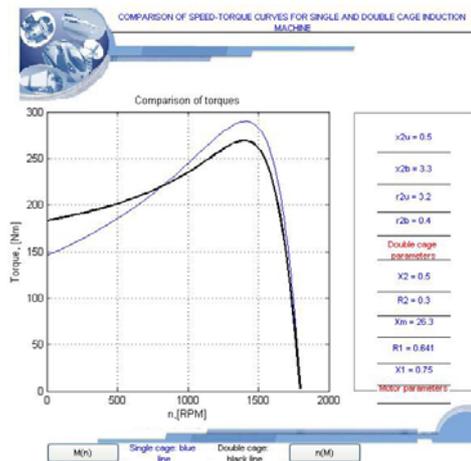

Fig. 13. Interface proposed

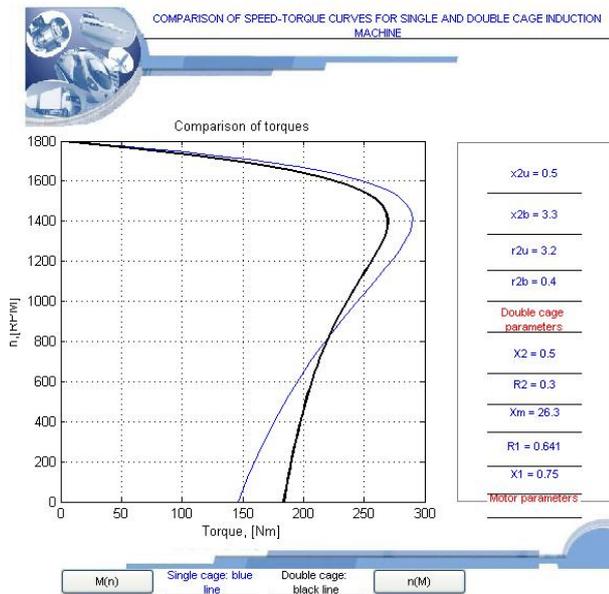Fig. 14. Torque-speed curves called by interface

Fig. 15. Speed- torque curves called by interface

Contribution of authors:

First author – 60%

Coauthor – 40%

VI. Conclusions

The paper proposes a learning tool to study or design an asynchronous motor with double cage rotor.

Using a graphical interface to implement numerical method of calculating the characteristics of an asynchronous motor with double cage rotor is much easier to be applied in different practical situation or learning scenarios.

An important advantage of this interface is that it could be improve to be able to use data from different data base.

A good reason to use this graphical interface is the actual context of industrial environment and educational background characterized by translating into computer mode all data, with declarative aim to increase the efficiency and the quality of process.

The opportunity of this paper is sustained by the need of organized the knowledge in an actual and efficient mode to be easy apply to improve the operation of electromechanical systems.

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