Determination of Asynchronous Machine Parameters by Means of Exhaustive Exploring Method

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Abstract: - This paper presents a new method for obtaining the values of the asynchronous machines parameters by means of the quantities acquired during a direct coupling to the mains. The method principle and an experimental implementation of it are detailed. The results obtained this way are compared to the ones resulted by using the classical methods. Finally the conclusions are presented.

Key-Words: - induction machine, parameters, method, simulation, experiment, comparisons.

1 Introduction

An ever greater number of speciality papers ([2], [3], [10] etc.) have lately presented different methods for obtaining the asynchronous machines parameters values, other ones than the classical ones. This family also comprises this method, which uses data acquired during a no-load starting and the mathematical model without considering the saturation and the iron losses.

In accordance with this method, the parameters computation will be reduced to a problem of optimization.

To optimize means to find the best solution from all possible solutions, from an established point of view, for a problem or for a decision situation.

In order to find the optimum three different stages must be crossed:

- to elaborate the mathematical model;
- to build the objective function;
- to search the optimum.

The stage in which the mathematical model is elaborated has got a special importance and, for this reason, in the most cases, the main effort and the most important amount of labour in the frame of an optimization problem is focussed on the problem knowledge and its quantitative description. The mathematical model is formed of a relations system containing the interdependences existing between the "n" variables of the problem.

The objective function is not anything else but a representation of variables, usually an analytical one.

To obtain the optimum solution involves the utilization of a searching method adequate for the mathematical model form and for the objective function, corresponding to the available computation facilities and in accordance with the researcher's knowledge and experience.

2 Computation method

The proposed method involves the acquisition of the A and B phase voltages, of the A and B phase currents, as well as of the speed, during the transient process of no-load starting of an induction motor. So, we have the currents and the speed determined experimentally (noted with index e) and the currents and the speed obtained by computation by integrating the induction machine mathematical model, which will be presented further on (noted with index c).

These ones will be used for building an objective function which will be minimized with the help of a specialized algorithm.

The point corresponding to this minimum, contains the searched values of the induction machine parameters.

2.1 Mathematical model elaboration

The mathematical model used in this situation is the one containing the voltages and fluxes equations, in the two-axes theory, with per unit quantities and in a reference frame solidary with the induction machine stator, to which the motion equation is added [7].

These equations can be written in the matrix form, too:

$$\begin{vmatrix} L_s & 0 & L_{sh} & 0 & 0 \\ 0 & L_s & 0 & L_{sh} & 0 \\ L_{sh} & 0 & L_r^/ & 0 & 0 \\ 0 & L_{sh} & 0 & L_r^/ & 0 \\ 0 & 0 & 0 & 0 & \dfrac{J}{p} \end{vmatrix} \frac{d}{dt} \begin{vmatrix} i_{sd} \\ i_{sq} \\ i_{rd}^/ \\ i_{rq}^/ \\ \omega \end{vmatrix} =$$

$$= \begin{vmatrix} u_{sd} - R_s i_{sd} \\ u_{sq} - R_s i_{sq} \\ u_{rd}^/ - R_r^/ i_{rd}^/ - \omega(L_r^/ i_{rq}^/ + L_{sh} i_{sq}) \\ u_{rq}^/ - R_r^/ i_{rq}^/ + \omega(L_r^/ i_{rd}^/ + L_{sh} i_{sd}) \\ \dfrac{3}{2} p L_{sh}(i_{sq} i_{rd}^/ - i_{sd} i_{rq}^/) + m_r \end{vmatrix} \quad (1)$$

By noting the constant matrix with $|A|$, the matrix of the unknown quantities with $|X|$ and the matrix from the second member with $|Y|$, the brief form is obtained:

$$|A| \frac{d}{dt} |X| = |Y|, \quad (2)$$

or, equivalently:

$$\frac{d}{dt} |X| = |A|^{-1} |Y|. \quad (3)$$

In these equations, if the rotor is in short-circuit ($u_{dr}^/ = u_{qr}^/ = 0$), u_{ds} and u_{qs}, obtained for the particular case β_B, are:

$$u_{ds} = u_{Ae};$$
$$u_{qs} = \frac{1}{\sqrt{3}} u_{Ae} + \frac{2}{\sqrt{3}} u_{Be}. \quad (4)$$

The computed values of the A and B phase currents are determined for the situation when there are not components of null succession and $\beta_B = 0$:

$$i_{Ac} = i_{ds}; \qquad i_{Bc} = -\frac{1}{2} i_{ds} + \frac{\sqrt{3}}{2} i_{qs}. \quad (5)$$

Moreover, the rotor angular speed is computed in the following manner:

$$\Omega_c = \frac{\omega}{p}. \quad (6)$$

The programming medium MATLAB has been used for the numerical simulation of the induction machine on the basis of these equations. An integration sub-routine for the differential equations has been carried out on the basis of the mathematical model presented before.

2.2 Objective function building

The used objective function is built for having minimum value when the mathematical model answer is closed to the data obtained experimentally. In other words, it must be minimum when the areas delimited by the graphics of the longitudinal and transversal components of the stator current phasor (determined experimentally and by computation), respectively between the ones of the speeds (determined experimentally and by computation) are minimum.
So, the objective function has got the form:

$$f(\bar{x}) = \int_0^{t_{\max}} \left[(i_{Ae} - i_{Ac})^2 + (i_{Be} - i_{Bc})^2 + k(\Omega_e - \Omega_c)^2 \right] dt \quad (7)$$

where :
- $\bar{x} = (R_s, R_r^/, L_s, L_r^/, L_{sh}, J)$;
- k is a weight chosen in a convenient way by the programmer.

The weight k is chosen inside the interval (1, 2) (greater when the speed curve is wanted to be approximated as exactly as possible) because, in general, in the automatic control systems the term containing the two speeds difference is the most important one.
The objective function is a combined criterion because it is described as a sum of squares. As a consequence, as [2] shows, its minimum belongs to R^+.

2.3 Optimum search

Among several methods for the determination of an objective function minimum, for our concrete situation, the exhaustive exploring method will be presented.
The authors of this paper has also used other minimization methods in other papers, the algorithms COMPLEX [4] and SIMPLEX [5]. This method has the advantage that ensures a higher precision for the optimum computation (it provides the absolute minimum of the function).
The other variants allow the minimum computation in a much reduced time. One or other from the two possibilities is chosen, depending on the concrete existing conditions.

When the exhaustive exploring method is used, the searching is done in orderly way, on the basis of a program established at the beginning.

In principle, the method involves to cross the following stages:

a) The objective function definition domain is established and in this domain the points ("space nodes") where the objective function will be evaluated will be chosen.

b) The search step on each direction will be established:

$$\Delta R_s = \frac{R_{s\max} - R_{s\min}}{n_{R_s}} \; ; \; \Delta R_r^{/} = \frac{R_{r\max}^{/} - R_{r\min}^{/}}{n_{R_r^{/}}}$$

$$\Delta L_s = \frac{L_{s\max} - L_{s\min}}{n_{L_s}} \; ; \; \Delta L_r^{/} = \frac{L_{r\max}^{/} - L_{r\min}^{/}}{n_{L_r^{/}}} \quad (8)$$

$$\Delta L_{sh} = \frac{L_{sh\max} - L_{sh\min}}{n_{L_{sh}}} \; ; \quad \Delta J = \frac{J_{\max} - J_{\min}}{n_J} \, ,$$

where n_{R_s}, $n_{R_r^{/}}$, n_{L_s}, $n_{L_r^{/}}$, $n_{L_{sh}}$, n_J are the number of intermediate points on each direction where the objective function is computed, points chosen conveniently in function of the expected precision.

c) The search will be initialized starting from the point of minimum:

$\bar{x}_{\min} = (R_{s\min}, R_{r\min}^{/}, L_{s\min}, L_{r\min}^{/}, L_{sh\min}, J\min)$.

In order to pass from one search point $\bar{x}_1 = (R_{s1}, R_{r1}^{/}, L_{s1}, L_{r1}^{/}, L_{sh1}, J_1)$ to another one $\bar{x}_2 = (R_{s2}, R_{r2}^{/}, L_{s2}, L_{r2}^{/}, L_{sh2}, J_2)$, a single component of the search point is modified. This thing gives the search an orderly character and makes it easy to be followed.

The total number of search points, therefore evaluations, of the objective function are determined with the relation:

$$N = (n_{R_s} + 1)(n_{R_r^{/}} + 1)(n_{L_s} + 1)(n_{R_r^{/}} + 1)(n_{L_sh} + 1)(n_J + 1) \quad (9)$$

By evaluating the objective function in all the network nodes, an **overall computation minimum** is obtained, which is the **real minimum** of the function. The finer the search step on each orthogonal direction of the search domain is, the highest the precision of the real minimum determination is.

3 Experimental scheme

In order to carry out the tests comprised in this paper, a computerized micro-bench has been conceived and carried out; its general view is depicted in the figure 1.

In order to determine the induction machine parameters by the original method presented before, the electrical scheme from the figure 2 has been carried out.

The scheme is made around a data acquisition board DAS 1601.

This analogical and digital high speed interface has been assembled inside a computer allowing, with the help of a program conceived in Matlab, both the acquisition and the adequate data processing.

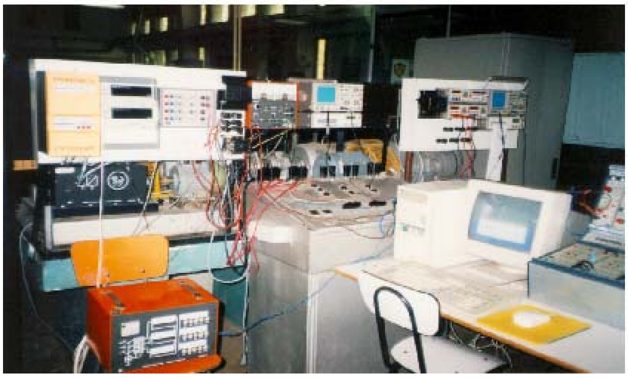

Fig. 1. General view of the computerized micro-bench for induction machines tests.

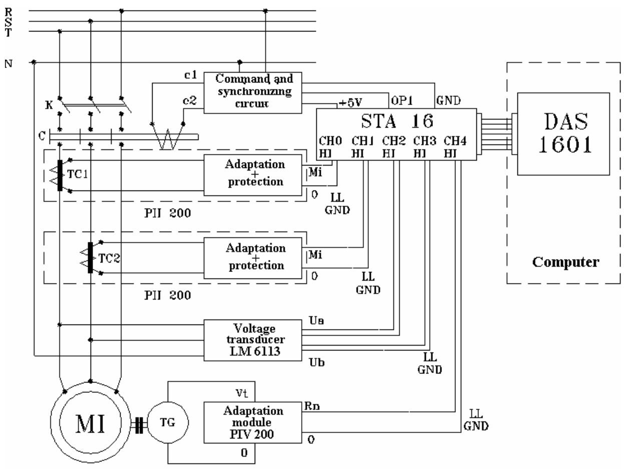

Fig. 2. Connections scheme.

The significances of the blocks used in the previous figure are presented further on.

The command and synchronizing circuit ensures the data acquisition starting before the motor starting. The delay occurring between the two moments is then corrected software.

The module PII 200 has been used to adapt the measured currents to the values required by the board.

It contains a current transformer in whose secondary there is connected a calibrated resistance on which a voltage drop of maximum $\pm$10 V occurs.
The speed-indicator generator TG is a direct current permanent magnets one, providing a voltage proportional with the machine speed (100 V at 1500 r.p.m).
The module PIV 200, as PII 200 too, belongs to the didactic bench CMA 200. It contains a block, endowed with a calibrated voltage divider, allowing the adaptation of the speed-indicator generator output voltage, $V_{t,}$ to values which are not dangerous for the acquisition board.
The voltage transducer LM 6113, carried out with operational amplifiers, has been used for measuring the motor A phase voltage, an adequate galvanic separation being ensured. It contains four transducer modules allowing the simultaneous acquisition of four voltages with values up to 700 V.

4 Results and conclusions

The results from the table 1 have been obtained with the help of the classical methods for the determination of the induction machine parameters, presented in the speciality literature.

Table 1

Parameter	R_s	R'_r	L_s	L'_r	L_{sh}	J
Value	8.35	5.92	0.512	0.512	0.48	0.004

By using these data, the dynamic regime of no-load starting by direct coupling to the supply mains has been then simulated, this one being compared to the results obtained experimentally (fig. 3, 4 5, 6, 7 and 8).

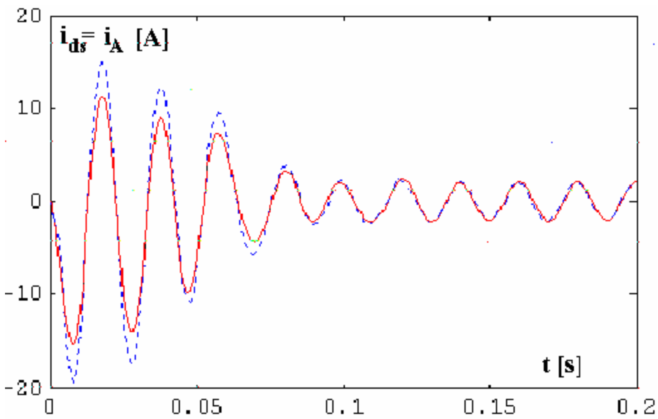

Fig. 3. Components i_{ds} determined experimentally (blue) and by simulation (red).

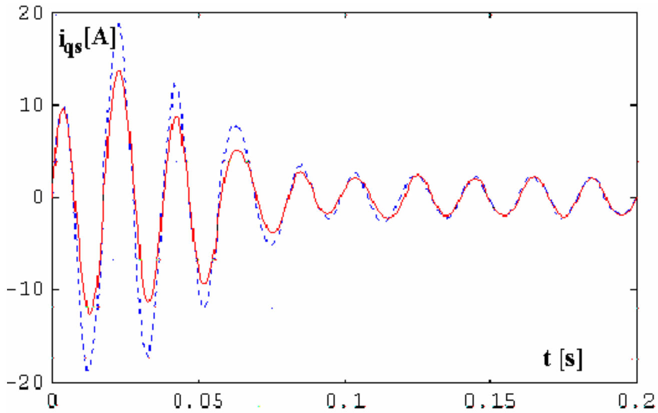

Fig. 4. Components i_{qs} obtained experimentally and by simulation.

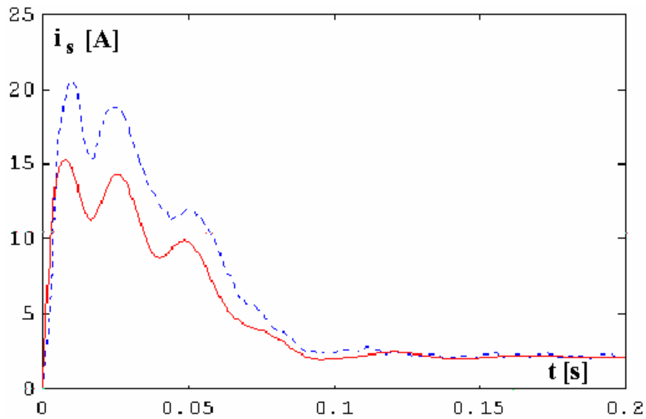

Fig. 5. i_s computed with the help of the experimental values (blue) and of the simulated ones (red).

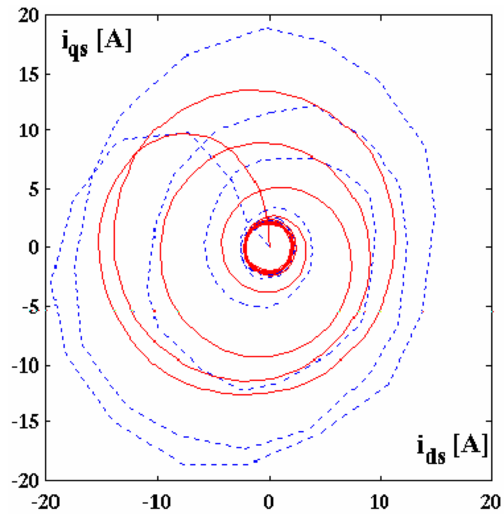

Fig. 6. Dependences iqs=f(i_{ds}) corresponding to the two cases.

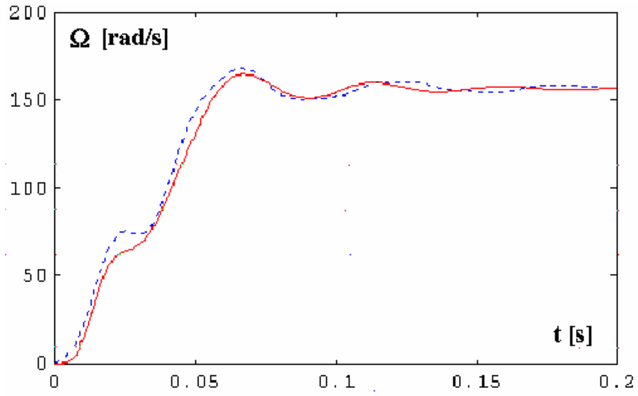

Fig. 7. Angular speeds determined experimentally (blue) and by simulation (red).

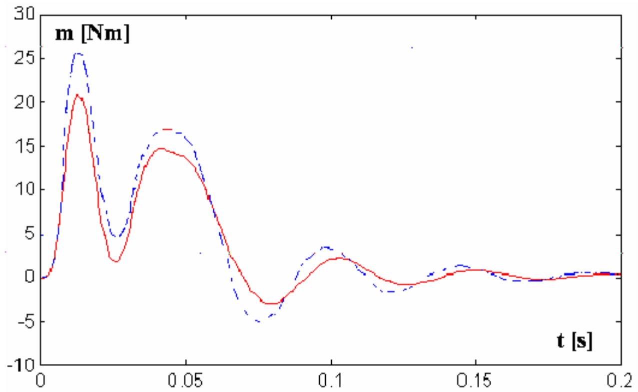

Fig. 8. Dependences torque versus time, in the considered situations.

By running the program conceived with the help of the objective function minimization algorithm for the case of a motor rated at 1,1 kW, the following parameters have been obtained:

Table 2

Parameter	R_s	R'_r	L_s	L'_r	L_{sh}	J
Value	8.35	5.5	0.548	0.508	0.498	0.004

It has to be mentioned that these parameters must not be regard as being even the real parameters of the machine, but that set of values which, for the respective mathematical model, provides the answer which is the closest to the real one by simulating.

The answer of the induction machine mathematical model in the case of no-load starting has been simulated by using these parameters (fig. 9 and fig 10).

The method proposed for the determination of the induction machine parameters, has the following **conclusions**, as the previous sections have already shown:

- it requires a very low energetic consumption;
- it provides an estimation precision which is superior over the similar methods approached in the literature;
- it may be used successfully both for the determination of the squirrel cage induction machine parameters and of the phase-wound rotor ones.
- in function of the user's request (reduced computation time or low computation error) the minimization of the objective function can be made with the algorithms COMPLEX, SIMPLEX or with the method detailed before.

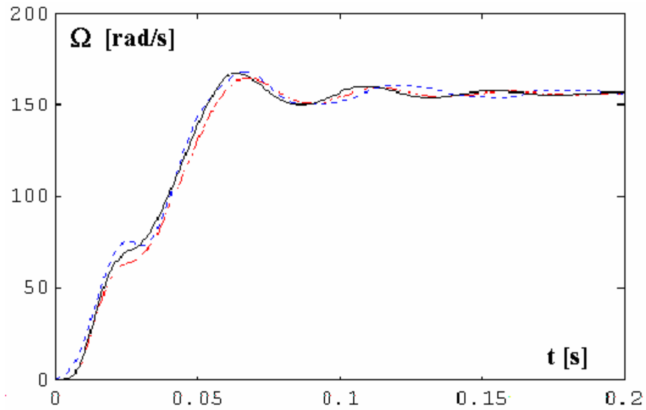

Fig. 9. Angular speed determined experimentally (blue), by simulating with parameters determined classically (red) and by simulation with parameters resulted by optimization (black).

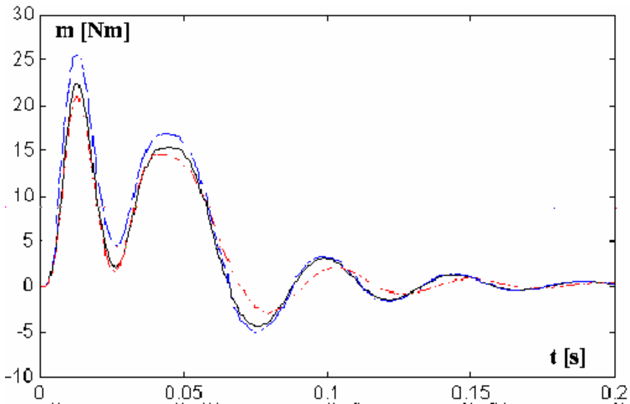

Fig. 10. Dependence m(t) for three cases presented before.

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