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COMPARISON OF THE PERFORMANCE CHARACTERISTICS OF AN INDUCTION MOTOR, THE PARAMETERS OF WHICH ARE DETERMINED EXPERIMENTALLY AND BY A GENETIC ALGORITHM

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Abstract: In the present study, the parameters of the T-shaped equivalent circuit of an induction motor (IM) are defined by way of experiment and by using a genetic algorithm. An algorithm is constructed for obtaining data about the performance characteristics of an IM through models created in the Matlab/Simulink environment. A virtual setup is developed by means of which a comparison is made of the performance characteristics of an IM, the parameters of which are obtained experimentally and by a genetic algorithm. The relative errors for the studied values are determined and reasonable grounds are given for the possibility of using a genetic algorithm to determine the parameters of the equivalent circuit.

Key words: *induction motor, Matlab/Simulink, genetic algorithm*

INTRODUCTION

In order to compute the performance and mechanical characteristics of induction motors and determine their efficiency at different loads, the exact values of the parameters (resistance and inductive reactance of the stator and rotor windings and of the magnetizing circuit) from the equivalent circuit of an induction motor (IM) have to be known.

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For determining the equivalent circuit parameters of IM, a number of methods have been created and new ones are continuously being developed. Most generally, these methods can be classified in two groups: analytical and experimental.

The analytical methods, according to the data that are used for determining the equivalent circuit parameters, are as follows: method based on the motor nameplate data; method of catalog data; method of reference data; etc.

The classic experimental method is based on data from the no-load test and short-circuit test and is difficult to apply in practice but the parameters defined through it correspond with high accuracy to the specific motor being tested. New contemporary experimental methods for determining the parameters of IM have been developed that allow avoiding the carrying out of no-load and short-circuit tests. In some, a genetic algorithm is used [1, 2], which optimizes the data from measurements at different loads of the supply voltage, current, power consumption, stator winding resistance, and rotational speed, in order to obtain the parameters of the T-shaped equivalent circuit.

The purpose of this study is by means of a virtual setup to take and compare the data necessary to build the performance characteristics of an induction motor (IM), with the parameters of the T-shaped equivalent circuit being determined by two different methods – experimentally and by using a Genetic Algorithm (GA).

MATERIAL AND METHODS

A block diagram is given in Fig. 1, in which the steps for obtaining data about the performance characteristics of an IM by means of a virtual setup are specified. The IM parameters are determined by two different methods –experimentally, and by using a Genetic Algorithm (GA). During the first step, experiments have been held in laboratory conditions with an induction motor (IM) of the type 1LA9083-2KA60, energy efficiency class EEF1, with the following catalogue data: Rated power $P_r = 1,1\ kW$, rotational speed $n_r = 2860\ min^{-1}$, rated voltage $U_r = 400V$, rated current $I_{lr} = 2,1A$, efficiency $\eta = 0,85$, power factor $cos\ \varphi = 0,89$, delta connection of the stator winding. To compute the parameters of the *T*-shaped circuit (Fig. 2) of the *IM* based on experimental data, the methodology described in [3] is applied.

The necessary input data according to the methodology are as follows: rated nameplate data of the IM, stator winding resistance, no-load and short-circuit test results. The no-load test provides the measured values for the current I_o, voltage U_o and power P_o at rated voltage, and the short-circuit test provides the current I_k, voltage U_k and power P_k at rated current.

The stator winding resistance R_l is measured using a measuring bridge or by the ammeter and voltmeter method with *DC* supply.

Based on the data obtained in the experimental study of the *IM*, the values of resistance and inductive reactance of the stator winding $R_l = 13,16\Omega$, $X_l = 18,05\Omega$, and rotor winding $R_2' = 20,03\Omega$, $X_2' = 18,05\Omega$ and of the magnetizing circuit $X_\mu = 799,31\ \Omega$ have been measured by the methodology, described in [3].

In order to determine the parameters of the T-shaped equivalent circuit of the IM using a GA (second step in Fig.1) the objective function is necessary to be selected, by means of which to obtain results similar to the ones produced experimentally.

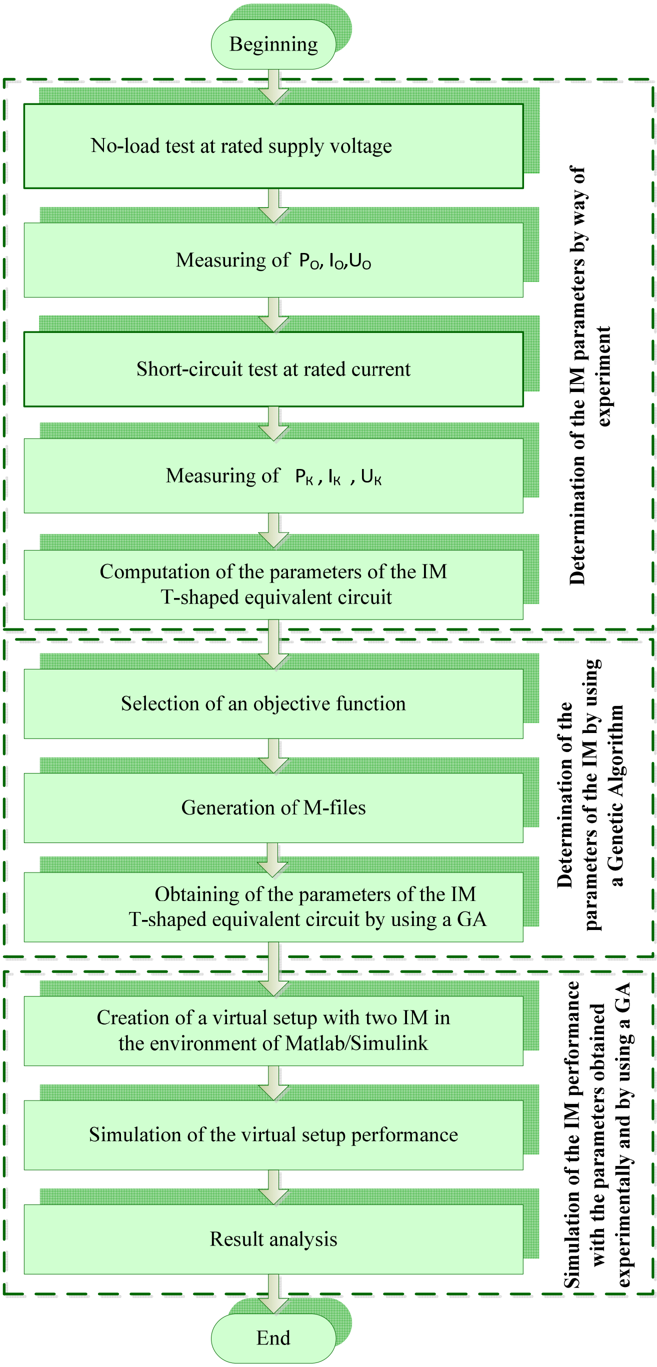

Figure 1. Algorithm for obtaining data on the IM performance characteristics using models in the Matlab/Simulink software environment

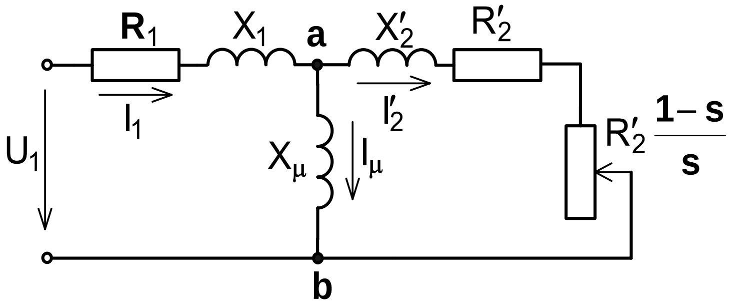

Figure 2. T – shaped equivalent circuit of an IM

RESULTS AND DISCUSSION

To create the objective function, it is necessary to define the equivalent resistance R_{eq}, the equivalent inductive reactance X_{eq} and the impedance Z_{eq} of the equivalent circuit using the following formulas:

$$R_{eq} = R_1 + \frac{\frac{X_\mu^2 R_2'}{s}}{\left(\frac{R_2'}{s}\right)^2 + \left(X_2' + X_\mu\right)^2}; \quad (1)$$

$$X_{eq} = X_1 + \frac{\left(\frac{R_2'}{s}\right)^2 X_\mu + X_2' X_\mu \left(X_2' + X_\mu\right)}{\left(\frac{R_2'}{s}\right)^2 + \left(X_2' + X_\mu\right)^2}; \quad (2)$$

$$Z_{eq} = \sqrt{R_{екв}^2 + X_{екв}^2}. \quad (3)$$

In the M-file of the GA, the power factor $cos\ \varphi$, current consumption I_l, power consumption P_l are computed by the formulas:

$$I_1 = \frac{U_1}{Z_{екв}}; \quad (4)$$

$$cos\,\varphi = cos\left(arctan\,g\frac{X_{екв}}{R_{екв}}\right); \quad (5)$$

$$P_1 = 3U_1 I_1\, cos\ \varphi\ . \quad (6)$$

For the study, the following objective function is selected, where n is the number of data groups:

$$F = \sum_{i=1}^{n}\left(\frac{cos\ \varphi_{ie}}{cos\ \varphi_{iм}} - 1\right)^2 + \sum_{i=1}^{n}\left(\frac{I_{1ie}}{I_{1iм}} - 1\right)^2 + \sum_{i=1}^{n}\left(\frac{P_{1ie}}{P_{1iм}} - 1\right)^2 \quad (7)$$

The measured values are marked with an index „*e*“, while the values computed through *GA* have an index “*m*”. The experimentally obtained data for I_{lie}, $\cos \varphi_{ie}$, P_{lie} and slip serve as input data to the *GA*. To determine the objective function optimum value (7), I_{liM}, $\cos \varphi_{iM}$ and P_{liM} are computed from the equations (4), (5) and (6). Output data of the *GA* are the parameters of the *T*-shaped equivalent circuit.

This paper presents the solution of the optimization problem by a GA using two sets of experimental data. They are obtained from the study of an IM in laboratory condition for two different loads (P_2/P_2r) – 28,18% and 93,80%. The IM is loaded by a separately excited DC generator. The resulting values for the phase voltage U_1, current I_1, power consumption P_1, rotational speed *n*, power factor $\cos \varphi$, motor shaft effective power P_2 are given in Tab. 1.

Table 1. Experimental results from the load test of an IM of EEF1 energy class

U_1 [V]	I_1 [A]	P_1 [W]	n [min^{-1}]	P_2 [W]	$\cos\varphi$ [-]	P_2/P_{2r} [%]
391	*0,570*	*374,1*	*2960*	*310,00*	*0,559*	*28,18*
391	*1,215*	*1266,0*	*2846*	*1031,85*	*0,887*	*93,80*

For solving the optimization problem, limitations are set on the equivalent circuit parameters. The range is specified within which their values change in relative units [4].

An M-file is generated that includes the object function, the experimental data from Tab. 1, and the basic dependencies (1) to (7) determined according to the circuit in Fig. 2. The solution of the optimization problem using a Genetic Algorithm produces the following values for the resistance and inductive reactance of the stator winding: $R_l = 15{,}99\ \Omega$, $X_l = 16{,}56\ \Omega$ and rotor winding: $R_2' = 18{,}44\,\Omega$, $X_2' = 16{,}56\,\Omega$ and for the magnetizing circuit $X_\mu = 775{,}59\ \Omega$.

At the third step of the algorithm described in Fig. 1, a virtual setup (Fig. 3) is created, with two *IM*, *AD1* and *AD2*, and the performance of the setup at different loads is simulated. The parameters of the equivalent circuit of *AD1* are determined experimentally, while those of *AD2* – by a *GA*. The proposed setup is used to compare the performance characteristics of the two motors.

For the designing of the stand, two completed blocks of a three-phase induction machine, designated as *AD1* and *AD2*, are used. The motors are powered by a Three-Phase Programmable Voltage Source. At the output of the Machines Measurement Demux1 and Machines Measurement Demux2 blocks information is obtained about the currents in the stator winding in different coordinate systems, the angular speed, electromagnetic torque, other state variables, which are fed to the input of the developed Performance 1 and Performance 2 subsystems. They are used to obtain data about the current consumption I_1, power consumption P_1, power factor $\cos \varphi$, rotational speed *n*, efficiency, motor shaft torque M_2, motor shaft effective power P_2 that are necessary to construct the performance characteristics of the induction motor.

The data about the performance characteristics of an IM, the parameters of which are determined experimentally and by a *GA*, are compared using the relative error δ. Its percentage value is computed by the developed subsystem Relative error that has 14 inputs and 3 outputs. The relative error δ of the studied values is computed by the formula:

$$\delta = \left| \frac{x_2 - x_1}{x_1} \right| 100, \%, \quad (8)$$

where X_1 is the value obtained from simulation on the virtual setup for *AD1*, while X_2 is the value obtained for *AD2*.

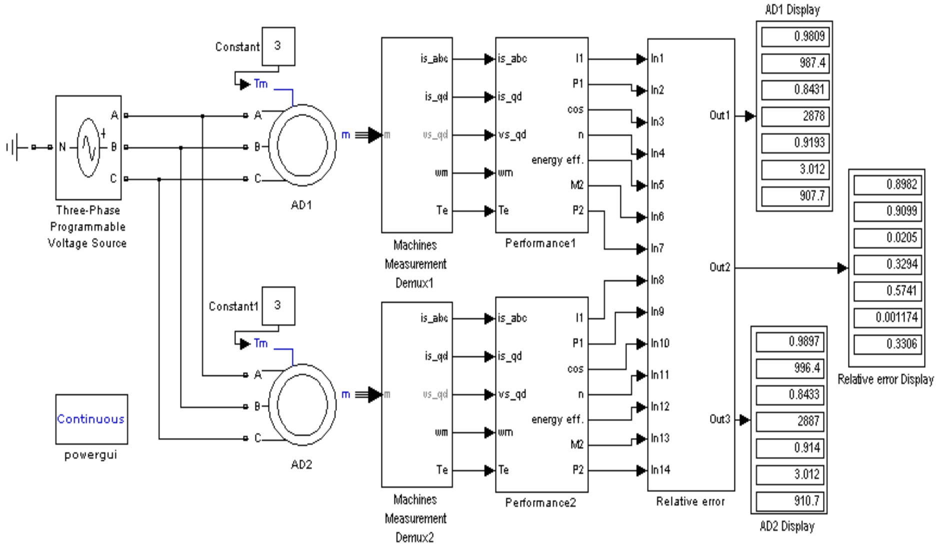

Figure 3. Virtual setup for taking the performance characteristics of an induction motor in the Matlab/Simulink environment

Table 2 Data about the relative error obtained for the two IM for which the parameters are determined experimentally and by using a GA at different relative loads (RL)

RL	δ_I	δ_{P_1}	$\delta_{\cos\varphi}$	δ_n	δ_η	δ_{M_2}	δ_{P_2}
%	%	%	%	%	%	%	%
10	*3,028*	*2,290*	*0,693*	*0,041*	*2,126*	*0,074*	*0,115*
25	*2,387*	*1,086*	*1,244*	*0,103*	*0,956*	*0,017*	*0,111*
50	*1,451*	*0,845*	*0,564*	*0,204*	*0,610*	*0,025*	*0,229*
75	*0,970*	*0,906*	*0,563*	*0,301*	*0,566*	*0,033*	*0,335*
100	*0,809*	*1,017*	*0,205*	*0,400*	*0,615*	*0,005*	*0,395*

To the first seven inputs of Relative error information is supplied for the values of the performance characteristics of the first motor, and to the inputs from 8 to 14 -of the second one, respectively. The display connected to output 1 visualizes the values for *AD1*, and the one connected to output 3 is used for *AD2*. From output 2 information is received for the relative error.

The procedure for adjustment of the individual blocks in the circuit is described in detail in [5, 6].

Table 2 shows the relative error δ of the studied values for the IM the parameters of which are determined experimentally and by a *GA*.

The highest relative error - 3.028% in the study is received for the current consumption at a relative load of 10%. From Tab. 2 it is evident that the errors for the other tested values are very small. On these grounds it can be asserted that by using a *GA* to determine the T-shaped equivalent circuit parameters of an IM, and the suggested virtual setup, we can receive data about the performance characteristics of an IM which describe with sufficient accuracy the data about the performance characteristics obtained by the simulated operation of an *IM* the parameters of which are determined by way of experiment.

CONCLUSIONS

An algorithm has been drawn up for obtaining data based on which the performance characteristics of an *IM* can be built in the Matlab/Simulink environment.

With the use of data about two different loads applied to a *VFD* and a *GA*, the parameters of the T-shaped equivalent circuit are determined. A virtual setup is created, in which the performance of an *IM* is simulated after obtaining the parameters of its T-shaped equivalent circuit in two different ways – experimentally, and by using a Genetic Algorithm. The obtained values for the relative errors of the studied parameters are very small, up to 3%. Therefore, the Genetic Algorithm can be used to determine the parameters of the equivalent circuit with sufficient accuracy, without carrying out no-load or short-circuit tests. Thus it is possible to easily take the performance characteristics of an induction motor by means of a virtual setup and to determine the power indices of automated drives at different loads.

BIBLIOGRAPHY

[1] Ertan, B., Leblebicioglu, K., Avenoglu, B., Ercan, B. 2003. Identification of parameters of an induction motor from field solution. *Proceedings of the Sixth International Conference on Electrical Machines and Systems ICEMS 2003*, Vol. 1, 2003 , pp. 1-6.

[2] Kostov, I., Spasov, V., Rangelova, V. 2009. Application of genetic algorithms for determining the parameters of induction motors. *Scientific-professional journal of technical faculties of the University of Osijek*, 2009, Vol.16, pp. 49-53.

[3] Христова, М. 2011. Методика за определяне натоварването и коефициента на полезно действие на асинхронните двигатели. *Енергетика*, 2011, брой 4, стр. 25-29.

[4] Волдек, А. 1971. *Електрически машини.* ДИ Техника. София. 1971.

[5] Христова, М., Кръстева, А. 2012. Изследване на трифазен асинхронен двигател в програмната среда на Matlab/Simulink. *Известия на съюза на учените*. Русе, 2012.

[6] Черных, И.В. 2008. *Моделирование электротехнических устройств в MATLAB, SimPowerSystems и Simulink*, М. ДМК Пресс, Москва 2008.

POREĐENJE KARAKTERISTIKA JEDNOG INDUKCIONOG MOTORA, ČIJI PARAMETRI SU ODREĐENI EKSPERIMENTALNO I GENETIČKIM ALGORITMOM

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Sažetak: U predstavljenom istraživanju, parametri T-ekvivalentnog kola jednog indukcionog motora (*IM*) su definisani eksperimentalno i upotrebom genetičkog algoritma. Algoritam je formiran za dobijanje podataka o performansama jednog *IM* kroz modele koji su kreirani u Matlab/Simulink okruženju. Virtuelni setap je razvijen poređenjem karakteristika jednog IM, čiji parametri su određeni eksperimentalno i genetičkim algoritmom. Za proučavane vrednosti su određene relativne greške i date su logične osnove za mogućnost upotrebe genetičkog algoritma za određivanje parametara ekvivalentnog kola.

Ključne reči*: indukcioni motor, Matlab/Simulink, genetički algoritam*

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