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# Estimation of Induction Motor Parameters Basing on Static Characteristics Determined by Means of Filed Circuit Model

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***ABSTRACT :*** *The paper presents the methodology of determining electromagnetic parameters of a mathematical circuit model of an induction motor. For this purpose, motor static characteristics calculated by means of the field-circuit model were used. The error mean-square was assumed to be a measure of closeness of the characteristics determined by the both models. Genetic algorithms were used in order to minimise the error. Calculations were carried out for the 1500 W induction motor.*

***Keywords:*** *Induction motor, Field-current model, Electromagnetic parameters.*

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## I. INTRODUCTION

Simulation investigations of static and dynamics properties of induction motors made by means of field-circuit models are time-consuming and expensive. That is why simplified circuit models are still used in these investigations. Application of induction motor circuit models requires the knowledge of coefficients of equations being the mathematical models or of parameters of the motor equivalent circuits. If the motor design data are known, one can determine its equivalent circuit parameters on the basis of design calculations. Because of magnetic core saturation as well as the skin effect in rotor bars, these parameters are not constant and they depend on the motor operating condition. They are usually given for locked-rotor, rated load and no-load operation of an induction motor. The paper presents the alternative way of determining motor electromagnetic parameters using, for this purpose, the motor static characteristics calculated by means of the field-circuit model.

The simplest mathematical monoharmonic model of an induction motor with one equivalent circuit in the rotor is considered. Additionally, the model parameters are assumed to be constant. The motor equivalent circuit parameters are determined through minimisation of the error mean-square between the motor static characteristics calculated by the field-circuit model and those calculated by the simplified circuit model. Genetic algorithms are used in the error minimisation process. The reference static characteristics of the motor are determined by means of the program Maxwell 2D by Ansoft Corp. The calculated parameters are compared with those determined from the design calculations realized by the program RMxprt by the same corporation. The calculations are carried out for the 1500 W induction motor.

## II. EQUATIONS OF INDUCTION MOTOR IN STEADY STATES. METHODOLOGY OFESTIMATION OF ITS ELECTROMAGNETIC PARAMETERS

The equations being the mathematical monoharmonic model of an induction machine in the symmetrical steady state can be presented in the form of the system of algebraic linear equations (1).

$$\begin{bmatrix} \underline{U}_s \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + j(X_{\sigma s} + X_m) + & jX_m \\ jsX_m & R_r^{\bullet} + js\left(X_{\sigma r}^{\bullet} + X_m\right) + \end{bmatrix} \begin{bmatrix} \underline{I}_s \\ \underline{I}_r^{\bullet} \end{bmatrix} \tag{1}$$

In these equations there is not taken into account the parameter representing active power losses in the machine core, since these losses are not taken into consideration in the field-circuit model, either. From the system of equations (1) it follows that the set of electromagnetic parameters of the machine mathematical model are resistances and leakage reactances of the stator and rotor as well as the magnetizing reactance:

$\left( P = \left[ R_s, R_r^{\bullet}, X_{\sigma s}, X_{\sigma r}^{\bullet}, X_m \right] \right).$

Solving the above system of equations for the given voltage vector and the slip there are calculated the stator and rotor currents, and basing on them the other quantities describing the Machin characteristics in the steady state. As a result of this, the static characteristics calculated by means of this model are the function of both the slip and the electromagnetic parameters. Assuming the motor static characteristics calculated on the basis of the field-circuit model to be the reference ones it is possible to select the set of the simplified circuit model parameters so that the error mean-square between the characteristics determined by the both models is minimised. Fig. 1 illustrates the process of determining the parameters.

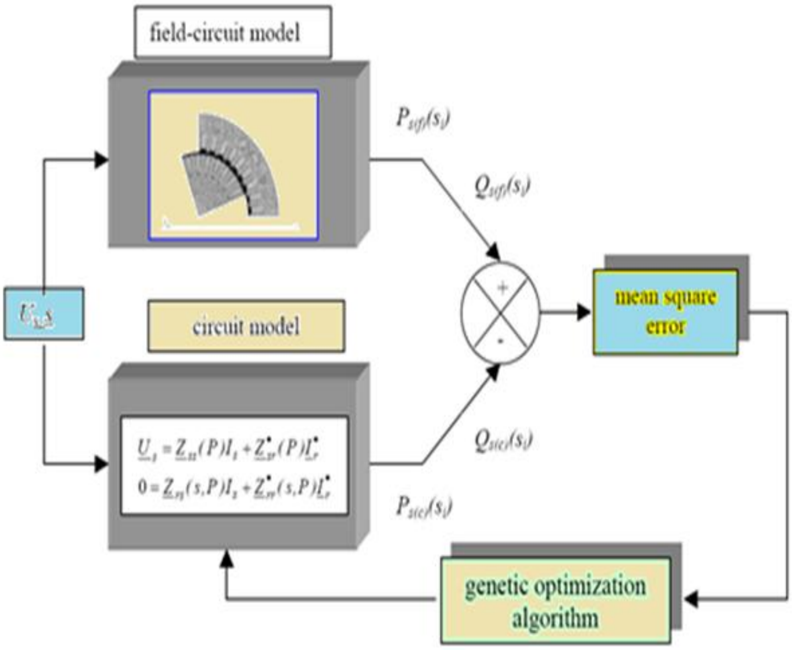


Fig.1.Illustration of the process of parameter determination.

In the paper the stator active and reactive power characteristics are taken to be the reference ones. The error mean-square calculated for the selected values of the slip is assumed to be the measure of the closeness of these characteristics. It is given by the relationship.

$$\varepsilon(P) = \sum_i \left\{ \left( \frac{P_{s(f)}(s_i) - P_{s(c)}(s_i, P)}{P_{s(f)}(s_i)} \right)^2 + \left( \frac{Q_{s(f)}(s_i) - Q_{s(c)}(s_i, P)}{Q_{s(f)}(s_i)} \right)^2 \right\} \tag{2}$$

The function defined above, called the objective function, is non-linear with respect to the parameter vector. That is why it is necessary to apply non-linear optimisation algorithms to its minimisation. Genetic algorithms belong to the group of the non-linear optimisation algorithms.

## III. APPLICATION OF GENETIC ALGORITHM FOR MINIMISATION OF OBJECTIVE FUNCTION

Genetic algorithms belong to the group of optimisation algorithms searching the space of allowed solutions using stochastic method and imitating process of evolution occurring in the nature. The optimal solution is achieved as a result of affiliation to succeeding generations of better and better individuals inheriting the best attributes.

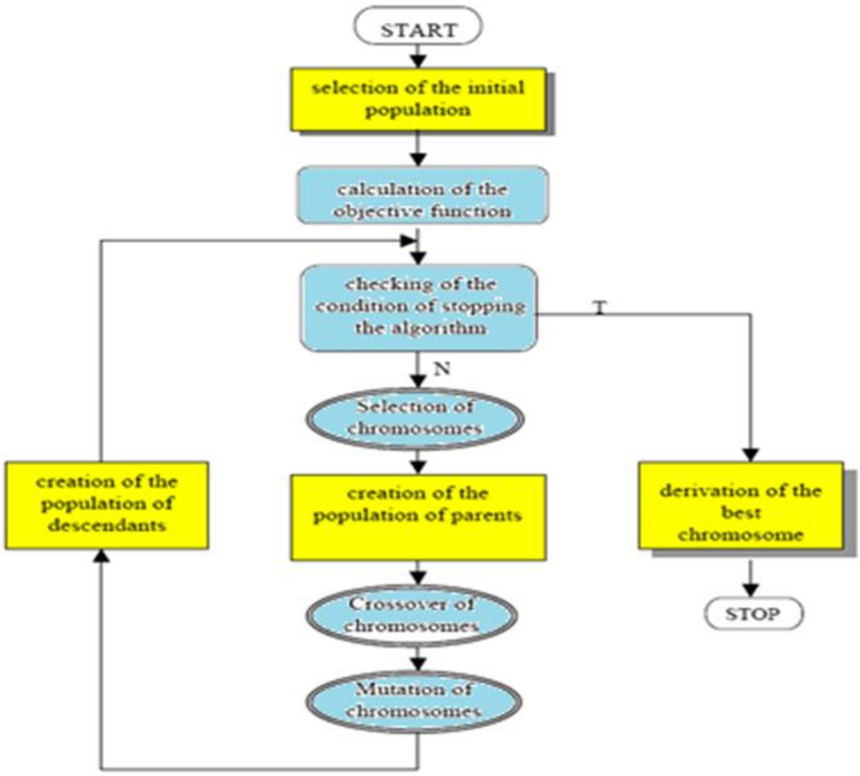


Fig. 2. Flow chart of the genetic algorithm.

Genetic algorithm makes simulation of process of evolution on populations of members-chromosomes consisting of sequence of genes. A gene is, depending on the used code systems, a real number (in the system of real coding) or zero or one (in the binary system). The process of evolution begins from generating the so called initial population in a random way and from determination of a fitness function (an objective function) for its members. Calculation of an objective function enables carring out the selection of members yielding creation of a parent population to which the members fulfilling the objective function in best way belong. The parent population is next subjected to the process of recombination. During this process change of chromosome structure is made, by means of genetic operators (crossover and mutation). The operation of crossover consists in exchange of some genes between the chromosomes while the operation of mutation changes values of individual genes. All processes appearing in the genetic algorithm are of random nature. Genetic algorithms do not require setting of initial guess values. The process of selection of members is made on the ground of calculation of the objective function value only and it is not required knowledge of its derivatives. Operation of the genetic algorithms is outlined in Fig. 2.

## IV. RESULTS OF ELECTROMAGNETIC PARAMETER ESTIMATION

Estimation of the machine electromagnetic parameters was carried out for the motor of the following ratings: $P_N = 1500W$ ; $U_{sN} = 400/230\,V; I_{sN} = 3.4/5.4A;$

Silnik TM 90-4LBC $cos(\phi_{sN}) = 0{,}79$ ; $n_n = 1400\ obr/min;\ M_n = 10.25\,Nm$

Taking into consideration the fact that the parameters $X_{\sigma s}, X_{\dot{\sigma r}}$ are not identifiable it was assumed in calculation that $X_{\sigma s} = X_{\dot{\sigma r}}$.

When using the genetic algorithm, the binary code system and the ranking method as a way of selection was assumed. For calculations the genetic algorithm with steady state was selected. It was assumed in it that 31% of the population was transferred to the next generation without using the reproduction operators. The other genetic algorithm parameters and the final result are presented in Table 1. The upper and lower limits of values of parameter changes given in the table determine the search space, whereas the number of decimal places after points of these numbers determines additionally the resolution. They together decide on the number of genes by means of which the parameter being searched is coded and, as a result, on the length of a chromosome corresponding to the vector of parameters. The genetic algorithm was used for determination of four parameters. The gene number representing the particular parameters was:

$R_s = 13, R_{\dot{r}} = 13, X_{\sigma s} = X_{\dot{\sigma r}} = 13, X_m = 16,$ whereas the chromosome length equalled 55.

Table 1. The results of the parameter estimation when using the genetic algorithm

| Genetic algorithm parameters | | Machine parameters | Upper limit | Lower limit | Final results |
|---|---|---|---|---|---|
| Population size | 101 | $R_s$ | 10,0 | 5 | 7.6743 |
| Generation number | 300 | $R_r^\bullet$ | 10,0 | 2 | 3.8745 |
| Crossover probability | 0,77 | $X_{\sigma s} = X_{\sigma r}^\bullet$ | 10,0 | 2 | 3.5815 |
| Mutation probability | 0,077 | $X_m$ | 500,0 | 50 | 108.96 |

The plot of the minimum and maximum values of the objective function for successive generations is shown in Fig.3. The quality of approximation of the reference characteristics

calculated on the basis of the machine field-circuit model and those determined basing on the simplified circuit model may be evaluated by comparison of the characteristics computed trough both models. It is shown in Figs. 4. Moreover, the motor parameters determined from the design calculations for typical operating conditions are presented in Table 2.

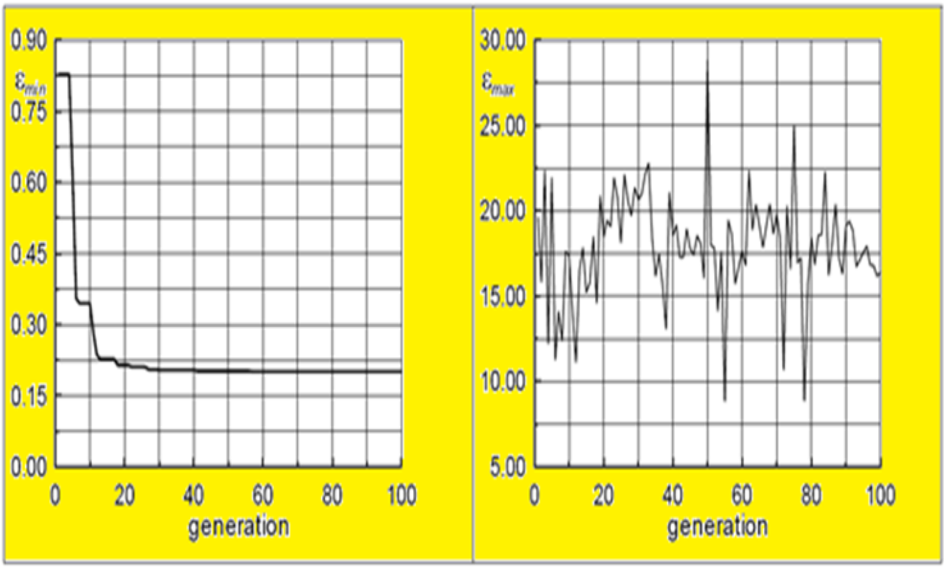


Fig.3. Minimum and maximum values of the objective function for successive generations

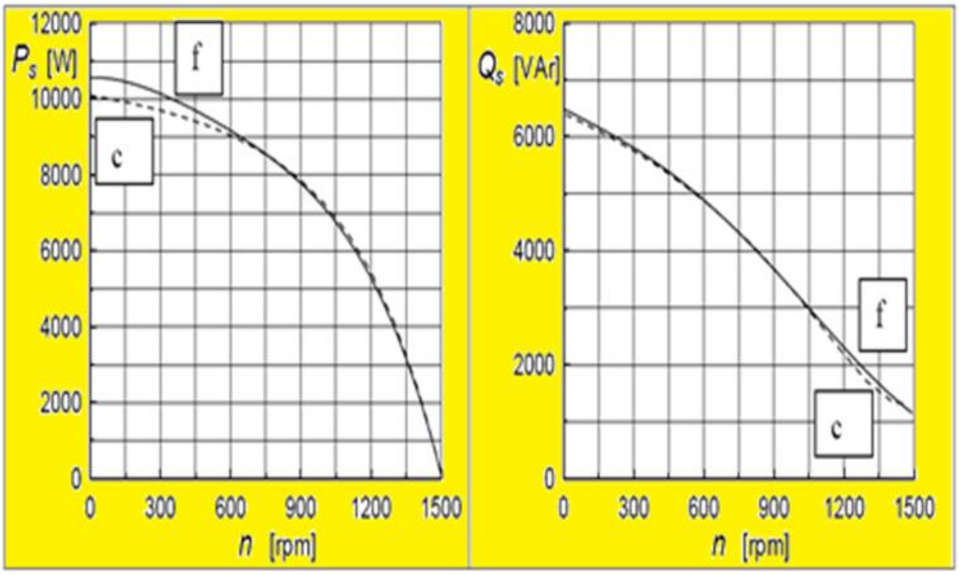


Fig.4. Stator active and reactive power calculated by field-circuit model (f) and circuit model.

Table.2. Parameters determined from the design calculations made by RMxprt program

| type of operation | $R_s$ [Ω] | $R_r^\bullet$ [Ω] | $X_{\sigma s}$ [Ω] | $X_{\sigma s}^\bullet$ [Ω] | $X_m$ [Ω] |
|---|---|---|---|---|---|
| locked-rotor operation | 6,60799 | 4,61022 | 3,12947 | 3,43048 | 123,873 |
| rated –load operation | 6,60799 | 4,53001 | 3,66657 | 4,37544 | 123,873 |
| no-load operation | 6,60799 | 4,52974 | 3,67334 | 4,38528 | 123,873 |

## V. CONCLUDING

The determined set of the parameters of the motor mathematical circuit model represents the motor static characteristics with a good accuracy. The largest differences between the characteristics occur for the slip close to one and are the result of the saturation and skin effects which are of especially great importance in this operating region. They can be reduced by modifying the machine mathematical model through assuming variable parameters [3], [4]. The methodology of determining the machine circuit parameters proposed in the paper may be the alternative for determining the induction motor equivalent circuit parameters on the basis of design data. The use of genetic algorithms as the global optimisation algorithms ensures that the obtained parameters make it possible to determine the motor static characteristics closest to the reference ones.

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