DETERMINATION OF INDUCTION MACHINE PARAMETERS BY USING PARTICLE SWARM OPTIMIZATION TECHNIQUE

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Abstract: In this paper the determination of induction machine parameters by using Particle Swarm Optimization (PSO) technique is presented. An equivalent circuit without considering the iron losses is analyzed. The circuit parameters are found as the result of the error minimization function between the estimated and maker data. In order to determine the parameters, the values of the phase current and power factor for three slip values of the machine have been used. The accuracy of the usage PSO is analyzed by determining the relative error between the optimized and real value of the phase current and power factor for all three slip values. The obtained results are also compared with results found in literature which are obtained by using Genetic Algorithm (GA). It is concluded that PSO is more efficient in solving the parameter estimation problems.

1. INTRODUCTION

The asynchronous machines, or induction machines, have been widely used due to their robustness, easy application, flexibility, ability to work in harsh environments as well as low cost. The performance characteristics of an induction motor are usually determined from its equivalent circuit. However, the manufacturers do not provide the equivalent circuit parameters, and, therefore, these parameters need to be determined for the purpose of the detailed analysis of steady-state or dynamic operation.

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The induction machine parameters are generally determined via the classical no-load and locked-rotor tests [1, 2]. However, these tests cannot be implemented easily. Namely, the no-load and blocked rotor tests are time-consuming tasks, especially if the motor is already coupled to driving equipment. The second classical method for induction machine parameters determination is based on the acceleration and deceleration tests [3]. However, this method requires special experimental setup for measurements. Beside classical methods, in the literature, different optimization methods for induction machine parameters determination can be found. Concretely, the induction machine parameters can be obtained by using the genetic algorithm - GA [4-8], Particle Swarm Optimization – PSO [9-11], the Bacterial Foraging Technique – BFT [12], the Artificial Neural Network – ANN [13-14], the Artificial Bee Colony Algorithm – ABCA [15], the Shuffled frog-leaping algorithm – SFLA [16], the Dynamic Encoding Algorithm – DEA [17], the Differential Evolution algorithm - DE [18]. Methods based on numerical iterative technique can also be found in literature, such as Newton-Raphson algorithm [19] or Levenberg-Marquardt algorithm [20]. Regardless of which method is used, the machine parameters are computed by using data from machine nameplate and catalog data, as it is presented in [21-22], or by using some results obtained by measurements [20].

In this article, a study has been carried out to determine the model parameters for the steady-state operation of a single rotor circuit induction motor by using PSO algorithm. This algorithm has already been used to this end in certain number of papers [9-11]. However, the induction machine in “d” and “q” reference frame is concerned in [9]. On the other hand, in [10], for approximate circuit model the problem formulation uses the starting torque, the maximum torque and the full load torque manufacturer data to estimate the stator resistance, the rotor resistance and the stator leakage reactance parameters. The magnetizing reactance parameter is not considered in this model.

The investigation presented in this paper is a continuation of the research initiated in [11]. Namely, in this article, RMS phase current and power factor data that correspond to three different values of the machine slip will be used for determining parameters of the induction machine. Furthermore, the impact of different objective function, which defines criteria for optimization, on the values of machine parameters will be analyzed. In [11] only one objective function for induction machine parameters determination is used.

The paper is organized as follows. In Section II the equivalent circuit of the induction machine is presented. Short description of PSO algorithm is given in Section III. The estimation of equivalent circuit parameters by using PSO is presented in Section IV, as well as comparison with results obtained by using GA. Concluding remarks are given in Conclusion section.

2. EQUIVALENT CIRCUIT OF THE INDUCTION MACHINE

Fig. 1 shows an equivalent circuit of the induction machine where R_1, X_1, R_2, X_2, and X_m represent the stator resistance, stator leakage reactance, rotor resistance, rotor leakage reactance, and magnetizing reactance, respectively [5].

Based on the circuit in Fig. 1, the stator current can be computed as follows:

$$\underline{I} = \frac{\underline{V}}{R_{eq} + jX_{eq}} \ , \tag{1}$$

where $R_{eq}+jX_{eq}$ is the equivalent circuit impedance. The equivalent circuit resistance R_{eq} and reactance X_{eq} in (1) are equal to:

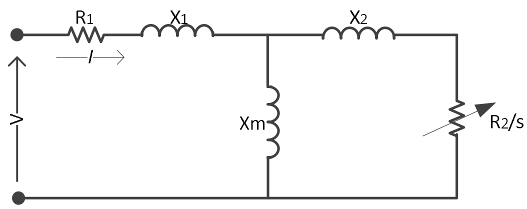

Fig. 1. Equivalent circuit of induction motor without considering the iron losses.

$$R_{eq} = R_1 + \frac{\frac{X_m^2 R_2}{s}}{\left(\frac{R_2}{s}\right)^2 + \left(X_2 + X_m\right)^2}$$
$$X_{eq} = X_1 + \frac{\left(\frac{R_2}{s}\right)^2 X_m + X_2 X_m \left(X_2 + X_m\right)}{\left(\frac{R_2}{s}\right)^2 + \left(X_2 + X_m\right)^2} \tag{2}$$

The power factor can be computed as follows:

$$\cos(\varphi) = \cos\left(\tan^{-1}\frac{X_{eq}}{R_{eq}}\right). \tag{3}$$

3. PARTICLE SWARM OPTIMIZATION TECHNIQUE

The PSO is a stochastic optimization method, which uses swarming behaviors observed in flock of birds [9, 10].The PSO concept consists of changing the velocity of each particle toward its personal best (*pbest*) and global best (*gbest*) locations in each iteration. Acceleration is weighted by a random term, with separate random number generating for acceleration toward *pbest* and *gbest* locations.

Let X and V denote the particle's position and its corresponding velocity in search space, respectively. At iteration K, each particle i has its position defined by:

$$X_i^K = [X_{i,1}, X_{i,2}, ..., X_{i,N}], \tag{4}$$

and the velocity is defined as

$$V_i^K = [V_{i,1},\ V_{i,2},...,\ V_{i,N}] \tag{5}$$

in search space N. Velocity and position of each particle in the next iteration can be calculated as

$$\begin{aligned} V_{i,n}^{k+1} = {} & W \times V_{i,n}^{k} + \\ & C_1 \times rand_1 \times \left(pbest_{i,n} - X_{i,n}^{k} \right) + \\ & C_2 \times rand_2 \times \left(qbest_{i,n} - X_{i,n}^{k} \right), \end{aligned} \tag{6}$$

where i={1,2,…,m}, n={1,2,…,N}, and

$$X_{i,n}^{k+1} = \begin{cases} X_{i,n}^{k} + V_{i,n}^{k+1} & X_{\min,i,n} \le X_{i,n}^{k+1} \le X_{\max,i,n} \\ X_{\min,i,n} & X_{i,n}^{k+1} \le X_{\min,i,n} \\ X_{\max,i,n} & X_{i,n}^{k+1} \ge X_{\max,i,n} \end{cases} \tag{7}$$

where m is the number of particle in the swarm, N is the number of dimensions in a particle, K is the pointer of iterations, $V_{i,n}^{k}$ is the velocity of particle i at iteration k, W is the weighting factor, C_j is the acceleration factor, $rand_j$ is the random number between 0 and 1, $X_{i,n}^{k}$ is the current position of particle i at iteration k; $pbest_i$ is the personal best of particle i and $gbest_i$ is the global best of the group.

It should be noted that the first term of formula (6) is the initial velocity of particle, which reflects the memory behavior of particle; the second term “cognition part”, represents the private thinking of the particle itself and the third part is the “social” part, which shows the particles behavior stem from the experience of other particles in the population.

The following weighting function is usually used in (6)

$$W = W_{\max} - \left(W_{\max} - W_{\min} \right) \times \frac{Iter}{Iter_{\max}} \tag{8}$$

where $W_{\max}$ and $W_{\min}$ are the initial and the final weight, respectively, $Iter$ is the current iteration number and $Iter_{\max}$ is maximum iteration number [10].

In the above procedures, the convergence speed of each particle could be influenced by the parameters C_1 and C_2 (acceleration factors). The optimization process will modify the position slowly, if the value of C_j is chosen to be very low. On the other hand, the optimization process can become unstable, if the value of C_j is chosen to be very high [10].

The constraints of the used optimization technique in the present research work are {R_1, X_1, R_2, X_2, X_m} which must be bounded within some pre-specified limits. These limits may be mounted as follows

$$\begin{aligned} R_1^{\min} &\le R_1 \le R_1^{\max} \\ X_1^{\min} &\le X_1 \le X_1^{\max} \\ R_2^{\min} &\le R_2 \le R_2^{\max} \\ X_2^{\min} &\le X_2 \le X_2^{\max} \\ X_m^{\min} &\le X_m \le X_m^{\max} \end{aligned} \tag{9}$$

where the superscripts *min* and *max* speak for the minimum and the maximum values of the respective variables. The lower bound ranges enable obtaining accurate results, while speed of convergence depends on constants C_1 and C_2.

4. ESTIMATION OF EQUIVALENT CIRCUIT PARAMETERS

The approach described in the previous section is applied to a three-phase induction machine (0.75 kW, 380V, 50Hz, 2 poles). Phase current and power factor data for three values of the slip are given in Table 1 [5]. The PSO parameters used in this paper are presented in Table 2.

The criterion for selecting the best individuals in the PSO algorithm is the objective function [5]. In this paper, in order to determine the induction machine parameters, the objective function (F_{objfunct}) is defined on three ways, as follows:

$$F_{objfun\_complete} = \sum_{i=1}^{n}\left(\frac{I_{c1}}{\mathrm{I}_{mi}}-1\right)^2 + \sum_{i=1}^{n}\left(\frac{\cos(\varphi_{ci})}{\cos(\varphi_{mi})}-1\right)^2 , \tag{10}$$

$$F_{objfun\_current} = \sum_{i=1}^{n}\left(\frac{I_{c1}}{\mathrm{I}_{mi}}-1\right)^2 , \tag{11}$$

$$F_{objfun\_\cos fi} = \sum_{i=1}^{n}\left(\frac{\cos(\varphi_{ci})}{\cos(\varphi_{mi})}-1\right)^2 . \tag{12}$$

Here I_{ci} and $\cos(\varphi_{\text{ci}})$ are the values computed by (1) and (3). I_{mi} and $\cos(\varphi_{\text{mi}})$ are measured or analytical values [5]. The variable varies from 1 to 3. It should be noted that the objective function (10) is only used in [11].

Table 3 shows the equivalent circuit parameters estimated by using PSO (for all objective functions) as well as with genetic algorithm [5]. The comparison of the value of the phase current and power factor, for parameters determined by using GA and PSO, are presented in Table 4. In this table in column Error the difference between the estimated and maker data is presented. The phase current – slip and the power factor – slip characteristics determined by using results presented in Table 3 are shown in Figs. 2 and 3, respectively.

As it can be seen from Figs. 2-3, and from Table 3, PSO enable obtaining much more accurate result in comparison with usage of GA, for the same objective function. On the other hand, the usage of simpler objective function results in greater differences between measured and estimated values of variables that are not covered by objective function.

Table I
Sets of used data

Stator current	***Slip***	***Power factor***
1.86	0.06	0.62
2.39	0.10	0.74
3.07	0.15	0.78

Table II
PSO parameters

c_1	c_2	$W_{\min}$	$W_{\max}$	$Iter_{max}$
0.5	0.1	01	0.5	1000

Table III
Estimated induction machine parameters

Parameter [Ω]	***GA [5]***	***PSO (eq.(10))***	***PSO (eq.(11))***	***PSO (eq.(12))***
R_1	10.28	10.3620	11.1713	5.2128
X_1	8.19	7.9488	4.7053	6.0729
R_2	10.48	10.4424	10.6612	11.6432
X_2	19.21	19.7503	19.3012	21.0359
X_m	143.17	143.4868	145.5904	168.880

Table IV
Comparison of results

Stator current [A]	***GA***	***Error GA***	***PSO (eq.(10))***	***Error***	***PSO (eq.(11)***	***Error***	***PSO (eq.(12))***	***Error***
1.86	1.8555	0.0045	1.8601	0.0001	1.8600	0	1.696	0.164
2.39	2.3847	0.0053	2.3927	0.0027	2.3900	0	2.247	0.143
3.07	3.0542	0.0158	3.0658	-0.0042	3.0700	0	2.963	0.107
Power factor	***GA***	***Error GA***	***PSO (eq.(10))***	***Error***	***PSO (eq.(11)***	***Error***	***PSO (eq.(12))***	***Error***
0.62	0.6193	0.0007	0.6214	-0.0014	0.638	-0.018	0.6204	-0.0004
0.74	0.7366	0.0034	0.7374	0.0026	0.7602	-0.0202	0.7387	0.0013
0.78	0.7812	-0.0012	0.7807	-0.0007	0.8102	-0.0302	0.7807	-0.0007

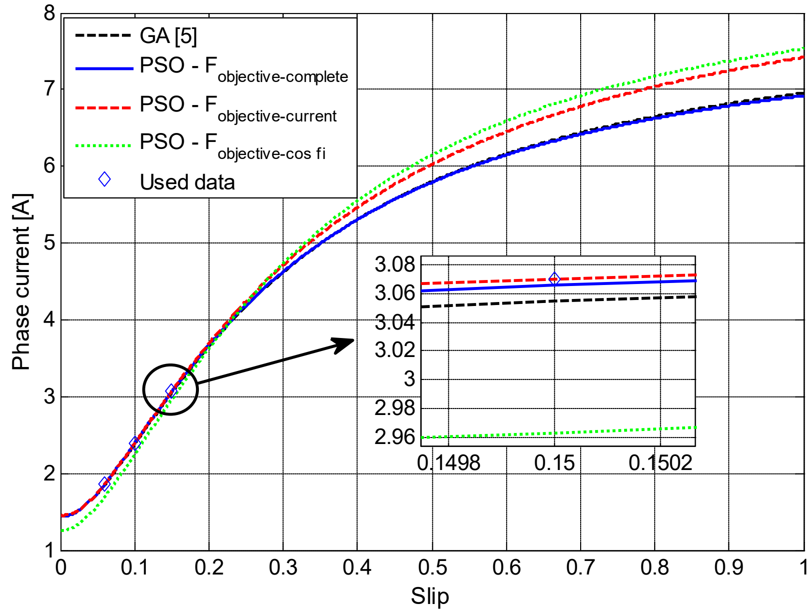

Fig. 2. Phase current – slip characteristics.

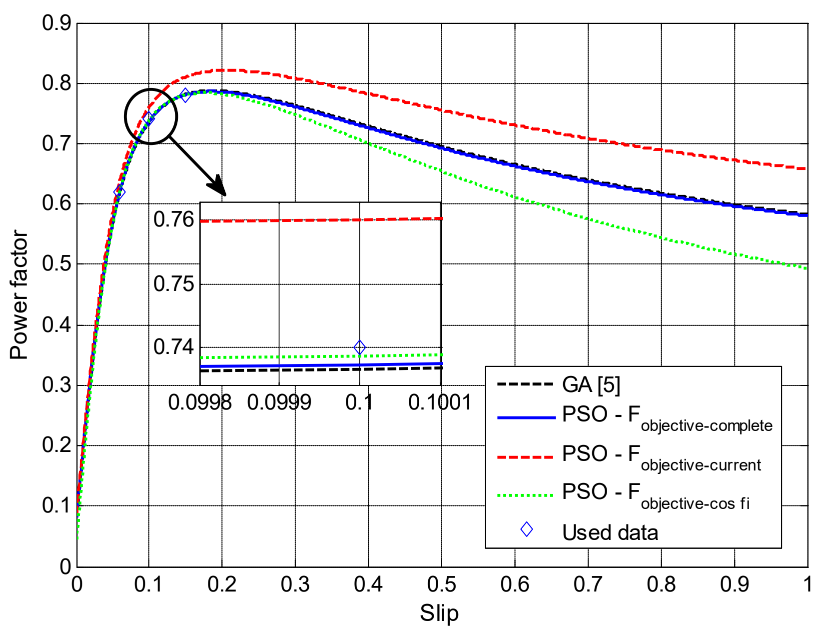

Fig 3. Power factor – slip characteristics.

5. CONCLUSION

An efficient approach for determining the equivalent circuit parameters of squirrel cage induction motors, based on usage of PSO, is presented.

Although the technique of using PSO for determining parameters of induction motor is not new, novel approach for its implementation have been proposed in this paper. Namely, values of the phase current and power factor that correspond of some values of slip are used as input data in calculations. The obtained results are compared with results found in literature (obtained by using GA). It is shown that PSO enable obtaining much more accurate results in comparison with usage of GA. Also, the usage of PSO is simpler, faster, less intrusive and cheaper than the conventional experimental methods for estimating the equivalent circuit parameters of induction motors.

It should be noted that although we have obtained more accurate results compared to the results presented in [5], it cannot be concluded that parameters obtained by using PSO are representative for the whole slip range. The reason for this conclusion lies in fact that in this procedure three values of phase current (and power factor) for three different small values of the slip have been used. In the future work this algorithm will be applied for a widespread slip range.

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