

RIVALRY HARMONY SEARCH & IMPERIALIST COMPETITIVE ALGORITHMS FOR ACCURATE PARAMETER ESTIMATION OF DOUBLE-CAGE ASYNCHRONOUS MACHINE

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In this research work, two optimization methods based on Imperialistic Competitive Algorithm (ICA) and Harmony Search Algorithm (HAS) are presented for offline parameter estimation of double-cage asynchronous machines. The methods utilize the manufacturer's name plate data to obtain the steady-state equivalent circuit parameters of the motor. The feasibility and accuracy of the proposed methods are evaluated for two different 5hp and 40hp motors, through the comparison of the simulation results with those obtained from the previously developed methods results. Simulation outcomes and performance curves prove the accuracy of the methods in estimating of the motor parameters.

Keywords: Harmony Search Algorithms, Imperialist Competitive Algorithms, Parameter Estimation, Double-Cage Asynchronous Machine

1. Introduction

The major problem with analysis of induction machines is the unavailability of manufacturer data to construct accurate models. Normally, nameplate data of the indication machines don't include equivalent circuit parameters of the machine such as, resistance and reactance of the stator and rotor and also the parameters of the magnetizing branch. That is why, it is necessary to obtain theses parameters by using accurate parameter estimation techniques [1].

Although the conventional technique for estimating the induction motor parameters is based on the no-load and the locked-rotor tests [2], these techniques cannot be implemented easily. Besides, in the locked-rotor condition, the frequency of the rotor is equal to the supply frequency, but under typical operations, the rotor frequency is perhaps 1–3Hz. This incorrect rotor frequency

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will give misleading results for the locked-rotor test. Classical approach with linear squares has been implemented to identify machine parameters.

A literature review indicates that there have been some research efforts addressing this issue.

Ref. [3] has presented by which an accurate dynamic induction motor model may be developed from a knowledge of standard specification data for the motor and it has discussed on induction machine modelling for electromagnetic transient program, Rf. [4] investigates the use of linear parameter estimation techniques to determine the rotor resistance, self-inductance of the rotor winding, as well as the stator leakage inductance of a three-phase induction machine. Ref. [6], has played on real time estimation of induction motor parameters.

A classical method by linear squares has done to estimate machine parameters in [5, 6], which the linear parameter estimation methods have applied. Beside, this problem has also analyzed by using a superior approach for non-linear system identification [7]. In [8, 9] the double-cage induction motor has simulated from manufacturer's data like; name plate data and motor performance characteristics. Authors in [10] present a modified Newton method to estimate machine parameters.

Evolutionary computation methods and Artificial intelligence-based methods, such as the genetic algorithms (GAs) and neural networks, Shuffled frog-leaping algorithm and particle swarm optimization, have also been used for parameter estimation of induction motors [10 – 15].

This paper employs Imperialistic Competitive Algorithm (ICA) and Harmony Search Algorithm (HSA) in order to solve the non-linear equations of the double cage induction motor and estimation of its parameters. The feasibility and accuracy of the proposed methods are evaluated for two different 5hp and 40hp motors, through the comparison of the simulation results with those obtained from the previously developed methods results. The paper is organized as follows. Section 2 focuses on problem definition and introduces objective function for parameter estimation. Section 3 presents a brief review of ICA and HAS methods. Discussion on the results will be given in section 4. Finally, conclusions will be presented in the last section.

2. Problem Definitions and Objective Function

The steady state equivalent circuit of a double-cage induction machine is shown in Fig 1. The aim of the parameter estimation problem is obtaining the circuits' parameters including $R_s, X_s, X_m, R_1, R_2, X_{1d}, X_{2d}$. In this model R_s and X_s are the stator resistance and leakage reactance, respectively. X_m is the magnetizing reactance. R_1, R_2 are the rotor resistances related to the cage1 and 2

respectively. X_{1d}, X_{2d} are the leakage reactance of the rotor relate to the cage1 and 2 respectively, and V_{ph} is the stator voltage per phase.

In order to estimate the parameters of the equivalent circuit, the name plate data and performance characteristics of the motor such as the starting torque, full load torque, maximum torque, full load power factor, the starting and full load current are required. The manufacturer's data for the two 5hp and 40hp motors considered in this study are given in Table 1 which has the star connection.

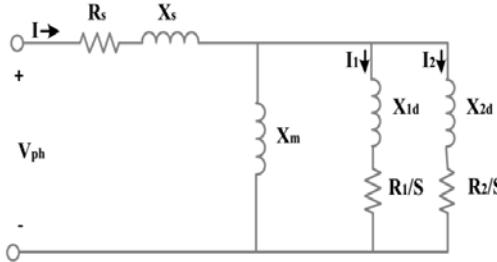


Fig. 1. Steady state equivalent circuit of the double-cage induction machine

Table 1

| | Manufacturer data | |
|----------------|-------------------|---------|
| | Motor 1 | Motor 2 |
| P_n (HP) | 5 | 40 |
| V (v) | 400 | 400 |
| f (Hz) | 50 | 50 |
| p | 2 | 2 |
| T_{st} (Nm) | 15 | 260.3 |
| T_{fl} (Nm) | 25 | 190 |
| T_{max} (Nm) | 42 | 370.5 |
| I_{st} (A) | 22 | 180 |
| I_{fl} (A) | 8 | 45 |
| pf_{fl} | 0.8 | 0.8 |
| S_{fl} | 0.07 | 0.09 |

In Table 1, P_n (HP) is the nominal power of the considered motor, $V(v)$ is the nominal line voltage, f (Hz) is the frequency, p is the number of the pole pairs, T_{st} (Nm) is the starting torque, T_{fl} (Nm) and T_{max} (Nm) are the full load torque and

maximum torque respectively, $I_{st}(A)$ and $I_{fl}(A)$ are the starting and full load current respectively, pf_{fl} is the full load power factor and S_{fl} is the full load slip.

The objective function which has been defined for estimating the parameters is as follows:

$$F = F_1^2 + F_2^2 + F_3^2 + F_4^2 + F_5^2 + F_6^2 \quad (1)$$

where

$$F_1 = \frac{T_{fl(cal)} - T_{fl(mf)}}{T_{fl(mf)}} \quad (2)$$

$$F_2 = \frac{T_{st(cal)} - T_{st(mf)}}{T_{st(mf)}} \quad (3)$$

$$F_3 = \frac{T_{max(cal)} - T_{max(mf)}}{T_{max(mf)}} \quad (4)$$

$$F_4 = \frac{pf_{fl(cal)} - pf_{fl(mf)}}{pf_{fl(mf)}} \quad (5)$$

$$F_5 = \frac{I_{st(cal)} - I_{st(mf)}}{I_{st(mf)}} \quad (6)$$

$$F_6 = \frac{I_{fl(cal)} - I_{fl(mf)}}{I_{fl(mf)}} \quad (7)$$

In the above equations, index (cal) stands for quantities which are calculated by estimated values of $R_s, X_s, X_m, R_1, R_2, X_{1d}, X_{2d}$ and index (mf) stands for those quantities which have been extracted from the manufacturer data given in Table 1. Equations (8-13) are used for determination of the stator and rotor currents of the motor in terms of slip.

$$I(S) = \frac{V_{ph}}{R_s + jX_{sd} + Z_p(S)} \quad (8)$$

$$I_1(S) = \frac{Z_p(S)I(S)}{(R_1/S) + jX_{1d}} \quad (9)$$

$$I_2(S) = \frac{Z_p(S)I(S)}{(R_2/S) + jX_{2d}} \quad (10)$$

where,

$$V_{ph} = (V/\sqrt{3})_{\angle -\frac{\pi}{6}} \quad (11)$$

$$Z_p(S) = \frac{1}{(1/jX_m) + \left(\frac{1}{(R_1/S) + jX_{1d}} \right) + \left(\frac{1}{(R_2/S) + jX_{2d}} \right)} \quad (12)$$

And the torque in term of the slip is given by:

$$T(S) = \frac{3p}{\omega_s} \left([I_1(S)]^2 \frac{R_1}{S} + [I_2(S)]^2 \frac{R_2}{S} \right) \quad (13)$$

T_{fl} , T_{st} and T_{max} are obtained by substituting S_{fl} , and S_{max} in equation (13) respectively, where S_{max} is given by the (14):

$$\frac{dT(S_{max})}{dS} = 0 \quad (14)$$

Equations (15-17) are shown the equations of the power, where \bar{S} is the complex power:

$$\bar{S}(S_{fl}) = \mathfrak{V}_{ph} [I(S_{fl})]^* \quad (15)$$

$$P_e(S_{fl}) = \text{Re}[\bar{S}(S_{fl})] \quad (16)$$

$$Qe(S_{fl}) = \text{Im}[\bar{S}(S_{fl})] \quad (17)$$

2. 1. CONSTRAINTS

- Minimum and maximum limits for the parameters are as:
 $X_{i,\min} \leq X_i \leq X_{i,\max}$
- Inner and outer cage leakage reactance and resistance limits are as:
 $X_{1d} > X_{2d}$ and $R_2 > R_1$
- All of the parameters should have positive values:
 $(R_s, X_s, X_m, R_1, R_2, X_{1d}, X_{2d}) > 0$

3. Overview of ICA and HSA

3. 1. HARMONY SEARCH (HS)

HS is a high-performance meta-heuristic algorithm which uses stochastic random search instead of a gradient search [16]. The process by which the musicians (who have never played together before) quickly refine their individual improvisation through adjusting the pitches of their instruments resulting in a pleasing harmony. The HS algorithm has been successful in several optimization problems such as [17-18]. Easy implementation makes the HS method as the major competitor of the other evolutionary algorithms. HS does not require differential gradients, thus it can consider discontinuous. It does not require initial value setting for the variables and is free from divergence. The flowchart of the method is illustrated in fig.2 (a).

Harmony search aims to find a vector x which minimizes or maximizes a certain objective function. The steps of algorithm are as follow:

Step 1) Generates random vectors X^1, \dots, X^{hms} as many as hms (harmony memory size), then stores them in harmony memory (HM). Step 2) Generates a new vector X' for each component X'_i , Step 3) Performs additional work if the value in step 2 come from HM. Step 4) If X' is better than the worst vector X^{worst} in HM, replace X^{worst} with X' . Step 5) Repeats from step 2 to step 4 until finishing criterion (e.g. maximum iterations) is satisfied, and step 5: Repeats from step 2 to step 4 until finishing criterion (e.g. maximum iterations) is satisfied.

The main parameters of the algorithm are:

hms= the size of the harmony memory. It generally varies from 1 to 100. (Typical value = 30), **hmcr**= the rate of choosing a value from the harmony memory. It generally varies from 0.7 to 0.99. **par**= the rate of choosing a neighboring value. It generally varies from 0.1 to 0.5. δ = the amount between two neighboring values in discrete candidate set and **fw** = the amount of maximum change in pitch adjustment [19].

The parameters of HSA in order to obtain the desire results to accurate parameter estimation have been setting as : Number of variables =7, Number of inequality constraints =0, M maximum number of iterations =400, Harmony memory size =300, Harmony consideration rate =0.9, Minimum pitch adjusting rate =0.4, Maximum pitch adjusting rate =0.9, Minimum bandwidth=0.0001, Maximum bandwidth =1.0

Tuning the parameters can affect the results. This process must have done for many times to obtain the desire results. In this study number of the iteration for both algorithms are equal.

3.2. IMPERIALIST COMPETITIVE ALGORITHM (ICA)

Imperialist competitive algorithm is a nearly developed evolutionary optimization method which is enthused by imperialist competition. In order to solve a problem, like other evolutionary algorithm, it requires an initial population which finally one of them will be the proper solution [20]. Initial population is the sum of countries which is divided into imperialists and colonies which together form empires. One imperialist with relevant colonies creates an empire. The total power of an empire is the sum of imperialist power and the percentage of relevant colonies power. All empires attempt to take possession of colonies of other empires until weak empires collapse and just one most powerful empire exists which the imperialist and the relevant colonies have the same value of cost function. So, the state with most powerful empire is the convergence point of

ICA. Fig. 2(b), depicts the flowchart of ICA. Two main operators of this algorithm are Assimilation and Revolution. Assimilation makes the colonies of each empire get closer to the imperialist state in the space of socio-political characteristics (optimization search space). Revolution brings about sudden random changes in the position of some of the countries in the search space. During assimilation and revolution a colony might reach a better position and has the chance to take the control of the entire empire and replace the current imperialist state of the empire. The steps of the algorithm are as follow [21]:

Step 1) Defines objective function, Step 2) Initialization of the algorithm. Generate some random solution in the search space and create initial empires. Step 3) Assimilation: Colonies move towards imperialist states in different directions. Step 4) Revolution: Random changes occur in the characteristics of some countries. Step 5) Position exchanges between a colony and imperialist. A colony with a better position than the imperialist, has the chance to take the control of empire by replacing the existing imperialist. Step 6) Imperialistic competition: All imperialists compete to take possession of colonies of each other. Step 7) Eliminates the powerless empires. Weak empires lose their power gradually and they will finally be eliminated. Step 8) If the stop condition is satisfied, stop, if not go to 2, and step 9) end.

Fig.1 (b) shows the flowchart of the Imperialist Competitive Algorithm. The parameters of ICA in order to obtain the desire results to accurate parameter estimation have been setting as: Number of variables =7, Number Of Countries =300, Number Of InitialImperialists = 40, Num Of Iteration = 400, Algorithm Parameters Assimilation Coefficient=2.5, Algorithm Parameters.Assimilation Angle Coefficient = 5, Algorithm Parameters Zeta = 0.02, Algorithm Parameters Damping Ratio = 0.99, Algorithm Parameters Uniting Threshold = 0.02

4. SIMULATION RESULTS

The proposed methods are applied for parameter estimation of two 5 and 40hp double cage asynchronous motors which their manufacturer's data are previously given in Table 1. In order to validate and verify the performance of the proposed algorithms, the simulation parameters for both of the methods are kept same.

Since proper choice of the parameters allows more flexibility to increase the effectiveness, capability and performance of the used algorithm. Thus, for comparison the effectiveness of the chosen meta-heuristics, the number of evaluations of the objective functions and the computation time must be same.

For estimating the unknown parameters of the double-cage induction motor ($R_s, X_s, X_m, R_1, R_2, X_{1d}, X_{2d}$), first the initial population of these parameters is generated randomly in the suitable rang.

Then equations (8-17) are used to determine the full load torque, full load power factor, full load current, maximum torque, starting torque and starting current of the motor by substituting the randomly generated parameters in these equations. Thereupon, equations (2-7) and then equation (1) are used along by considering the constraints to solve the objective functions (F). This course of action is continuing until minimizing the value of the objective function and afterward satisfying stop criteria of the used algorithms. The final values of $R_s, X_s, X_m, R_1, R_2, X_{1d}, X_{2d}$ satisfying the stop criteria are the estimated parameter.

The best values of $R_s, X_s, X_m, R_1, R_2, X_{1d}, X_{2d}$ for 5 hp and 40 hp motors which have been obtained from the HSA and ICA methods, after 20 runs, are shown in Table 2 and Table 3, respectively. Tables 4 and 5 compare the results obtained from ICA and HS methods, for 5hp and 40hp motor respectively. Figs.3 and 4 illustrates the performance curves, obtained from the model of the considered double cage motors utilizing parameters obtained from the ICA and HAS methods. As it can be clearly seen from the results which are shown in Tables 4 and 5, as well as Fig 4 and 5, there are a good agreement in all slip regions with the manufacturer data.

Fig.5 compares the results in terms of the best costs for the two methods developed in this study (ICA, HAS) and the corresponding results with the modified shuffle frog leaping algorithm (MSFLA) which has been previously reported in [22]. The MFSLA results have been more convergence and the best results for parameter estimation problem which reported so far. As it can be clearly seen from the figure, both of proposed methods have a good convergence and their corresponding results are better than the MFSLA results which have reported in [22].

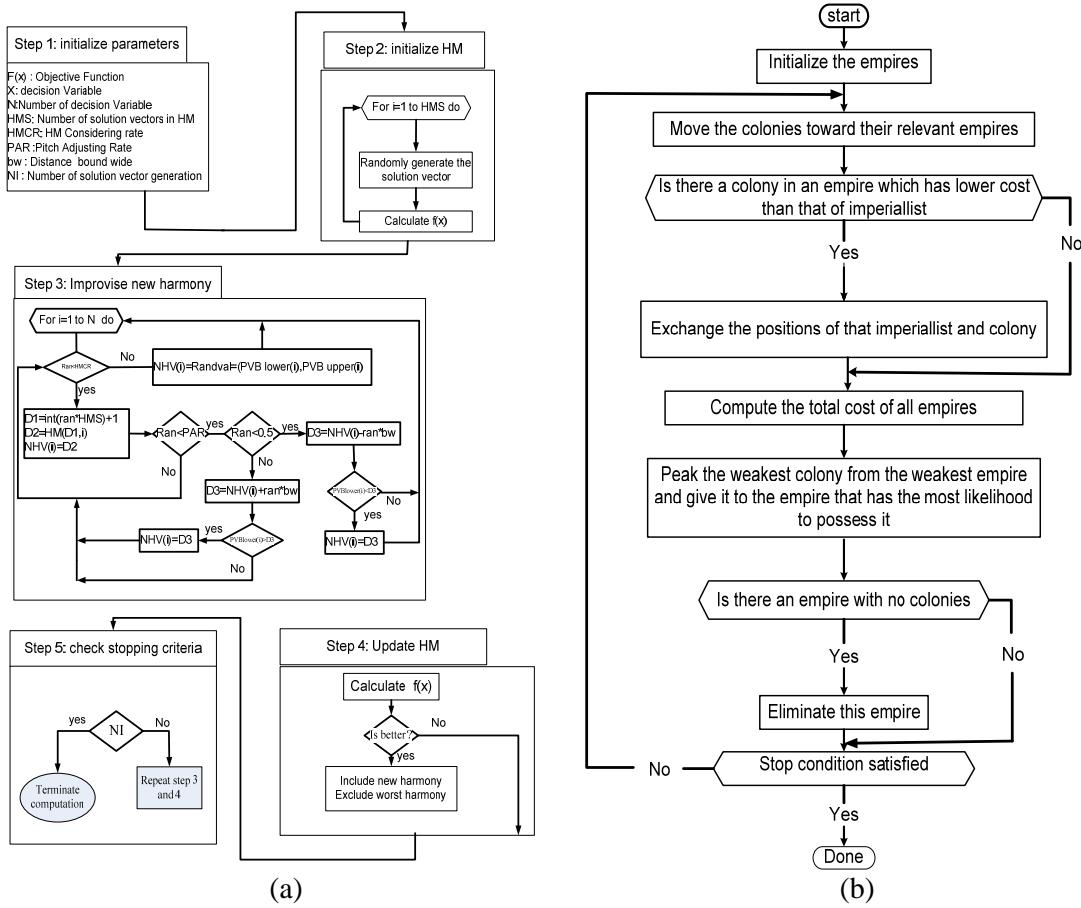


Fig. 2. Flowcharts of a) Harmony search algorithm and b) Imperialist competitive algorithm.

Table 2

The parameters obtained from ICA and HSA methods for 5hp motor.

| Parameter | ICA | HSA |
|-----------|---------|---------|
| R_s | 2.3357 | 1.716 |
| X_s | 1.1971 | 10 |
| X_m | 76.241 | 76.4954 |
| R_I | 3.8203 | 3.0097 |
| R_2 | 4.5455 | 4.0782 |
| X_{Id} | 20 | 0.3825 |
| X_{2d} | 18.1686 | 0.3 |

In [22], authors have used modified shuffle frog leaping algorithm (MSFLA) to obtain parameters of the circuit model of the double cage asynchronous machine.

Table 3

The parameters obtained from ICA and HSA methods for 40hp motor

| Parameter | ICA | HSA |
|-----------|---------|---------|
| R_s | 0.0001 | 0.0951 |
| X_s | 0.8394 | 0.2170 |
| X_m | 13.9198 | 13.6963 |
| R_I | 0.8121 | 0.8426 |
| R_2 | 0.9311 | 1.0360 |
| X_{1d} | 0.8526 | 2.1894 |
| X_{2d} | 0.6153 | 1.7885 |

Table 4

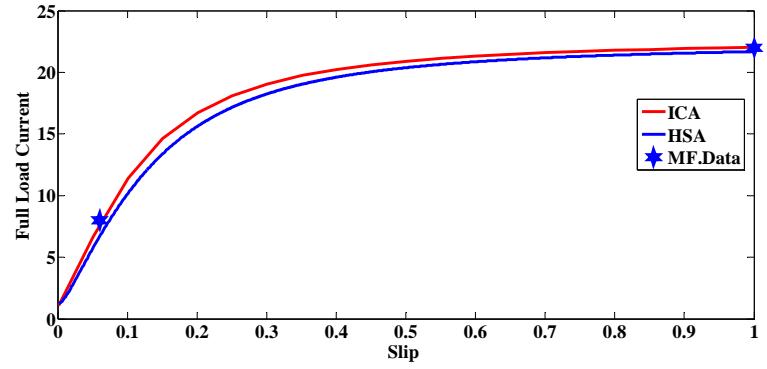
Comparison of the results obtained from ICA and HAS methods, for 5 hp motor

| Variable | MF.Data | ICA | Error, % | HAS | Error, % |
|----------------|---------|---------|-------------|---------|----------|
| $T_{fl} (Nm)$ | 25 | 25.6771 | 2.71 | 25.8504 | 3.4 |
| $T_{st} (Nm)$ | 15 | 15.4056 | 2.7 | 15.1029 | 0.69 |
| $T_{max} (Nm)$ | 42 | 41.3934 | -1.44 | 41.5332 | -1.1 |
| pf | 0.8 | 0.8068 | 0.86 | 0.8102 | 1.27 |
| $I_{st} (A)$ | 22 | 21.9924 | ≈ 0 | 21.4179 | -2.65 |
| $I_{fl} (A)$ | 8 | 8.026 | 0.26 | 7.7907 | -2.62 |

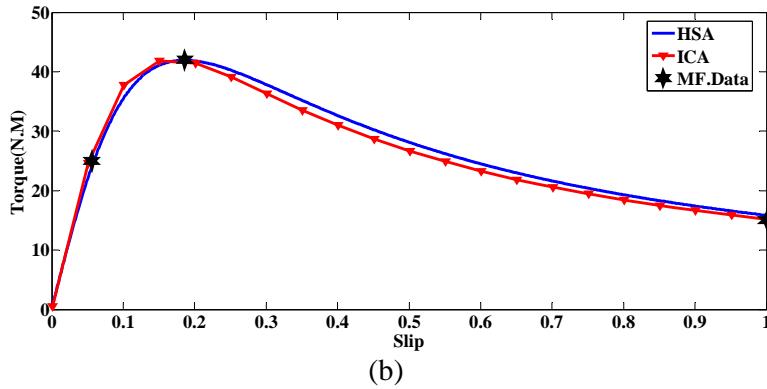
Table 5. Comparison of the results obtained from ICA and HAS methods, for 40hp motor

| Variable | MF.Data | ICA | Error, % | HAS | Error, % |
|----------------|---------|----------|-------------|----------|----------|
| $T_{fl} (Nm)$ | 190 | 177.498 | -6.58 | 174.5951 | -8.11 |
| $T_{st} (Nm)$ | 260.3 | 260.2917 | ≈ 0 | 266.0759 | 2.22 |
| $T_{max} (Nm)$ | 370.5 | 370.5460 | ≈ 0 | 379.7576 | 1.43 |
| pf | 0.8 | 0.8457 | 5.71 | 0.8462 | 5.77 |
| $I_{st} (A)$ | 180 | 180.0656 | ≈ 0 | 182.6850 | 1.49 |

| I_{fl} (A) | 45 | 47.5890 | 5.75 | 47.8990 | 6.44 |
|--------------|----|---------|------|---------|------|
|--------------|----|---------|------|---------|------|

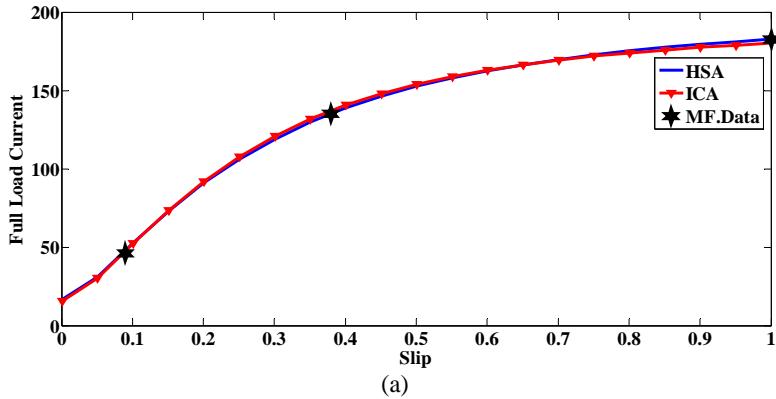


(a)

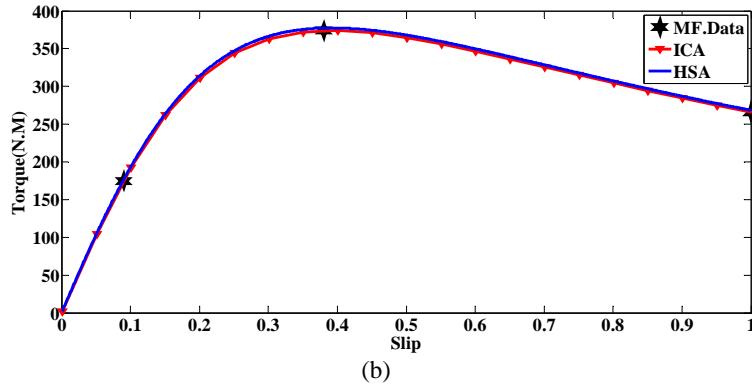


(b)

Fig. 3. Performance curves of the 5hp motor obtained from the motor model using ICA and HSA methods, (a) Current versus slip curve; (b) Torque versus Slip curve.



(a)



(b)

Fig. 4. Performance curves of the 40hp motor obtained from the motor model using ICA and HSA methods (a) Current versus slip curve; (b) Torque versus Slip curve.

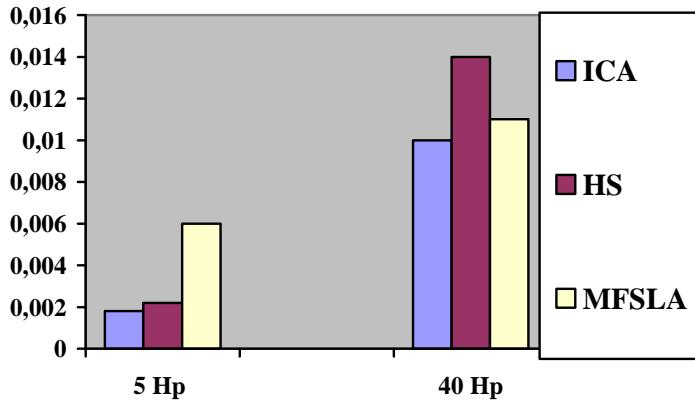


Fig. 5. Comparison of the best costs for ICA, HS and MSFLA (respectively) after 20 runs, for 5 hp and 40 hp motors

5. Conclusion

The study presented two methods for parameter estimation of double-cage induction machines based upon Harmony Search Algorithm (HSA), and Imperialist Competitive Algorithm (ICA). The methods were applied to 5hp and 40Hp double-cage induction motors. Comparison of the result achieved by ICA and HAS methods, in terms of function cost, performance curves and parameter absolute values, with the corresponding results obtained from the previously developed methods, proved the capability of the presented methods in this study in accurate estimation of the double-cage induction machines parameters.

R E F E R E N C E S

- [1] *Sakthivel, V.P., Bhuvaneswari, R., Subramanian, S.*: 'Multi-objective parameter estimation of induction motor using particle swarm optimization', Eng. Appl. Artif. Intell., 2010, 23, (3), pp. 302– 312
- [2] *Say, M.G.*: 'Alternating current machines' (Pitman Press, 1983, 5th edn.)
- [3] *Rogers, G.J., Shirmohammadi, D.*: 'Induction machine modelling for electromagnetic transient program', IEEE Trans. Energy Convers., 1987, 2, (4), pp. 622 –628
- [4] *Dong Hwa Kim, and Jea Hoon Cho*, "Parameter Estimation of a squirrel Double Cage Induction Motor Using Clonal Selection of Immune Algorithm" IEEE Industrial Electronics Society, Busan, Korea, pp. 1190-1194.
- [5] *Koubaa, Y.*: 'Recursive identification of induction motor parameters', J. Simulat. Model. ract. Theory, 2004, 12, (5), pp. 363– 381
- [6] *Stephan, J., Bodson, M., Chiasson, J.*: 'Real time estimation of induction motor parameters', IEEE Trans. Ind. Appl., 1994, 30, (3), pp. 746 –759
- [7] *Wang, K., Chiasson, J., Bodson, M., Tolbert, L.M.*: 'A nonlinear least squares approach for identification of the induction motor parameters', IEEE Trans. Autom. Control, 2005, 50, (10), pp. 1622– 1628.
- [8] *Ansuj, S., Shokooh, F., Schinzingher, R.*: 'Parameter estimation for induction machines based on sensitivity analysis', IEEE Trans. Ind. Appl., 1989, 25, (6), pp. 1035– 1040.
- [9] *Lindenmeyer, D., Dommel, H.W., Moshref, A., Kundur, P.*: 'An induction motor parameter estimation method', Elect. Power Energy Syst., 2001, 23, pp. 251– 262.
- [10] *Pedra, J., Corcoles, F.*: 'Estimation of induction motor double-cage model parameters from manufacturer data', IEEE. Trans. Energy Convers., 2004, 19, (2), pp. 310–317.
- [11] *Bishop, R.R., Richards, G.G.*: 'Identifying induction machine parameters using a genetic optimization algorithm', IEEE Southeastcon Proc., 1990, 2, pp. 476– 479.
- [12] *Bae, D.*: 'Determination of induction motor parameters by using neural network based on FEM results', IEEE Trans. Magnet., 1997, 33, pp. 1924– 1927.
- [13] *Alonge, F., Dippolito, F., Ferrante, G., Raimondi, F.M.*: 'Parameter identification of induction motor model using genetic algorithms', IEE Proc. Control Theory Appl., 1998, 145, (6), pp. 587–593.
- [14] *Rahimpour, E., Rashtchi, V., Pesaran, M.*: 'Parameter identification of deep-bar induction motors using genetic algorithm', Elect. Eng., 2007, 89, pp. 547 –552.
- [15] *Sakthivel, V.P., Bhuvaneswari, R., Subramanian, S.*: 'Bacterial foraging technique based parameter estimation of induction motor from manufacturer data', Electr. Power Compon. Syst., 2010, 38, (6), pp. 657–674.
- [16] *Geem ZW, Kim JH, Loganathan GV*. A new heuristic optimization algorithm: harmony search. Simulation 2001;76(2):60–8
- [17] *Coelho, Leandro dos Santos, and Viviana Cocco Mariani*. "An improved harmony search algorithm for power economic load dispatch." Energy Conversion and Management 50.10 (2009): 2522-2526.
- [18] *Vasebi, M. Fesanghary and S.M.T. Bathaei*, Combined heat and power economic dispatch by harmony search algorithm, Electrical Power and Energy Systems 29 (2007) 713–719.
- [19] *Lee, Kang Seok, and Zong Woo Geem*. "A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice." Computer methods in applied mechanics and engineering 194.36 (2005): 3902-3933.
- [20] *E. Atashpaz-Gargari, C. Lucas*, "Imperialist competitive algorithm: An algorithm for optimization inspired by imperialistic competition", IEEE Congress on Evolutionary Computation (CEC), pp. 4661-4667, Sep 2007.

- [21] *Nazari-Shirkouhi, S., et al.* "Solving the integrated product mix-outsourcing problem using the imperialist competitive algorithm." *Expert Systems with Applications* 37.12 (2010): 7615-7626.
- [22] *Gomez-Gonzalez, M.; Jurado, F.; Pérez, I.*, "Shuffled frog-leaping algorithm for parameter estimation of a double-cage asynchronous machine," *Electric Power Applications, IET* , vol.6, no.8, pp.484,490, September 2012.