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Recent Metha-Heuristic Algorithms in High Induction Motor Design: A Comparison Study

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Abstract: The design of the electrical machines is a complicated process. On top of that, it follows the objective physical and mathematical principles, but on the other hand, knowledge of these principles is often insufficient to produce a correct and economic design, and must be complete by considerable judgment, rules of thumb and experience which can be acquired only after intensive training on the job. This paper carries out efficiency optimization of 37 kW, 380 V, 1800 synchronous r.p.m., three phase squirrel cage induction motor (SCIM) using two swarm intelligence techniques Firefly algorithm (FA) and accelerated particle swarm optimisation (APSO). A comparison between APSO and FA swarm techniques is done. Efficiency and power factor are achieved to the goal and efficiency results satisfies high efficiency level (IE 2 class > 93.0%). APSO is the best method for optimization in comparison with FA if efficiency is to be optimized.

Keywords: Metaheuristic, Design, Induction motor, High efficiency.

1. Introduction

Electric motors consume over half of the energy produced by power stations. This represents almost three-quarters of industrial consumption and almost half of the consumption of commercial sectors in industrialised countries. Motors therefore represent the most significant electrical loads and are therefore the main targets for achieving significant energy savings [1-2].

The design of asynchronous motors covers a very wide field of activity, ranging from machines with a few watts of power intended for computer applications to a motor with a few megawatts installed in heavy industrial processes. This type of machine represents a large part of the electrical machinery market, especially squirrel-cage machines, are the most commonly used electrical machines [3]. Considerable efforts have been and still are being made to perfect the theory and methods of analysis and designs thereof, in order to improve its performance and optimise its price [1-15].

2. Proposed Method

In this work we present an optimal design method to optimize the three-phase induction motor in the manufacturing process. The APSO and FA have been adapted to optimize its design to improve its performances. The motor design procedure consists of a system of nonlinear equations imposing the characteristics of the induction motor, motor performances, magnetic stresses and thermal limits.

The results of the computer simulation are given to show the efficiency of the proposed design process and the optimization techniques applied.

3. Problem Formulation

APSO and FA are implemented with the direct design described in [12] formulated by the following equation:

$$\begin{cases} \min \sum losses(D_{is}, d_1, d_2, h_r, b_{tr}, b_{ts}, b_{s1}, b_{s2}, h_s) \\ s.t. \quad \cos\varphi \geq 0.861 \\ \qquad \eta \geq 0.936 \\ \qquad T_{c0} \leq 101 \\ \qquad i_{LR} \leq 6 \\ \qquad t_{LR} \geq 1.75 \\ \qquad t_{bk} \leq 2.5 \\ \qquad D_{out} = 343 \\ \qquad D_{shaft} = 70 \end{cases} \tag{1}$$

D_{is} is the stator bore diameter, d_1 is the rotor slot higher diameter, d_2 is the rotor slot lower diameter, h_r is the rotor slot useful height, b_{tr} is the rotor tooth width, b_{ts} is the stator tooth width, b_{s1} is the stator slot lower width, b_{s2} is the stator slot higher width, h_s is the stator slot useful height, η is the efficiency, T_{c0} is the winding temperature, i_{LR} is the per unit locked rotor current, t_{bk} is the per unit breakdown torque, D_{out} is the stator outer diameter, D_{shaft} is the shaft diameter.

Where losses is the total losses in induction motor defined by:

$$\sum lossees = P_{c0} + P_{Al} + P_{iron} + P_{mv} + P_{sup} \tag{2}$$

P_{c0} are stator copper loss, P_{Al} are the rotor Aluminum loss, P_{iron} are the iron loss, P_{mv} are the frictionand windage loss and P_{sup} are the stray load loss.

Table 1 shows the brief specification of 37 kW three phase induction motor for optimizing design. The inner diameter of stator and shaft are fixed respectively for assembling prototype [16].

Table 1. Induction motor specification.

Designation	Value
Phase number	3
Input voltage [V]	380
Frequency [Hz]	60
Output power [kW]	37
Pole number	4
Stator out diameter [mm]	343
Shaft diameter [mm]	70

4. Accelerated Particle Swarm Optimization (APSO)

Accelerated Swarm Optimization (APSO) was developed by Xin She Yang in 2008 is a population-based stochastic optimization technique and a simplified version that uses both the best current global and the best individual. The aim of the optimal use of the individual is to increase the diversity of quality solutions. APSO could accelerate the convergence of the algorithm is to use only, the best overall. Thus, in the APSO each particle is attracted by the position of the best current global gbest and its best pbest location of history, while tending to move randomly. When a particle finds a better location than all previously found locations, it updates it as the best current for particle i. There is a best current for all n particles at any time t during iterations. The objective is to find the best overall of all the best current solutions until the objective no longer improves or after a number of iterations [17].

The typical values for this APSO are $\alpha \approx 0.1 \sim 0.4and\beta \approx 0.1 \sim 0.7$; however, $\alpha \approx 0.2$ and $\beta \approx 0.5$ are recommended [18]. In general, any stochastic search algorithm shows improved performance with a relatively larger population. Nevertheless, a very large population will cost more in terms of fitness function evaluations without producing significant improvements. In this simulation, the population size is set to 150.

In APSO [19], the speed vector is generated by a simple formula given by the Eq. (3):

$$v_i^{t+1} = v_i^t + \alpha \xi_n + \beta(gbest - x_i^t) \tag{3}$$

5. Firefly Algorithm

Firefly algorithm is one of recent metaheuristic nature-inspired algorithm, which was developed by Dr. Xin-She Yang at Cambridge University in 2007. Whereas this algorithm has some similarities with other algorithms based on the collective intelligence of the group such as PSO, but relatively speaking this algorithm is relatively simple in theory and implementation. And the most prominent advantage is the use of the random movement of individuals, taking into account the mutual influence between individuals at the same time. Some recent literatures show that the algorithm is very effective in solving some optimization problems and can be better than the other traditional algorithms. And the stability of the firefly algorithm proved to be superior to other well-known optimization algorithm [20].

The firefly algorithm is inspired by the flashing behaviour of fireflies. The movement of each Firefly is guided by its flashing pattern and attraction strategy. The algorithm takes into account the tree following points [21]:

- All fireflies are unisex so that one Firefly is attracted to other fireflies regardless of their sex.
- Attractiveness is proportional to brightness, so for any two flashing fireflies, the less bright Firefly will move towards the brighter Firefly. Both attractiveness and brightness decrease as the distance between fireflies increases. If there is no Firefly brighter than a particular Firefly, that Firefly will move randomly.
- The brightness of a Firefly is affected or determined by the landscape of the objective function.

The movement equation of a less bright Firefly *I* attracted by a brighter firefly *j* is determined by:

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha\left(rand - \frac{1}{2}\right), \quad (4)$$

where r_{ij} is the cartesian distance between two fireflies *i* and *j*. it is defined by:

$$r_{ij} = \sqrt{\sum_{k=1}^{d}(x_{i,j} - x_{j,k})^2}, \quad (5)$$

β_0 is the attractiveness at $r = 0$, α is a random parameter and parameter γ characterizes the variation of the attractiveness.

6. Simulation Results

The change of objective function values according to the iteration is shown in Fig. 1. It is seen that the APSO method converges at the smallest iteration number. The APSO algorithm converges at the 29th iteration. However, FA algorithm converges at the 127th iteration.

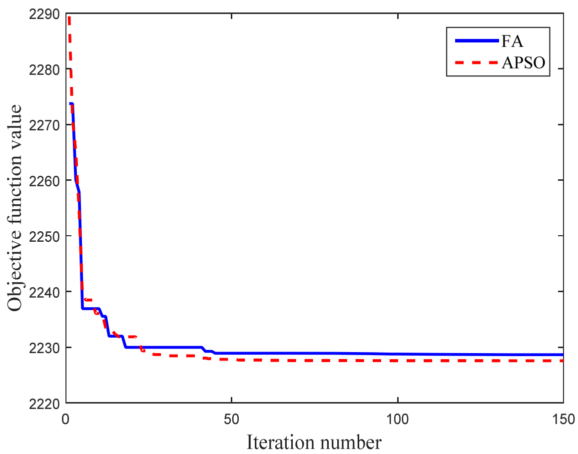

Fig. 1. Iteration number versus the objective function value.

The performances and the optimal design variables of the motor obtained with the two methods are given in Table 2.

It is clear from the table that the APSO is able to offer the better efficiency and the desired power factor than that of the FA approach.

Fig.2 represent the variation of efficiency vs. shaft torque for three different techniques APSO, FA and conventional technique. APSO and FA methods are seen to have caught the actual values with very small differences. It is also observed that the values of the efficiency satisfies high efficiency level (IE 2 class > 93.0%) for the three techniques. The values obtained by APSO and FA are close to the target value.

Table 2. Comparison of the results obtained by the FA and APSO methods for a 37kW SCIM.

Designation	Conception conventional	FA	APSO
D_{is} [mm]	221	215	215
d_1 [mm]	7.3477	7.5	7.5
d_2 [mm]	2.8419	2.5	2.5
b_{s1}	6.5195	5.2430	5.289712
b_{s2}	10.3856	8.7699	8.943088
h_r [mm]	28.6257	28.7	28.69998
b_{tr} [mm]	9.2754	5.0420	5
b_{ts}[mm]	8.2721	4.4	4.4
h_s [mm]	29.4923	28.3769	28.03786
i_{LR}	5.9638	5.9812	5.9959
t_{LR}	0.9928	0.9964	1.0008
t_{bk}	2.9135	2.9278	2.9323
Power factor [%]	86.44	86.18	86.18
Efficiency [%]	93.23	93.51	93.52
T° of winding [°C]	112.2971	113.2397	113.8508

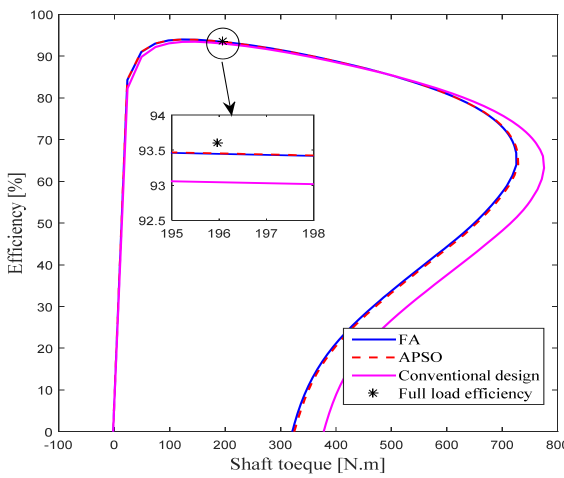

Fig. 2. Efficiency-Shaft torque characteristic after optimization.

The change of objective function value according to the number of trial is shown in Fig. 3 for the two methods APSO and FA. It is seen that the values obtained by the FA as a result of 30 operations are bigger than the values obtained by the APSO. It is seen that the maximum fitness value is obtained by the FA at the 20th operation, and the minimum fitness value is obtained at the 1st operation by the APSO. However, the lowest fitness values is obtained by FA at the 23th operation.

The CPU times obtained by the 30 operations of the two methods are given in Fig. 4. It is seen that the FA has the longest solution time and the APSO has the shortest solution time. The solution times of the APSO methods are seen to be less than 1 s. While the FA method reached two seconds.

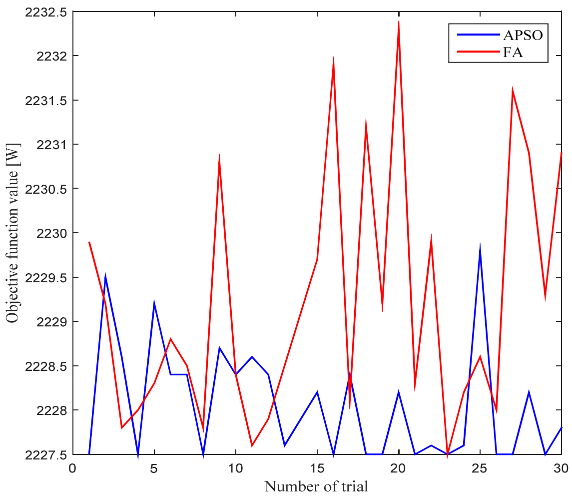

Fig. 3. Distribution of the total loss of the two methaheuristic.

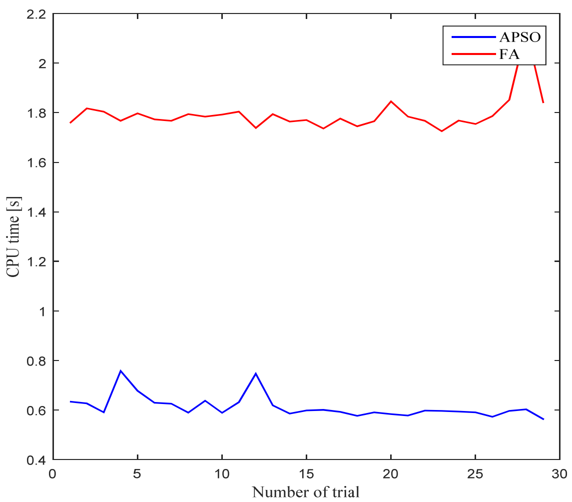

Fig. 4. Distribution of the CPU time of the two methaheuristic.

7. Conclusions

APSO and FA are two powerful populations based heuristic algorithms for solving multimodal optimisation problems. The results of SCIM performances clearly demonstrate the ability of the APSO and FA to produce the best global design parameters that maximise its efficiency and starting torque as well. It has been exhibited that the proposed approaches encourage the continued use of APSO and will go a long way in serving as a useful tool in design problems.

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