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CUCKOO OPTIMIZATION ALGORITHM BASED DESIGN FOR LOW-SPEED LINEAR INDUCTION MOTOR

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Abstract. In these years, linear induction machines (LIMs) are widely used in rapid transportation applications and these machines achieve thrust directly without gear device, link or axial mechanism system. Furthermore LIMs have numerous other benefits such as not complex body and easy repairing. Unfortunately LMIs have big disadvantage: not good efficiency and weak power factor. These disadvantages cause high energy loss and a rise in input current value, and occupy transmission line capacity. In this research article, a multiobjective optimization system based on cuckoo optimization algorithm (COA) to enhance both efficiency and power factor is introduced, concurrently. The suggested intelligent system is established on capability of nature-based optimization algorithms in selecting the optimal solution. One benchmark and standard example is applied to show the operation of the design method and optimization system. The advantage features of the COA is due to its capability to concurrently refine a local search, as searching globally solution in search space. Furthermore, computer simulation results demonstrate that proposed method have a low dependency on oscillation of the variables. Also, the applied optimization technique was very speedy, requiring a low time to discover the optimum result in search space.

Keywords: COA, Linear induction motors, optimization, efficiency, power factor

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1. INTRODUCTION

The linear electrical motors may be categorized into following: DC motors, induction motors, synchronous motors and stepping motors etc. Among these motors that mentioned, the linear induction motor (LIM) has many valuable benefits such as reduction of mechanical losses and the size of motion devices, silence, high starting thrust force, and easy maintenance, repairing, and replacement (Neto, et al., 1998). Linear motors are electrical machines which unlike normal machines do not have rotors in the traditional sense, but parts which move in a direct line when the motor is excited. In a general three phase induction motors, the stator provides a rotating magnetic field which induces the rotor to rotate along with it.

A researcher consider the Linear Induction Motor (LIM) to be structured out of its rotary counterpart where the stator and the rotor have been cut and unrolled. Now, the stator generates a motion magnetic field instead of a rotating one. The rotor is induced to move along it. The exciting part of the LIM (like the stator in the normal rotary machine) is named the primary and the part in which currents are induced (like the rotor in the normal rotary machine) is named the secondary of the LIM devices. Commonly either of the primary or the secondary part of this MLI is stationary and extends over the entire range of motion of the other sections. Therefore, LIMs can be categorized as either short-primary (also named short-stator in research articles and books) or short-secondary (named short-rotor) LIMs. LIMs can also be categorized based on its structure as primary and one secondary placed one on top of the other, Double Sided LIM (DLIM) in which there are two primaries on the two sides of a secondary versions. They are also categorized as high-speed and low-speed LIMs versions(Laporte, 1997).

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Nowadays, major of the linear induction motors find usages at low speeds and at standstill. Particularly, these include belt conveyors, material handling instruments, door of house and curtain of house operators, overhead cranes instruments, and short-stroke actuators and devices. Single-sided linear induction motor has been used in the very different used in industrial applications. Particularly, LMI with low speed is applied in transportation. The reason why it is chosen the LIM for transportation is the low energy consumption, high speed, and low pollution advantages. Electrical energy converts into mechanical energy and linear motion is reached.

There are not sufficient search on LMI issue. In reference (Yoon, et al., 1997) optimization design is based on some features such as end effect, transverse edge effect and normal force aspects. In reference (Yoon, 1997) optimization is performed based on starting thrust and output power to input volt–ampere ratio. Reference (Imani, 1993) introduces the optimization issue applying the finite element approach and the sequential unlimited minimization method (SUMM). In (Mishima, 2005) optimization of the stator-winding arrangement for magnetic levitation part (Maglev) systems is investigated. In reference [9] an optimum draft and model of LIM based on efficiency and power factor as an objective function is suggested and analyzed.

This research article introduce intelligent technique to design of a low speed single sided linear induction motor by cuckoo optimization algorithm method. In the propose method both power factor and efficiency are selected in fitness function. The section two describes the LMI and Magnetic equivalent circuit of LIM. The section 3 introduce the optimization technique. Section 4 presents the optimization problem. Section 5 presents some computer simulation results and finally section 6 conclude the paper.

2. MAGNETIC EQUIVALENT CIRCUIT OF LIM

An induction or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor, as in universal, DC and large synchronous motors. An induction motor's rotor can be either wound type or squirrel-cage type.

Three-phase squirrel-cage induction motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and VFD applications.

In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through an external impedance. The rotating magnetic flux induces currents in the windings of the rotor; in a manner similar to currents induced in a transformer's secondary winding(s). The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors. The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors.

For rotor currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion.

The structure of the suggested LIM is shown in Fig. 1. Also Fig. 2 illustrate the magnetic equivalent circuit (MEC) of LIMs [10]. We have:

$$X_m = \frac{12\mu_0 w_l a_e k_w^2 N_{ph}^2}{\pi^2 p g_{ei}} \tag{1}$$

$$\mathrm{X}_1 = \frac{2\mu_0 w_l}{p}\left[\left(\lambda_s\left(1+\frac{3}{2p}\right)+\lambda_d\right).\frac{2a}{q}+\lambda_e I_{ce}\right]\mathrm{N}_{\mathrm{ph}}^2 \tag{2}$$

$$\mathrm{R}_1 = \frac{1}{\sigma_c}\left(\frac{4a+2I_{ce}}{N_{ph} I}\right) J_c \mathrm{N}_{\mathrm{ph}}^2 \tag{3}$$

$$\mathrm{R}_2^{/} = \frac{12 a_e k_w^2 N_{ph}^2}{\tau d p \sigma_{ei}} \tag{4}$$

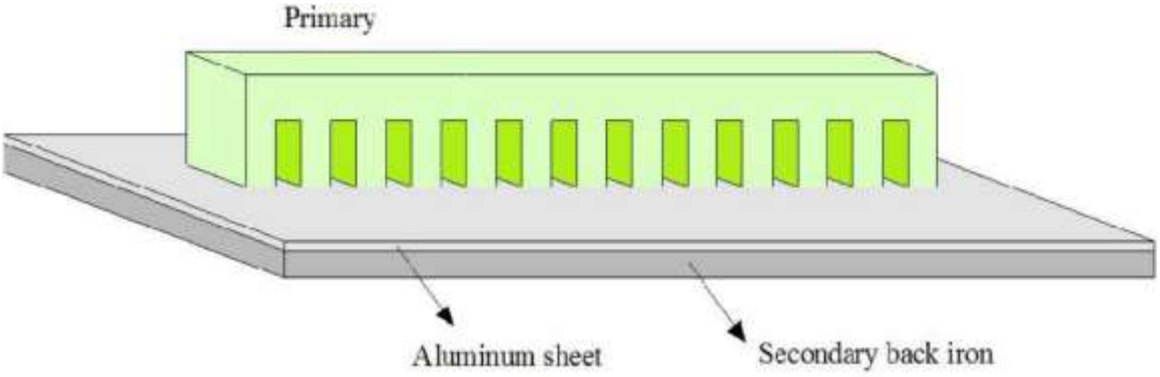

Figure 1. Structure of a LIM.

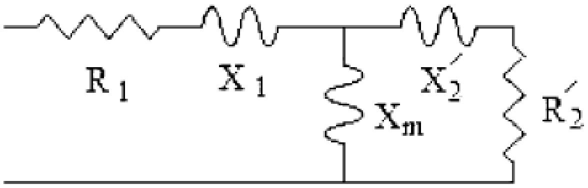

Figure 2. Equivalent electrical circuit of proposed motor.

The effectiveness factor, one of the valuable index in design model, is then defined using [10]:

$$G = \frac{2 f_l \mu_0 \sigma_{ei} d\tau}{\pi g_{ei}} \tag{5}$$

$$\mathrm{J_m} = \frac{\sqrt{2} m N_{ph} I k_w}{p\tau} \tag{6}$$

Thus, the magnitude of first part of flux density in the air gap is computed as follows [10]:

$$\mathrm{B_{g1}} = \left| \frac{j\mu_0 \mathrm{J_m}}{\pi \frac{\mathrm{g_m}}{\tau}\left(1 + jsG\right)} \right| \tag{7}$$

If the be air gap flux density below 0.5 T, then the iron power losses is very low and the thrust, the efficiency, and the power factor are defined as follow [10]

$$\mathrm{F_x} = \frac{3I^2 R_2^{/}}{2sf_l\tau\left[\left(\frac{1}{sG}\right)^2 + 1\right]} \tag{8}$$

$$\eta = \frac{\mathrm{F_x} 2\tau f_l \left(1 - s\right)}{\mathrm{F_x} 2\tau f_l + 3I^2 R_1} \tag{9}$$

$$\cos\varphi = \frac{\mathrm{F_x} 2\tau f_l + 3I^2 R_1}{3\mathrm{VI}} \tag{10}$$

Fig. 3 illustrate the changes of the efficiency with respect the air gap length and the aluminum thickness. Fig. 4 illustrate the oscillation of the power factor with the air gap length and the aluminum thickness. It is clear that a reduction in the air gap length and the aluminum thickness leads to an growth in the power factor magnitude.

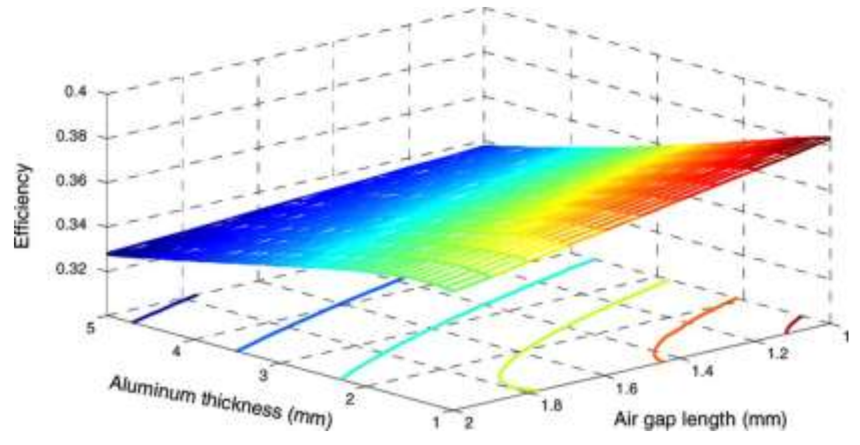

Figure 3. Analysis of effects the air gap length and aluminum thickness.

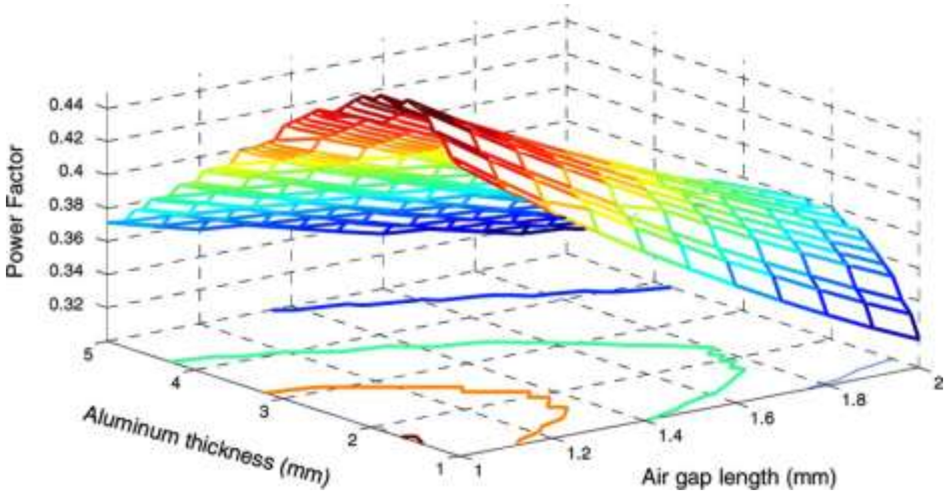

Figure 4. Effects of air gap length and aluminum thickness on the power factor of the analyzed LIM

While the number of pole pairs growths, the efficiency decreases and the power factor growths. Effects of primary current density on the power factor and the efficiency are illustrated in Fig. 5. It is clear that larger current densities growth the power factor and reduce the efficiency of LIMs.

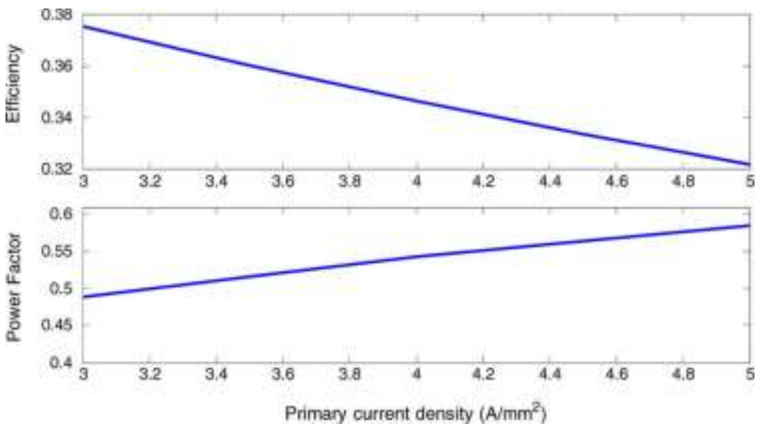

Figure 5. Illustration effects of the number of pole pairs.

3. CUCKOO OPTIMIZATION ALGORITHM (COA)

Cuckoo optimization algorithm is an optimization algorithm developed by Rajabioun (Rajabion, 2011). It was inspired by the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds (of other species). Some host birds can engage direct conflict with the intruding cuckoos. For example, if a host bird discovers the eggs are not their own, it will either throw these alien eggs away or simply abandon its nest and build a new nest elsewhere. Some cuckoo species such as the New World brood-parasitic Tapera have evolved in such a way that female parasitic cuckoos are often very specialized in the mimicry in colors and pattern of the eggs of a few chosen host species.

Cuckoo search idealized such breeding behavior, and thus can be applied for various optimization problems. It seems that it can outperform other metaheuristic algorithms in applications.

Cuckoo search (CS) uses the following representations:

Each egg in a nest represents a solution, and a cuckoo egg represents a new solution. The aim is to use the new and potentially better solutions (cuckoos) to replace a not-so-good solution in the nests. In the simplest form, each nest has one egg. The algorithm can be extended to more complicated cases in which each nest has multiple eggs representing a set of solutions.

The flowchart of COA is illustrated in Fig. 6. Such other nature based optimization algorithms, the COA starts with an initial generation of particles (Rajabioun, 2011). These first particles or cuckoos have some eggs to lay in several host birds’ nests. Some of these eggs which are more like to the host bird’s eggs have the chance to pickup and become a old bird. The rest eggs are identified by host birds and are destroyed. The big eggs show the suitability of the nests in that environment. The more eggs survive in an environment, the more profit is achieved in that territory. Therefore the location in which large eggs survive will be the term that COA is going to optimize. The main steps of COA are presented in Fig. 7 as a pseudo-code (Rajabioun, 2011).

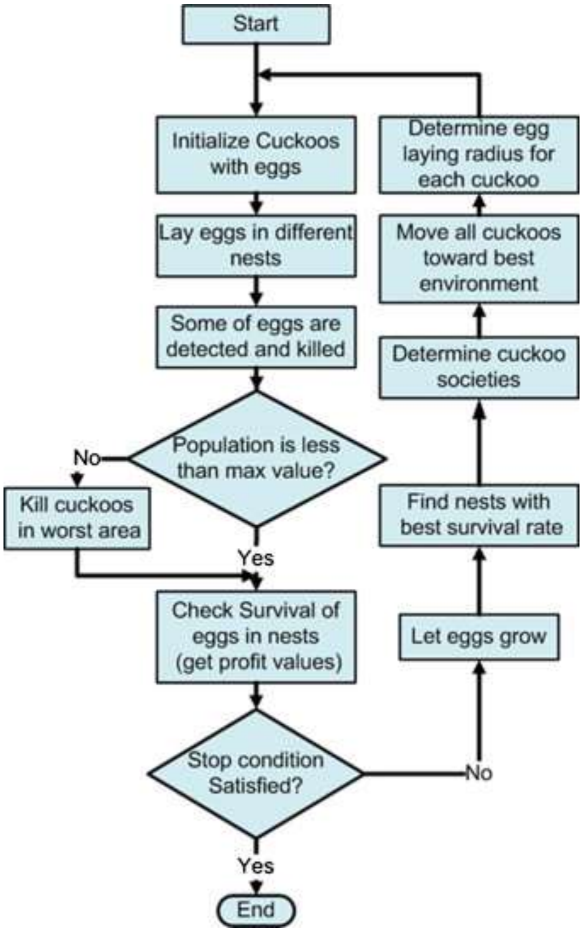

Figure 6. Flowchart of Cuckoo Optimization Algorithm.

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1. Initialize bird habitat with some chance points on the profit function
2. Dedicate some eggs to each birds
3. Describe ERL for each bird
4. Let birds to lay eggs inside their related ERL
5. Destroy those eggs that are detected by host bird
6. Let eggs hatch and chicks grow
7. Test the habitat of each newly grown bird
8. Limit cuckoo's maximum number in environment and kill those who live in worst lodging
9. Cluster birds and find best family and find target lodging
10. Let new cuckoo population immigrate toward target lodging
11. If stop term is achieved stop, if not go to 2
```

Figure 7. Pseudo-code for cuckoo optimization algorithm.

4. PROPOSED METHOD

Several of the conventional LIM variables and dimensions are chosen as design variables whose values are determined in optimization procedure by COA technique. In this research article, draft variables are the primary winding current density, the primary width to pole pitch ratio, the aluminum sheet thickness, and the maximum thrust slip. Table 1 shows the limits of the design procedure. The rated thrust, the input voltage and frequency, and the mechanical speed—the main fixed features the draft procedure are 128 N, 220 V, 50 Hz, and 2.5 m/s, respectively.

Table 1. Design limits and conditions.

Parameter	Symbol	Unit	Minimum value	Maximum value
Maximum thrust slip	S	-	0.1	0.5
Aluminum thickness	d	Mm	1	4
Primary width/pole pitch	a/τ	-	0.5	4
Primary current density	J_c	A/mm^2	3	5
Efficiency	J_c	-	0.35	-
Power factor	J_c	-	0.3	-

To achieve an optimal draft considering both power factor and efficiency, the fitness function is described as below:

$$J_\tau\left(x_1,...,x_n\right)=\eta\left(x_1,...,x_n\right)^{k_1}.PF\left(x_1,...,x_n\right)^{k_2} \tag{11}$$

Here k_1 and k_2 are fixed numbers and $x_1,...,x_n$ are draft parameters. When efficiency factor of LMI is most valuable than power factor, we may select $k_1=1,\ k_2=0$ and as power factor is most valuable, these fixed numbers will be chosen as $k_1=0,\ k_2=1$. If we have $k_1=k_2=1$ both efficiency and power factor will be optimized concurrently. The three mentioned problems are assigned optimal 1, optimal 2 and optimal 3, respectively (Hassanpour Isfahani, 2008).

5. SIMULATION RESULTS

In table 2 the motor dimensions and properties using traditional, genetic algorithm, and COA design optimization methods is mentioned. Traditional motor variables and GA explore results are given from reference [12]. Table 2 shows that maximum efficiency is achieved in the first optimization case (or optimal 1) for both GA and COA. But COA result is more better than GA one system. Also, the highest of power factor is obtained in optimal 2 case and also, COA result is very better than GA system. In the remaining case, case of optimal 3, in comparison with traditional draft GA enhanced the power factor around 1.3 times better. Unfortunately it destroys the efficiency around 0.9 times. In other aspect, COA enhanced both power factor and efficiency around 1.97 and 1.24 times respectively which have significant. It is valuable note to mention that COA in all optimization problems that used in this article (optimal case through 1–3) enhanced both efficiency and power factor in the comparison with classical draft and of course in each issue the basic target function is much more optimized.

Table 2. Optimization results and conventional motor parameters.

Parameter	Conventional design [12]	GA [12]			COA		
		Opt.1	Opt.2	Opt.3	Opt.1	Opt.2	Opt.3
Efficiency	0.36	0.393	0.325	0.327	0.4901	0.4345	0.4461
Power factor	0.32	0.3	0.42	0.415	0.5729	0.6463	0.6295
Maximum thrust slip	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Aluminum thickness	2	1.4	1.7	1.7	1	1	1
Primary width/pole pitch	2	2.5	3.9	3.9	2	4	4
Primary current density	4	3	5	5	3	5	4.01

Fig. 8 illustrate the improvement of fitness function selected in the proposed method through several iterations in these three optimization issues by GA system (Hassanpour, 2008). As depicted in this figure in the best state, optimization algorithm reach to optimal point after 50 iteration. The improvement of these fitness functions by COA is illustrated in Fig. 9. As said in previous sections, the fitness function of COA is chosen as the inverse of genetic algorithm one and Fig. 9 shows the average and minimum charge of all cuckoos versus iteration.

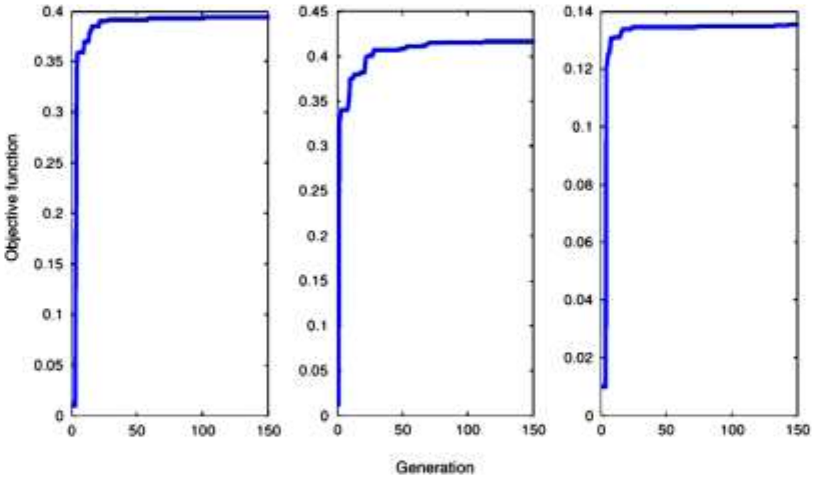
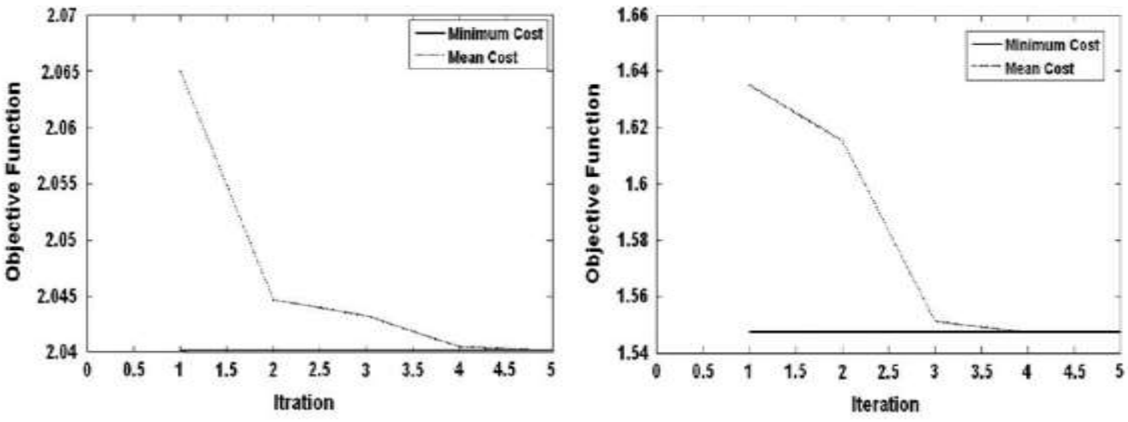


Figure 8. Enhancement of fitness function by GA (Hassanpour, 2008).



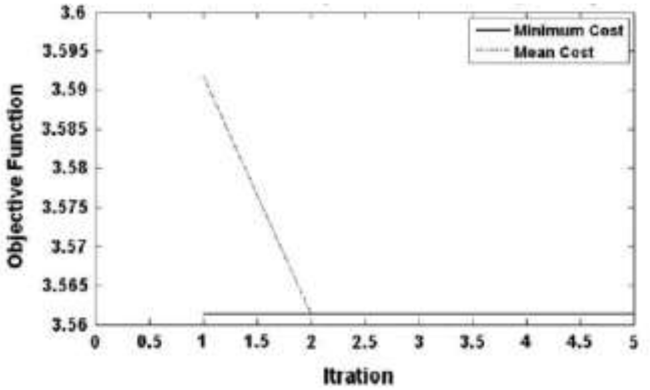


Figure 9. Average and minimum charge of all cuckoos versus iteration in these three optimization issues (from left to right: Optimal1, Optimal2, Opimalt3).

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