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Improved Shuffled Frog Leaping Algorithm for the Combined Heat and Power Economic Dispatch

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Abstract

This paper presents an improved shuffled frog leaping algorithm (ISFLA) for combined heat and power economic dispatch (CHPED) problem. The proposed ISFLA technique which is a frog population based global search and optimization technique, has been developed to solve the CHPED problem. ISFLA is an improved version of shuffled frog leaping algorithm in which new solutions are produced in respect to global best solution. The CHPED problem difficulty is its constraints which of satisfied simply by using ISFLA. In order to evaluate the efficiency of the proposed ISFLA, It has been tested on standard test system and obtained results are compared with other methods. The numerical results show that the proposed method is faster and more precise than other methods.

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Keywords

Combined Heat and Power Economic Dispatch, Improved Shuffled Frog Leaping Algorithm, Optimization.

Introduction

In the last three decades with rising fuel prices, the importance of alternative fuel debate, increasing energy efficiency, reducing environmental pollution and increasing demand use of co-generation systems that simultaneously produce heat and power is quite very noticeable. There are limitations on co-generation units is that the heat generated is dependent on the production of power. The objective of economic dispatch (ED) problem in a conventional unit is to find the optimal point for the power production such that the total demand matches the generation with minimum fuel cost. However, the objective of combined heat and power economic dispatch (CHPED) is to find the optimal point of power and heat generation with minimum fuel cost such that both heat and power demands are met while the combined heat and power units are operated in a bounded heat versus power plane. A technique was developed in [1] to solve the CHPED problem using separability of the cost function and constraints. In this method two-level strategy is adopted; the lower level solves economic dispatch for the values of power and heat lambdas and the upper level updates the lambda's sensitivity coefficients. The procedure is repeated until the heat and power demands are met. Alternatives to the traditional mathematical approaches: evolutionary computation techniques such as genetic algorithm (GA) [2, 3], evolutionary programming (EP) [4], multi-objective particle swarm optimization (MPSO) [5], harmony search (HS) [6], fuzzy decision making (FDM) [7], self adaptive real genetic algorithm (SARGA) [8], particle swarm optimization with improved inertia weight (PSO-IIW) [9], Time varying acceleration coefficient particle swarm optimization [10], Artificial Bee Colony [12] and Improved ant colony search algorithm (ACSA) [11] have been successfully applied to CHPED problem. In [2], improved genetic algorithm with multiplier updating (IGAMU) approach is implemented to solve the CHPED problem using penalty based constraint handling method.

The CHPED Problem Formulation

Combined heat and power systems are higher efficiency and produce fewer harmful emissions than conventional units. Figure 1 shows the heat-power Op-

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eration Region of a combined cycle co-generation unit. The feasible operation is enclosed by the boundary curve WXYZ.

The objective function and its related constraints of CHPED problem as

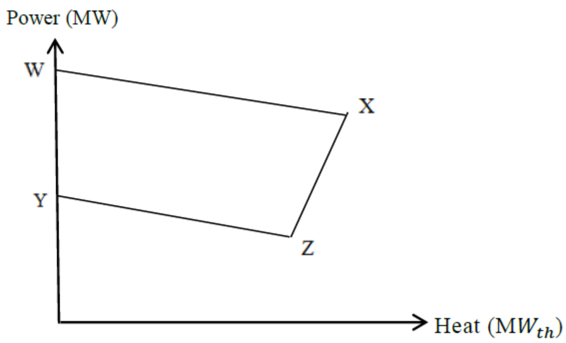

Figure 1: *Feasible operating region of a CHP unit*

follows:

$$min f_{cost} = \sum_{i=1}^{N_p} C_i(P_i) + \sum_{j=1}^{N_c} C_j(O_j, H_j) + \sum_{k=1}^{N_k} C_k(T_k) \tag{1}$$

$$\sum_{i=1}^{N_p} P_i + \sum_{j=1}^{N_c} P_j = P_d + P_L \tag{2}$$

$$\sum_{j=1}^{N_c} H_j + \sum_{k=1}^{N_k} H_k = H_d \tag{3}$$

$$P_i^{min} \leq P_i \leq P_i^{max}, i = 1, 2, .., N_p \tag{4}$$

$$P_j^{min} \leq P_j \leq P_j^{max}, j = 1, 2, .., N_c \tag{5}$$

$$H_j^{min} \leq H_j \leq H_j^{max}, j = 1, 2, .., N_c \tag{6}$$

$$H_k^{min} \leq H_k \leq H_k^{max}, k = 1, 2, .., N_k \tag{7}$$

where min f_{cost} is the total minimum fuel cost; C_i, C_j and C_k are the unit production costs of the conventional power, co-generation and heat-alone units, respectively; P_i and P_j are power generations of conventional power and co-generation units; H_j and T_k are heat generation of co-generation and heat-alone units; H_d and P_d are heat and power demands; N_p, N_c and N_k denote the number of conventional power, co-generation and heat-alone units, respectively

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P_i^{min} and P_i^{max} are the minimum and maximum power generation limits of the conventional units; O_j^{min} and O_j^{max} are the minimum and maximum power generation limits of the co-generation units; H_j^{min} and H_j^{max} are the minimum and maximum heat generation limits of the co-generation units; H_k^{min} and H_k^{max} are the minimum and maximum heat generation limits of the heat-alone units.

Overview of Shuffled Frog Leaping Algorithm

The shuffled frog leaping algorithm (SFLA) is an optimization technique that is inspired by the behaviour of a group of frogs to find a place that has the most food. This algorithm introduced in 2003 [13]. In this algorithm, each individual of population called a frog and the use two strategies, local search and global search to produce the next generation and if the objective function improved, replacing the current frog. This algorithm consists of three parts as follows:

Generate Initial Population

Randomly generate an initial population $N = [X_1, X_2, X_3, X_4, ..., X_n]T$ of n solutions in the multi-dimensional solution space, where n represents the size of frog population. Position of i^{th} frog is $X_i = [X_{i1}, X_{i2}, X_{i3}, X_{i4}, ..., X_{is}]$, where s is number of parameters to be optimized.

Grouping

The frogs are sorted according to fitness level. All population is divided in to m (m memeplexes) subsets, each containing p frogs. So $n = m$ x p. Communication strategies between frogs and group in such a way that the first frog of sorted population goes to the first memeplex, the second frog goes to the second memeplex frog m goes to the m frog, so in each memeplex, there will p frogs.

Local Search

In local search the worst frog's position each group improved with respect to best frog's position in the same group. For this purpose, the following steps are repeated.

Step 1) The best and worst frogs determine based on position fitness and X_b, X_w are called respectively.

Step 2) The worst frog's position change with respect to The best frog's position is as follow:

$$D = rand * (X_b - X_w) \tag{8}$$

$$X_w^{new} = X_w^{old} + D \tag{9}$$

Where D Leap Frog Vector, $rand$ is random number between 0 and 1, X_w^{old} old position of the worst frog and X_w^{new} new position of the worst frog. If new solution better than previous solution, the new frog replace to old frog and go to step 5, otherwise go to step 3.

Step 3) The best solution of all groups (X_g) replace X_b in equation 8 and new frog generate by equation 9. If new solution is better than previous solution, the new frog replace to old frog and go to step 5, otherwise go to step 4.

Step 4) Randomly generate a new frog and replace the worst frog.

Step 5) Repeat step 1 to 4 until stop condition.

Stop Condition

Local search process continues until convergence criteria is satisfied.

Improved Shuffled Frog Leaping Algorithm

Although SFLA has a high speed, but it may to solve complex non-linear mathematical models to be trapped in local search. For this reason in this paper introduces improved shuffled frog leaping algorithm (ISFLA) which is faster than SFLA. In ISFLA move the worst frog in each group (X_w) is changed in each iteration of local search. At first the worst solution in each iteration will produce follows Mutation vector:

$$X_w = X_g + F * (X_{t1} - X_{t2}) \tag{10}$$

where X_{t1} and X_{t2} are two different frogs that randomly select among frogs group. F is the Mutation factor that determine difference between X_{t1} and X_{t2} and X_g The best solution is generated up to the current iteration. So the j^{th} parameter vector X_w^{new} in next iteration by equation 14.

$$\begin{cases} X_{wj} & \text{if } rand < CR_g \text{ or } j = rm \\ X_w^{old} & \text{otherwise} \end{cases} \tag{11}$$

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Where $rand$ is random number between 0 and 1, CR_g is general crossover probability which is defined value usually selected from within the range [0,1]. rm is a random number is selected from within the range of solution parameters and suggests that at least one of the values of the parameters of X_w^{new} is selected from value X_w^{old}. If fitness value of new solution is better than old solution, new frog will be replaced previous frog. Otherwise, equations 10, 11 is repeated with replace, best solution of each group(X_b) with X_g and local crossover probability (CR_b) with general crossover probability (CR_g). If at this stage one of the solution did not improve, a frog is generated randomly in the range of solution space and will be replaced the previous frog. The flowchart for ISFLA is shown in figure 7.

Improved Shuffled Frog Leaping Algorithm for CHPED Problem

In This section, an algorithm based on ISFLA for solving CHPED problem is described below:

Initialization

In the Initialization process, the position of a set of frogs will be generated randomly.
Let $X_i = [P_{i,1}, P_{i,2}, P_{i,3}, ..., P_{i,Np}, P_{i,Np+1}, ..., P_{i,Np+Nc}, H_{i,1}, ..., H_{i,Nc}, H_{i,Nc+1}, ..., H_{i,Nc+Nh}]$. The X_i are the real power outputs of conventional unit, power and heat outputs of co-generation units and heat alone units. In the Initialization process, Position of each frog is chosen so that equality and inequality constraints are met.

Sorting and Grouping

Frogs are sorted based on their position fitness and according strategy part 3-2 are grouped.

Local Search

Local search process is presented in according to process section 3-3 and Corrective strategy is based in part 4.

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Feasible Operation Region by Combined Heat and Power System

In combined heat and power units Power and heat output are reciprocally dependent. Therefore these constraints are introduced as feasible operation region constraints that they are very difficult to be met. In [14] a new penalizing proposed that infeasible solutions are penalized. When power and heat out put of combined heat and power unit is outside its feasible region, a penalty factor depending on the minimum distance between the combined heat and power unit output and the feasible region boundary is worked. Figure 2 shows the minimum distance expressed. If $\alpha h + \beta p + \gamma = 0$ is the equation of the line WX then distance (P_0, H_0) from the line WX calculated by Eq. 12. Then a penalty factor is calculated using Eq. 13.

$$L = \frac{|\alpha H_0 + \beta P_0 + \gamma|}{\sqrt{\alpha^2 + \beta^2}} \tag{12}$$

$$PF = Z.\sum_{i=1}^{n} L_i \tag{13}$$

Where (PF_i) is the penalty factor of i_{th} solution and Z is constant value. The penalty factor add to cost function.

$$F_{cost} = f_{cost} + PF \tag{14}$$

So, if $F_{cost} = f_{cost}$, x is feasible solution.
Else, $F_{cost} = f_{cost} + PF$, x is infeasible solution.

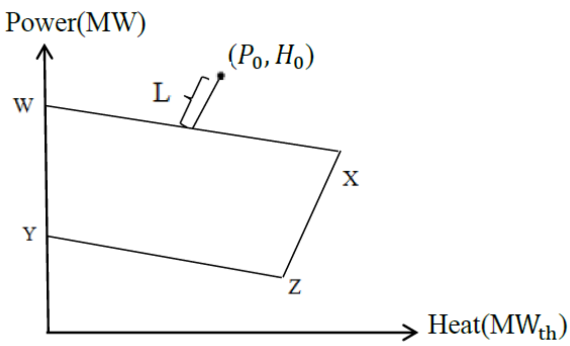

Figure 2: *Penalty calculation graphical form*

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Stop

In this paper, the algorithm stop condition, the maximum allowable iterations is considered as the process of searching for a specified number of iterations is performed and finally the position of the best frog is considered as the final answer.

Numerical Results

In this section is presented the numerical results of ISFLA for solve CHPED problem. To show the efficiency of the proposed method is tested on the 4 units system which consists of a conventional unit, two co-generation units and a heat alone unit. The units data are given [8]. The feasible operating regions of the two co-generation units are given in figure 3 and 4. The power demand P_D and heat demand H_D are 200 MW and 115 MW_{th} respectively. The fuel cost of conventional, co-generation and heat alone units are given in equations 16-19. The objective function is of the CHPED problem is:

$$min f_{cost} = C_1(P_1) + C_2(P_2, H_2) + C_3(P_3, H_3) + C_4(P_4) \quad (15)$$

$$C_1(P_1) = 50P_1 \quad (16)$$

$$C_2(P_2, H_2) = 2650 + 14.5P_1 + 0.0345P_1^2 + 4.2H_1 + 0.03H_1^2 + 0.031P_1H_1 \quad (17)$$

$$C_3(P_3, H_3) = 1250 + 36P_2 + 0.0435P_2^2 + 0.6H_2 + 0.027H_2^2 + 0.011P_2H_2 \quad (18)$$

$$C_4(P_4) = 24.3H_4 \quad (19)$$

The results obtained from ISFLA is compared with PSO, ABC, DE. All these methods are coded in MATLAB 7 and executed using on a 2 GHz Pentium IV personal computer with 1 GB of RAM. The setup parameters for the ISFLA are given in Table 1. Table 2 compares the four computational results of this system obtained from ISFLA, PSO, ABC, DE. It is found that the ISFLA provides lower production cost and CPU time. Figure 6 shows the cost convergence obtained from ISFLA, PSO, ABC, DE.

Sensitivity Analysis

In this section is investigated impact of the ISFLA parameters on the accuracy and speed of response. For this purpose Sensitivity analysis is done on the test system. Table 3 is demonstrated ISFLA sensitive to change in mutation

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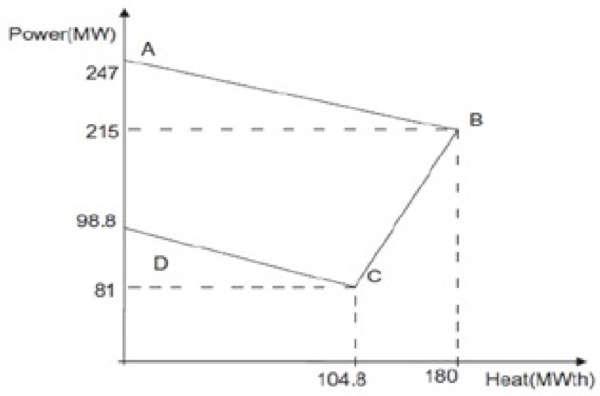

Figure 3: *Feasible operating regions of combined heat and power unit 1*

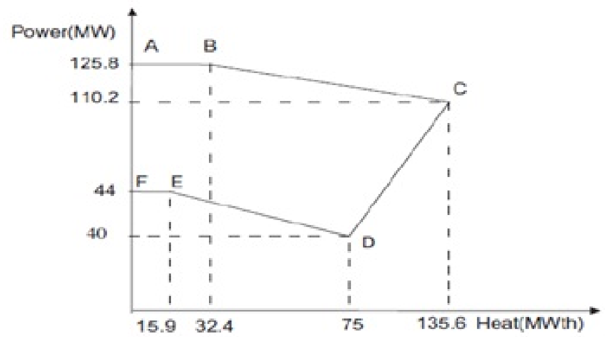

Figure 4: *Feasible operating regions of combined heat and power unit 2*

factor(F). As it can be seen that when F = 0.5, The algorithm can provide the best performance.

Table 4 and 5 are demonstrated ISFLA sensitive to change in general crossover probability (CR_g) and local crossover probability (CR_b) respectively. Numerical results demonstrate the best size for (CR_g) and (CR_b) are 0.3 and 0.9 respectively.

As the results in in table 6 show, the ISFLA based approach can reach

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Table 1: *Setting parameters of ISFLA for test systems*

Parameters	**Size**
Population	100
Number of group	50
F	0.5
CR_g	0.9
CR_b	0.3

Table 2: *Best results obtained from ISFLA, ABC ,PSO,DE*

Power/Heat	ISFLA	ABC	PSO	DE
P_1(MW)	0.00	0.24	0.00	0.02
P_2(MW)	159.99	158.78	158.55	159.94
P_3(MW)	40.01	40.96	41.44	40.02
H_2(MW_{th})	39.99	39.58	38.74	39.93
H_3(MW_{th})	75.00	75.23	76.25	74.99
H_4(MW_{th})	0.00	0.18	0.00	0.06
Cost(dollar)	9257.07	9276.7	9268.9	9258.9
CPU time (s)	0.32	0.35	0.33	0.34

to the best solution with all population sizes. These furnish a robustness of the ISFLA regarding to the population size. However, the standard deviation of final solution solutions is greater with small population size. Total cost variation during ISFLA cycles for different population sizes is demonstrated in figure 5.

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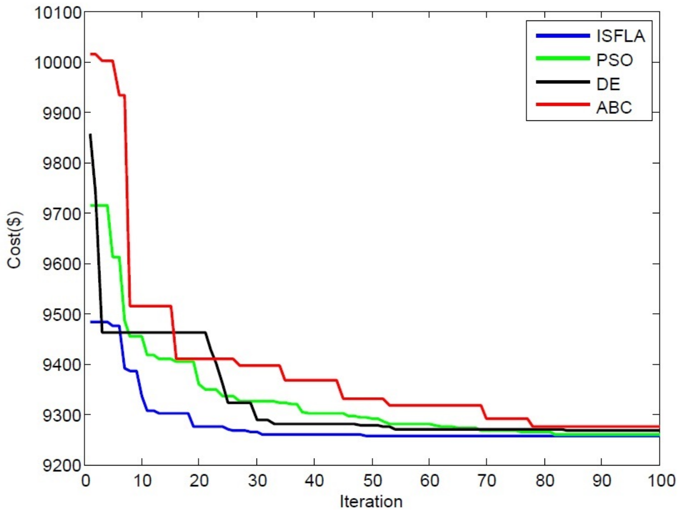

Figure 5: *Convergence of ISFLA in CHPED problem*

Table 3: *Impact of changes of mutation factor in final solution of CHPED*

F	Best solution	Mean solution	Worst solution
0.1	9333.3	9377.1	9495.5
0.2	9267.6	9299.1	9335.1
0.3	9259.3	9266.2	9282.9
0.4	9257.2	9258.1	9267.9
0.5	**9257.07**	**9257.07**	**9257.07**
0.6	9257.2	9257.5	9261.2
0.7	9257.7	9258.1	9259.8
0.8	9358.6	9264.4	9269.4
0.9	9260.9	9268.5	9273.6
1	9269.9	9277.8	9294.2

Conclusion

This paper presented an improved shuffled frog leaping algorithm for solving combined heat and power economic dispatch problem. ISFLA has effectively

Table 4: *Impact of changes of (CR_g) in final solution CHPED*

CR_b	Best solution	Mean solution	Worst solution
0.1	9358.3	9490.0	9802.6
0.2	9313.3	9402.9	9463.3
0.3	9403.5	9477.1	9716.0
0.4	9298.4	9321.7	9513.8
0.5	9274.0	9338.6	9428.4
0.6	9271.5	9331.1	9430.0
0.7	9266.3	9298.5	9324.3
0.8	9257.4	9295.6	9338.9
0.9	**9257.07**	**9257.07**	**9257.07**
1	9257.1	9258.1	9260.0

Table 5: *Impact of changes of (CR_b) in final solution CHPED*

CR_g	Best solution	Mean solution	Worst solution
0.1	9259.4	9266.1	9282.9
0.2	9257.1	9259.2	9260.07
0.3	**9257.07**	**9257.07**	**9257.07**
0.4	9271.4	9331.3	9436.7
0.5	9273.3	9338.6	9428.4
0.6	9358.5	9489.9	9715.9
0.7	9297.9	9321.5	9514.1
0.8	9402.9	9476.9	9715.9
0.9	9357.9	9489.9	9801.5
1	9313.5	9403.1	9464.1

provided the best solution satisfying both equality and inequality constraints. For the chosen example, ISFLA has superiority to other methods in terms of solution accuracy and computation time. Moreover, the results of ISFLA are

Table 6: *Impact of different population sizes in final solution of CHPED*

Population size	Best solution	Mean solution	Worst solution	Standard deviation	CPU time(s)
50	9257.07	9257.07	9257.07	0	0.28
75	9257.07	9258.07	9257.07	0	0.30
100	9257.07	9258.07	9257.07	0	0.32

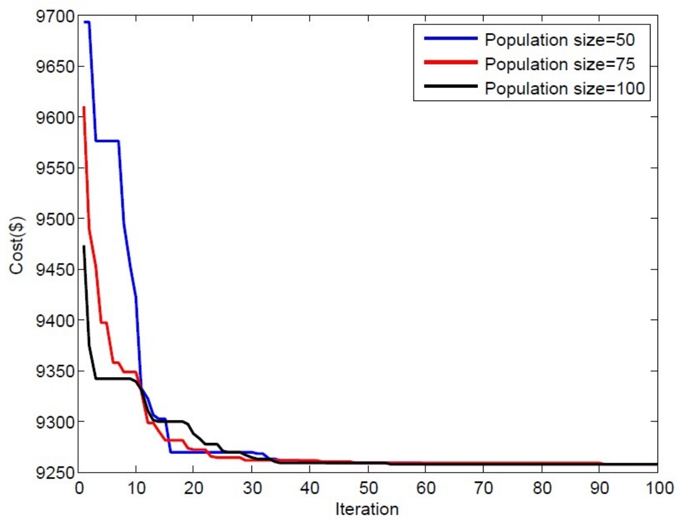

Figure 6: *Convergence process of the ISFLA with different population sizes*

very close to other numerical methods. Hence, ISFLA algorithm has the merits of global exploration, robustness and statistical soundness.

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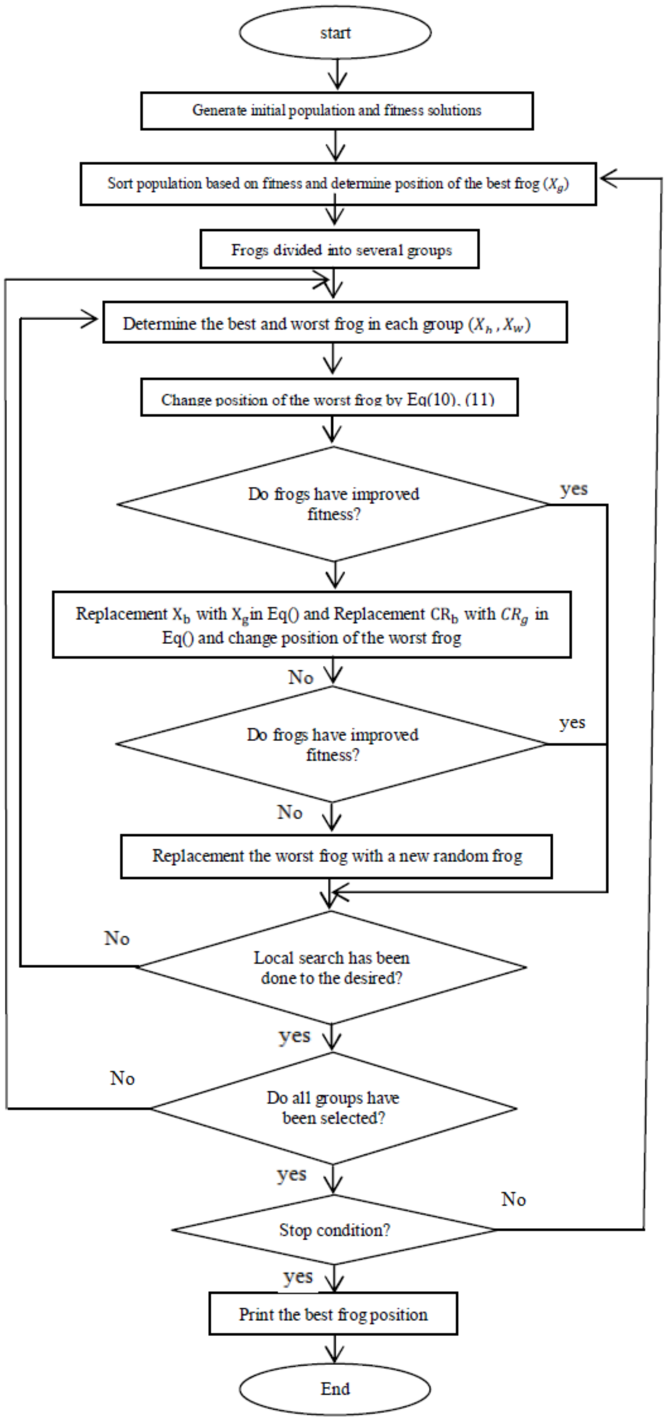

Figure 7: *ISFLA flowchart*