Indonesian Journal of Electrical Engineering and Computer Science
Vol. 12, No. 1, October 2018, pp. 168~174
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v12.i1.pp168-174

Optimal Economic Load Dispatch using Multiobjective Cuckoo Search Algorithm

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Article Info

Article history:

Received Apr 19, 2018
Revised Jun 20, 2018
Accepted Jul 4, 2018

Keywords:

Carbon emission minimization
Economic load dispatch
Fuel cost minimization
Multiobjective cuckoo search algorithm

ABSTRACT

In this paper, Multiobjective Cuckoo Search Algorithm (MOCSA) is developed to solve Economic Load Dispatch (ELD) problem. The main goal of the ELD is to meet the load demand at minimum operating cost by determining the output of the committed generating unit while satisfying system equality and inequality constraints. The problem formulation is based on a multiobjective model in which the multiobjective are defined as fuel cost minimization and carbon emission minimization. MOCSA is based on the inspiration from the brooding parasitism of cuckoo species in nature. Three cases are considered to test the effectiveness of the proposed technique which are fuel cost minimization, carbon emission minimization and multiobjective function with fixed weighted sum. The effectiveness of the MOCSA's performances are illustrated through comparative study with other techniques such as Multiobjective Genetic Algorithm (MOGA) and Multiobjective Particle Swarm Optimization (MOPSO) in terms of fitness functions. The proposed study was conducted on three generating unit system at various loading condition. The result proved that MOCSA provide better solution in minimizing fuel cost and carbon emission usage as compared to other techniques.

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1. INTRODUCTION

Power system is aimed to generate the required amount of power output in order to meet a particular load demand with minimum fuel cost that known as Economic Load Dispatch (ELD). The generation cost for each unit are calculated from the fuel cost, operation, maintenance, labour etc [1]. Previously, there are several meta-heuristic techniques have been proposed by previous researcher in solving electrical load dispatch problem. Compared to the conventional methods, meta-heuristics have a good global search capability and do not require specific domainin formation on the optimized problem. Reference [2]–[4] were presented different techniques to solve ELD problems by taking cost as the objective functions. However, the amount of carbon emission output does not take into account. Due to the increased awareness of environmental issues, there are few researcher proposed a technique to solve ELD problem considering the level of carbon emission [5]–[8]. Reference [9] proposed a multi-objective for ELD using Bacterial Foraging Algorithm (BFA). BFA provide poor convergence performance due to high complexity in a large constrained problem. Therefore, there is a need to determine the most efficient and economical of the power generation unit as to fulfil the aim in minimizing the operating fuel cost and minimizing the carbone emission at fast execution time.

Genetic Algorithm (GA) technique is also one of effective in searching technique for medium and large size problem by dealing with the problem of convergence on local sub-optimal solutions. A capability to evolve populations of possible solution and constantly converge to a high quality solution is a population based on the heuristic search algorithm that inspired by genetic evolution [10]. The combination of two existing solution which is the natural genetics and natural selection have to share the properties of their parents, so that it will probably produce two good solution of children. However, GA requires longer computational time in determining the convergence solution [11]. In addition, Particle Swarm Optimization (PSO) technique is one of modern heuristic algorithm that has been used in solving continuous nonlinear optimization problem [12]. PSO is also an iteration method that will lead the particles and finally swarm to obtain the optimum region as well as obtaining the best point in the search space. Therefore, this method may given better performance as compared to the classical method because it does not need to solve the complex mathematical formulas in finding the best solution in ELD problem. Unfortunately, this method still in research progress for proving its potential in solving any constraint optimization problem so that it can be used to optimize a wide range of functions with various constraints [13].The applications of Cuckoo Search Algorithm (CSA) to solve engineering optimization problems have shown its promising efficiency. The CSA was inspired by the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of host birds. The breeding behaviour of cuckoo can be applied to various optimization problems [14]. CSA obtained better solutions than existing solutions in [10], [11], [15], [16]. An important advantage of CSA is its simplicity. A multiobjective optimization namely Multiobjective Cuckoo Search Algorithm (MOCSA) is proposed in this paper as it taking fuel cost minimization and carbon emission minimization as the objective function.

2. RESEARCH METHOD

The main objective function of ELD is to minimize the total power generation cost. It should meet the load demand and satisfying all the constraints. Two objective functions are considered which are cost minimization and carbon emission reduction. The analysis is divided into three cases. Firstly, ELD with cost minimization. Secondly, ELD with carbon emission minimization. Lastly, multiobjective ELD considering both objective functions simultaneously. Economic Load Dispatch (ELD) problem considering cost as objective function can be modeled as (1).

$$\min F_\tau\,(P) = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

Where F_τ is the total fuel cost, $F_i(P_{Gi})$ is the fuel cost of generating unit i and n is the number of generator. The fuel cost function of a generating unit is usually described by a quadratic function of power output, P_i as shown in (2).

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

Where a_i, b_i, c_i are fuel cost coefficients of unit i. The units for the a_i, b_i, c_i are \$/MW. The emission equation of a generating unit is usually described by a quadratic function of power output, P_i as

$$E_i(P_i) = d_i P_i^2 + e_i P_i + f_i \tag{3}$$

Where d_i, e_i, f_i are emission coefficients of unit i. The units for the d_i, e_i, f_i are kg/h.

There are two methods for solving an optimization problems which are analytical method and numerical method. The analytical method involves precise mathematical derivation and formula to obtain the solution. However, this method depends strictly on the problem characteristics which is not suitable for solving realistic problems. The numerical method is constructed with a series of iterations to obtain the optimal solution [17]. The optimal solution can be obtained by selecting the suitable variables and objective functions. This method is more suitable to solve the real problems with many constraints.

In multi-objective optimization, both objective functions need to be considered simultaneously. The fitness for both objective functions are calculated individually. Usually, both objective functions are contradictory with each other. Therefore, both fitness need to be normalized as (4) in order to calculate the final solution. The analysis is carried out by assuming that all weighting factors, α_i have the same values. The value of all weighting factors should fulfil (5). In this paper, the final solution is selected based on the maximum value of multiobjective fitness, F_T as described in (6).

$$f_{ni} = \frac{\max(f_i) - f_i}{\max(f_i) - \min(f_i)} \tag{4}$$

Where f_{ni} is normalized value for i^{th} objective function

$$\sum_{i=1}^{k} \alpha_i = 1 \tag{5}$$

Where α_i is weighting factor for i^{th} objective function

$$F_T = \sum_{i=1}^{k} (\alpha_i \times f_{ni}) \tag{6}$$

Where k is numbers of objective function.

In solving ELD problems, there are constraints that need to be considered such as transmission loss, power balanced, and generator limit. The equation for transmission loss is expressed as (7).

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{m} P_i B_{ij} P_j \tag{7}$$

Where the coefficient are called loss coefficient or B-coefficients. B-coefficients are assumed constant. Beside transmission loss, the optimization also should considered the power balanced in the system. The total power generation should be equal to the total demand plus losses.

$$P_D + P_L - \sum_{i=1}^{n} P_i = 0 \tag{8}$$

Where P_D is the total load demand, P_L is the total transmission losses, and P_i is the total power generation. Generator limit of each unit need to be considered in solving ELD problem. The total power output for each of generating unit should lie between lower and upper operating limits.

$$P_{i,min} \le P_i \le P_{i,max} \tag{9}$$

Where $P_{i,min}$ is the minimum power output limit, and $P_{i,max}$ is the maximum power output limit.

In 2009, Xin-Sin Yang and Suash Deb has presented an algorithm that capable in giving a great efficiency in solving various optimization problems and real-world application which is called as Cuckoo Search Algorithm (CSA) [14]. In the past few decades, numerous research paper have been issued regarding cuckoo search finding. This is because CSA technique provide a better populations in faster run time without excessive experimentation for parameter running.

In this paper, MOCSA is applied to solve ELD for cost minimization, ELD for emission minimization, and ELD for multiobjective optimization.

Cuckoo search is an optimization based on behaviour of Cuckoo. It was inspired by the obligate brood parasitism by some Cuckoo species by laying their eggs in the nest of other host bird. There are two stages of probability generating in conventional methods. The first stage is Lévy flight which randomly generates and the second stage is explained the action of host birds to abandon Cuckoo eggs. In addition, the birds' flight behaviour have a bit characteristic of Lévy flight, where the Lévy flight is a random walk. There are three types of brood parasitism which are intraspecific brood parasitism, nest take-over and co-operative breeding. The behaviour of parasitic cuckoos is often chose a nest where the host bird just laid its own eggs. Some Cuckoos species have specialized in the imitation in colour and chosen the host species. Therefore, it can reduces the probability of eggs being abandoned and at the same time it will increases their reproductively. It can be assumed that only one egg is placed in a nest at a time. Each egg represent a solution where the egg in the nest represents a solution whereas the Cuckoo egg represents as a new solution**.** Egg that has good quality is carried over to the next generations. In addition, the aim of comparison is to select the new solutions to supplant a poor solution in the nests. Next, the host bird will decide either thrown the egg or nest and the bird will builds up a new nest at a new place. In Cuckoo search algorithm, each Cuckoo will lays only one egg at a time with dumps egg in randomly chosen nest, the eggs with high quality will carry over the next generation, the number of available hosts' is constant and the host bird will discover the Cuckoo egg with a probability between 0 and 1.

Figure 1 illustrates the flowchart of MOCSA for solving ELD problem. In the initialization process, the population were randomly generated within constraints such as power balance, generator limit constraint and transmission losses. The system read the data which consist of power demand, fuel cost, minimum and maximum generation limits and B-coefficients. The discovery rate of alien eggs is set to be 0.25. There are three main stages in the iterative search process including global Lévy flight random walk, local random walk, and selection operation. The first two stages are the steps to determine new solutions. The first new solution is generated via Lévy flights as shown in (10). Then, all the fitness functions were calculated based on (2) and (3). The operation of the local random walk produces the second new solution generation using (11).

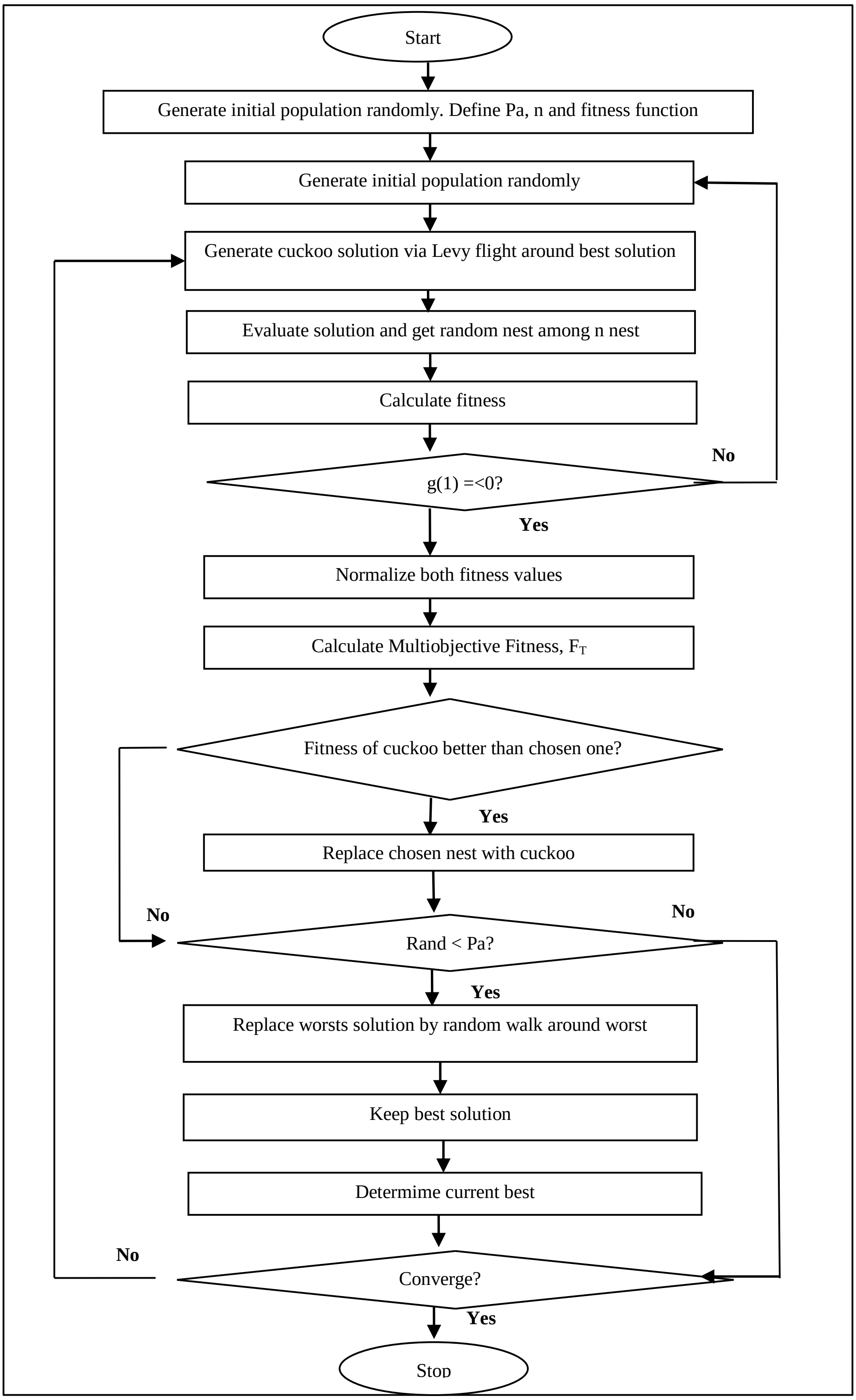

Figure 1. Flowchart of Multiobjective Cuckoo Search Algorithm

$$X_d^{(G)} = X_d^{(G-1)} + \alpha \oplus \text{Levy}\ (\beta) \tag{10}$$

Where X_d is the population and α is a step size for updating new solution.

$$X_{d,new} = \begin{cases} X_d + rand(X_{r1} - X_{r2}) if\ RN < P_a \\ X_d \quad otherwise \end{cases} \tag{11}$$

Where X_{r1} and X_{r2} are random solutions withdrawn from the population.

In the last stage, MOCSA will perform a selection process. During the selection process, all fitness function were normalized before calculating the multiobjective fitness (F_T). If new fitness, F_T value is better than old F_T, the new fitness value will be updated as a new nest. Otherwise, it will go back to generate Cuckoo randomly. The selection process can be represented by (12). The value of fitness obtained need satisfy with the various constraints in economic dispatch problem. The number of nest is set to 20 and the best fitness value obtained will be compared with the best value of G_{best}.

$$X_D = \begin{cases} X_{d,new} \quad if\ Fitness(X_{d,new}) < Fitness(X_d) \\ X_d \quad otherwise \end{cases}, d = 1, \ldots, N_p \tag{12}$$

Where $X_{d,new}$ is a new solution at the same nest d.

3. RESULTS AND ANALYSIS

Multiobjective Cuckoo Search Algorithm (MOCSA) was developed by using MATLAB in determining the optimal ELD. The proposed technique was tested on three generating units system and the output results were compared to Multiobjective Genetic Algorithm (MOGA) and Multiobjective Particle Swarm Optimization (MOPSO) technique at various load demand. For comparison purposes, the analysis were also carried out using CSA, GA and PSO for single objective optimization. The input data for three generating unit in term of the fuel cost and emission function was given in Table 1 and Table 2 respectively. The data is acquired from [7].

Table 1. Three Generating Units Data for Fuel Cost

Units	Generating Capacity (MW)		Fuel Cost Coefficient in \$/h		
	P_i^{min}	P_i^{max}	a_i	b_i	c_i
1	35	210	0.03546	38.30553	1243.53110
2	130	325	0.02111	36.32782	1658.56960
3	125	315	0.01799	38.27041	1356.65900

Table 2. Three Generating Units Data for Emission

Units	Generating Capacity (MW)		Emission Coefficient in kg/h		
	P_i^{min}	P_i^{max}	d_i	e_i	f_i
1	35	210	0.00683	-0.5455	40.26690
2	130	325	0.00461	-0.5116	42.89553
3	125	315	0.00461	-0.5116	42.89553

In order to determine the relationship of power losses (P_L) and ELD, the data for loss coefficient or B-coefficients given in Table 3 was used. It was assumed to be a constant value for the three generating unit system. Table 4 tabulates the result obtained for single objective function of the cost minimization using CSA technique. The results were compared to the PSO and GA technique.

Table 3. Loss Coefficient for Three Generating Unit System

$$B_{ij} = \begin{bmatrix} 0.000071 & 0.000030 & 0.000025 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{bmatrix}$$

Table 4. Fuel Cost Minimization as the Objective Function

Technique	Fuel Cost ($/h)			Emission Output (kg/h)		
Load (MW)	CSA	PSO	GA	CSA	PSO	GA
350	18 564.5	18 564.6	18 566.0	164.952	164.359	164.395
400	20 812.3	20 812.4	20 828.5	206.360	205.716	206.056
450	23 112.4	23 112.5	23 127.1	257.337	256.628	257.001
500	25 465.5	25 465.6	25 469.3	318.022	317.233	317.362
550	27 872.4	27 872.6	27 875.4	388.558	387.673	387.796
600	30 334.0	30 334.2	30 335.0	469.091	468.092	468.168
650	32 851.0	32 851.3	32 852.7	559.769	558.639	558.751
700	35 424.4	35 424.7	35 426.8	660.746	659.467	659.623
750	38 055.1	38 055.4	38 058.9	772.179	770.732	770.977

From the results tabulated in Table 4, it is clearly shown that the CSA technique gives better performance in giving the best optimum solution for minimizing fuel cost as compared to the GA and PSO technique. However, the result for the emission output was slightly higher as compared to GA and PSO technique. This is because the result only focused on the minimization of the fuel cost as it is set as the objective function for this case. In order to obtain a better performance for emission output using the CSA technique, the emission is set as the objective function. The results obtained is presented in Table 5.

Table 5. Carbon Emission as the Objective Function

Technique	Fuel Cost ($/h)			Emission Output (kg/h)		
Load (MW)	CSA	PSO	GA	CSA	PSO	GA
350	18 595.3	18 589.2	18 591.8	159.011	159.076	159.118
400	20 844.7	20 848.5	20 850.3	200.155	200.221	200.256
450	23 146.7	23 144.0	23 146.5	250.798	250.866	250.929
500	25 502.0	25 498.5	25 500.2	311.080	311.150	311.273
550	27 911.5	27 914.4	27 918.4	381.143	381.216	381.258
600	30 376.0	30 369.1	30 373.4	461.131	461.207	461.352
650	32 896.3	32 891.0	32 897.6	551.196	551.274	551.299
700	35 473.3	35 466.2	35 471.1	651.488	651.569	651.531
750	38 107.9	38 126.8	38 128.5	762.165	762.249	762.314

Based on the results tabulated in Table 5, similar observation could be seen where CSA provide the lowest carbon emission for all loading condition as compared to other techniques. It is proved that CSA technique produced better performance in terms of fitness function as compared to the GA and PSO technique. Thus, in order to obtain better performance in terms of both cost minimization and emission minimization, multiobjective approach has been proposed. The performance of multiobjective CSA (MOCSA) is compared with those obtained using Multiobjective Genetic Algorithm (MOGA) and Multiobjective Particle Swarm Optimization (MOPSO) as presented in Table 6.

Table 6. Multiobjective Optimization

Technique	Fuel Cost ($/h)			Emission Output (kg/h)		
Load (MW)	MOCSA	MOPSO	MOGA	MOCSA	MOPSO	MOGA
350	18 589.2	18 589.4	18 593.2	159.075	159.112	159.185
400	20 838.3	20 838.5	20 848.1	200.222	200.248	200.312
450	23 139.9	23 140.0	23 142.6	250.869	251.022	251.725
500	25 494.7	25 495.0	25 499.4	311.156	312.264	312.324
550	27 903.7	27 904.1	27 905.4	381.225	382.025	382.201
600	30 367.6	30 368.2	30 372.3	461.220	462.007	462.122
650	32 887.3	32 888.0	32 888.6	551.291	552.024	552.299
700	35 463.6	35 464.6	35 466.0	651.590	651.586	651.598
750	38 097.4	38 098.6	38 099.9	762.276	763.019	763.033

The results presented in Table 6 showed that MOCSA provide lowest fuel cost and lowest carbon emission as compared to MOPSO and MOGA. It can be concluded that MOCSA using wighted sum technique were produced optimum solution in minimizing the fuel cost while decreasing the carbon emission output for clean environment.

4. CONCLUSION

This paper had presented a new technique for solving economic dispatch problem based on multiobjective function namely Multiobjective Cuckoo Search Algorithm (MOCSA). Cuckoo Search Algorithm (CSA) is a meta-heuristic optimization technique based on the brood parasitism of some cuckoo species, along with Levy flights random walks. An important advantage of this algorithm is its simplicity. Multiobjective approached were proposed in order to optimize two objective functions simultaneously. The objective functions considered in this paper are fuel cost minimization and carbon emission minimization. The proposed algorithm were tested on three generating unit at various loading conditions. From the comparative studies, it can be concluded that MOCSA provide the lowest fuel cost and carbon emission values as compared to other techiques such as Multiobjective Genetic Algorithm (MOGA) and Multiobjecive Particle Swarm Optimization (MOPSO).

ACKNOWLEDGEMENTS

The authors would like to thank the Universiti Tenaga Nasional and the Ministry of Higher Education (MOHE), Malaysia through research grant 20160104FRGS for the financial support to this research.

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