



# **Solution of Economic Dispatch Problem Using Cuckoo Search Algorithm**

Wawan Heryawan<sup>1</sup>, Medi Yuwono Tharam<sup>2</sup>, Hasan<sup>3</sup>, Wendhi Yuniarto<sup>4</sup>, Hardiansyah<sup>5</sup>

Department of Electrical Engineering, State Polytechnic of Pontianak, Indonesia<sup>1,2,3,4</sup>

Department of Electrical Engineering, University of Tanjungpura, Indonesia<sup>5</sup>

**ABSTRACT:** This paper presents a cuckoo search algorithm (CSA) for solving the economic dispatch (ED) problem considering ramp rate limits, prohibited operating zones and transmission loss. CSA is a new meta-heuristic optimization method inspired from the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds of other species. The effectiveness of the proposed approach has been tested on 6 generator system. The results shows that performance of the proposed approach reveal the efficiently and robustness when compared results of other optimization algorithms reported in literature.

**KEYWORDS:** Cuckoo Search Algorithm, Economic Dispatch, Ramp Rate Limits, Prohibited Operating Zones.

## **I. INTRODUCTION**

The Economic Dispatch (ED) problem is one of the fundamental issues in power system operation and planning, where the total required load is distributed among the generation units in operation. The main objective of ED problem is to minimizing total generation cost while satisfying load and operational constraints. Traditionally, fuel cost function of a generator is represented by single quadratic function. But a quadratic function is not able to show the practical behaviour of generator. For modelling of the practical cost function behaviour of a generator, a non-convex curve is used in literature. The ED problem is a non-convex and nonlinear optimization problem. Due to ED complex and nonlinear characteristics, it is hard to solve the problem using classical optimization methods.

Most of classical optimization techniques such as lambda iteration method, gradient method, Newton's method, linear programming, Interior point method and dynamic programming have been used to solve the basic economic dispatch problem [1]. These mathematical methods require incremental or marginal fuel cost curves which should be monotonically increasing to find global optimal solution. In reality, however, the input-output characteristics of generating units are non-convex due to valve-point loadings and multi-fuel effects, etc. Also there are various practical limitations in operation and control such as ramp rate limits and prohibited operating zones, etc. Therefore, the practical ED problem is represented as a non-convex optimization problem with equality and inequality constraints, which cannot be solved by the traditional mathematical methods. Dynamic programming (DP) method [2] can solve such types of problems, but it suffers from so-called the curse of dimensionality. Over the past few decades, as an alternative to the conventional mathematical approaches, many salient methods have been developed for ED problem such as genetic algorithm (GA) [3], improved tabu search (TS) [4], simulated annealing (SA) [5], neural network (NN) [6], evolutionary programming (EP) [7, 8], particle swarm optimization (PSO) [9, 10], differential evolution (DE) [11], and gravitational search algorithm (GSA) [12], biogeography-based optimization (BBO) [13].

Recently, a new meta-heuristic search algorithm, called cuckoo search algorithm (CSA) [14, 15], has been developed by Yang and Deb. In this paper, cuckoo search algorithm has been used to solve the ED problem considering ramp rate limits, prohibited operating zones, and transmission loss. Feasibility of the proposed method has been demonstrated on 6 generator system. The results obtained with the proposed method were analyzed and compared with other optimization results reported in literature.



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## II. PROBLEM FORMULATION

The objective of an ED problem is to find the optimal combination of power generations that minimizes the total generation cost while satisfying equality and inequality constraints. The fuel cost curve for any unit is assumed to be approximated by segments of quadratic functions of the active power output of the generator. For a given power system network, the problem may be described as optimization (minimization) of total fuel cost as defined by (1) under a set of operating constraints.

$$F_T = \sum_{i=1}^n F_i(P_i) = \sum_{i=1}^n (a_i P_i^2 + b_i P_i + c_i) \quad (1)$$

where  $F_T$  is total fuel cost of generation in the system (\$/hr),  $a_i$ ,  $b_i$ , and  $c_i$  are the cost coefficient of the  $i$ -th generator,  $P_i$  is the power generated by the  $i$ -th unit and  $n$  is the number of generators.

The cost is minimized subjected to the following constraints:

### (1) Active Power Balance Equation

For power balance, an equality constraint should be satisfied. The total generated power should be the same as total load demand plus the total line loss.

$$P_D = \sum_{i=1}^n P_i - P_{Loss} \quad (2)$$

where  $P_D$  is the total load demand and  $P_{Loss}$  is total transmission losses. The transmission losses  $P_{Loss}$  can be calculated by using  $B$  matrix technique and is defined by (3) as,

$$P_{Loss} = \sum_{i=1}^n \sum_{j=1}^n P_i B_{ij} P_j + \sum_{i=1}^n B_{0i} P_i + B_{00} \quad (3)$$

where  $B_{ij}$  is coefficient of transmission losses and the  $B_{0i}$  and  $B_{00}$  is matrix for loss in transmission which are constant under certain assumed conditions.

### (2) Minimum and Maximum Power Limits

Generation output of each generator should lie between minimum and maximum limits. The corresponding inequality constraint for each generator is

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad \text{for } i = 1, 2, \dots, n \quad (4)$$

where  $P_i^{\min}$  and  $P_i^{\max}$  are the minimum and maximum outputs of the  $i$ -th generator, respectively.

### (3) Ramp Rate Limits

The actual operating ranges of all on-line units are restricted by their corresponding ramp rate limits. The ramp-up and ramp-down constraints can be written as (5) and (6), respectively.

$$P_i(t) - P_i(t-1) \leq UR_i \quad (5)$$

$$P_i(t-1) - P_i(t) \leq DR_i \quad (6)$$

where  $P_i(t)$  and  $P_i(t-1)$  are the present and previous power outputs, respectively.  $UR_i$  and  $DR_i$  are the ramp-up and ramp-down limits of the  $i$ -th generator (in units of MW/time period).

To consider the ramp rate limits and power output limits constraints at the same time, therefore, equations (4), (5) and (6) can be rewritten as follows:

$$\max\{P_i^{\min}, P_i(t-1) - DR_i\} \leq P_i(t) \leq \min\{P_i^{\max}, P_i(t-1) + UR_i\} \quad (7)$$

### (4) Prohibited Operating Zones

In practical operation, the entire operating range of a generating unit is not always available due to physical operation limitations. Units may have prohibited operating zones due to robustness in the shaft bearings caused by the operation of steam valves or to faults in the machines themselves or the associated auxiliaries, such as boilers, feed pumps etc.



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Such faults may lead to instability in certain ranges of generator power output. Therefore, for units with prohibited operating zones, there are additional constraints on the unit operating range as follows:

$$P_i \in \begin{cases} P_i^{\min} \leq P_i \leq P_{i,1}^l \\ P_{i,k-1}^u \leq P_i \leq P_{i,k}^l, & k = 2, 3, \dots, pz_i \\ P_{i,pz_i}^u \leq P_i \leq P_i^{\max}, & i = 1, 2, \dots, n_{pz} \end{cases} \quad (8)$$

where  $P_{i,k}^l$  and  $P_{i,k}^u$  are the lower and upper boundary of prohibited operating zone of unit  $i$ , respectively. Here,  $pz_i$  is the number of prohibited zones of unit  $i$  and  $n_{pz}$  is the number of units which have prohibited operating zones.

### III. CUCKOO SEARCH ALGORITHM (CSA)

Cuckoo search (CS) is inspired by some species of a bird family called cuckoo because of their special lifestyle and aggressive reproduction strategy. This algorithm was proposed by Yang and Deb [14]. The CS is an optimization algorithm based on the brood parasitism of cuckoo species by laying their eggs in the communal nests of other host birds, though they may remove others' eggs to increase the hatching probability of their own eggs. Some host birds do not behave friendly against intruders and engage in direct conflict with them. If a host bird discovers the eggs are not their own, it will either throw these foreign eggs away or simply abandon its nest and build a new nest elsewhere [15].

The CS algorithm contains a population of nests or eggs. Each egg in a nest represents a solution and a cuckoo egg represents a new solution. If the cuckoo egg is very similar to the host's, then this cuckoo egg is less likely to be discovered; thus, the fitness should be related to the difference in solutions. The better new solution (cuckoo) is replaced with a solution which is not so good in the nest. In the simplest form, each nest has one egg. When generating new solutions for  $x^{(t+1)}$ , say cuckoo  $i$ , a Lévy flight is performed:

$$x_i^{(t+1)} = x_i^t + \alpha \oplus \text{Lévy}(\lambda) \quad (9)$$

where  $\alpha > 0$  is the step size which should be related to the scales of the problem of interest. In most cases, we can use  $\alpha = O(1)$ . The product  $\oplus$  means entry-wise multiplications. Lévy flights essentially provide a random walk while their random steps are drawn from a Lévy distribution for large steps:

$$\text{Lévy} \sim u = t^{-\lambda}, (1 < \lambda \leq 3) \quad (10)$$

which has an infinite variance with an infinite mean. Here the consecutive jumps/steps of a cuckoo essentially form a random walk process which obeys a power-law step-length distribution with a heavy tail. The rules for CS are described as follows:

- Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest;
- The best nests with high quality of eggs (solutions) will carry over to the next generations;
- The number of available host nests is fixed, and a host can discover a foreign egg with a probability  $p_a \in [0, 1]$ . In this case, the host bird can either throw the egg away or abandon the nest so as to build a completely new nest in a new location.

The later assumption can be approximated by the fraction  $p_a$  of the  $n$  nests which are replaced by new ones (with new random solutions). With these three rules, the basic steps of the CS can be summarized as the pseudo-code shown below,

- 1) Define the objective function  $f(x)$ ,  $x = (x_1, \dots, x_d)^T$
- 2) Set  $n$ ,  $p_a$ , and MaxGeneration parameters
- 3) Generate initial population of  $n$  available nests
- 4) Move a cuckoo ( $i$ ) randomly by Lévy flights
- 5) Evaluate the fitness  $f_i$
- 6) Randomly choose a nest ( $j$ ) among  $n$  available nests
- 7) If  $f_i > f_j$  the replace  $j$  by the new solution
- 8) Abandon a fraction  $p_a$  of worse nests and create the same fraction of new nests at new location via Lévy flights
- 9) Keep the best solutions (or nests with quality solutions)



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- 10) Sort the solutions and find the best current solution
- 11) If stopping criteria is not satisfied, increase generation number and go to step 4
- 12) Post-process results and find the best solution among all.

## IV.SIMULATION RESULTS

The proposed cuckoo search algorithm (CSA) has been applied to solve ED problem for verifying its feasibility. A sixgenerator systems with power loss, ramp rate limits and prohibited operating zones are considered. The total load demand on the system is 1263 MW. The parameters of all generating units are presented in Table 1 and Table 2 [9], respectively.

**Table 1** Cost coefficients and unit operating limits

Unit	$P_i^{\min}$ (MW)	$P_i^{\max}$ (MW)	a	b	c
1	100	500	0.0070	7.0	240
2	50	200	0.0095	10.0	200
3	80	300	0.0090	8.5	220
4	50	150	0.0090	11.0	200
5	50	200	0.0080	10.5	220
6	50	120	0.0075	12.0	190

**Table 2** Ramp rate limits and prohibited operating zones

Unit	$P_i^0$ (MW)	$UR_i$ (MW/h)	$DR_i$ (MW/h)	Prohibited zones (MW)
1	440	80	120	[210, 240] [350, 380]
2	170	50	90	[90, 110] [140, 160]
3	200	65	100	[150, 170] [210, 240]
4	150	50	90	[80, 90] [110, 120]
5	190	50	90	[90, 110] [140, 150]
6	110	50	90	[75, 85] [100, 105]

The transmission losses are calculated by  $B$ matrix loss formula which for 6 generator system is given as:

$$B_{ij} = \begin{bmatrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0.0000 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0.0000 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{bmatrix}$$

$$B_{0i} = 1.0e^{-3} * [-0.3908 \quad -0.1297 \quad 0.7047 \quad 0.0591 \quad 0.2161 \quad -0.6635]$$

$$B_{00} = 0.0056$$

The obtained resultfor 6 generator system using the CSA method are given in Table 3 and the results are comparedwith other methods reported in literature, including BBO, GA, PSO and IDP. It can be observed that CSA can get total generation cost of 15443.07 (\$/hr) and power losses of 12.4448 (MW), which is the best solution among all the methods. Note that the outputs of the generators are all within the generator’s permissible output limit. The cost convergence characteristic of six generator system obtained from CSA is shown in Fig. 1.



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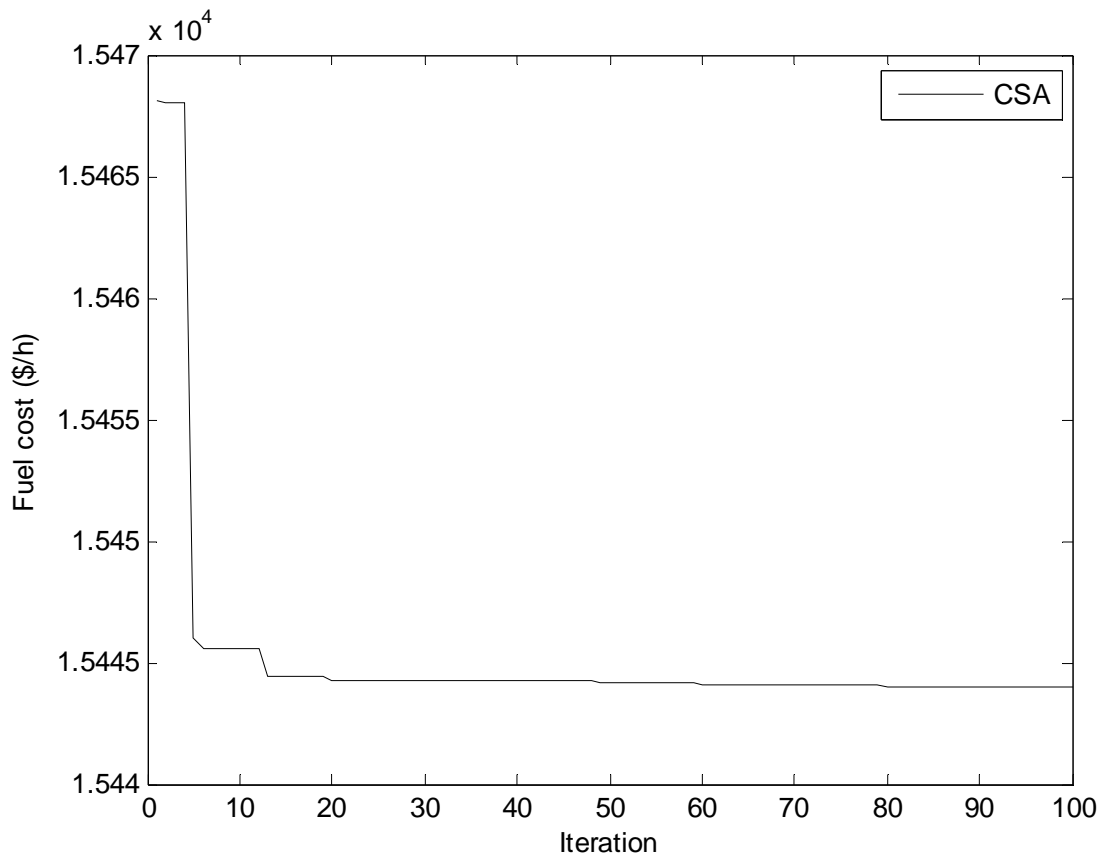
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**Table 3** Comparison of the best results of each methods ( $P_D = 1263$  MW)

Unit Output	BBO[13]	GA[16]	PSO[16]	IDP[16]	CSA
P1 (MW)	447.3997	474.8066	447.4970	450.9555	447.3990
P2 (MW)	173.2392	178.6363	173.3221	173.0184	173.2408
P3 (MW)	263.3136	262.2089	263.0594	263.6370	263.3812
P4 (MW)	138.0060	134.2826	139.0594	138.0655	138.9796
P5 (MW)	165.4104	151.9039	165.4761	164.9937	165.3914
P6 (MW)	87.0797	74.1812	87.1280	85.3094	87.0529
Total power output (MW)	1275.4460	1276.0217	1275.9584	1275.9794	1275.4448
Total generation cost (\$/hr)	15443.09	15459	15450	15450	15443.07
Power losses (MW)	12.446	13.0217	12.9584	12.9794	12.4448



**Fig. 1** Cost convergence characteristic of 6-generator system

## V. CONCLUSION

In this paper, a cuckoo search algorithm (CSA) has been successfully applied for solving economic dispatch problem considering ramp rate limits, prohibited operating zones and transmission loss. The proposed technique has provided the global solution in the 6 generator system and the better solution than the previous studies reported in literature.



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