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Cuckoo Search Algorithm for Environmental/Economic Dispatch Problem

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Abstract: *This paper proposes a new meta-heuristic search algorithm, called cuckoo search algorithm (CSA). The cuckoo search 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. The new algorithm is implemented to solve combined environmental economic dispatch (CEED) problem in power systems considering the power limits, valve-point effect and transmission loss. The CEED is to minimize both the operating fuel cost and emission level simultaneously while satisfying the load demand and operational constraints. The effectiveness of the proposed algorithm has been tested on 10-generator system and the results were compared with other methods reported in recent literature. The simulation results show that the proposed algorithm outperforms previous optimization methods.*

Keywords - *Economic dispatch, emission dispatch, combined environmental economic dispatch, cuckoo search algorithm, valve-point effect.*

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I. Introduction

The economic dispatch (ED) is one of the most fundamental issues in power system operation and control for allocating generation among the committed units. The objective of ED problem of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints. This makes the ED problem a large-scale highly nonlinear constrained optimization problem. Therefore, recently most of the researchers made studies for finding the most suitable power values produced by the generators depending on fuel costs [1, 2]. In these studies, they produced successful results by using various optimization algorithms. Despite the fact that the traditional ED can optimize generator fuel costs, it still cannot produce a solution for environmental pollution due to the excessive emission of fossil fuels [3-5].

Currently, a large part of energy production is done with thermal sources. Thermal power plant is one of the most important sources of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) which create atmospheric pollution [6]. Emission control has received increasing attention owing to increased concern over environmental pollution caused by fossil based generating units and the enforcement of environmental regulations in recent years [7]. Numerous studies have emphasized the importance of controlling pollution in electrical power systems [8].

Combined environmental economic dispatch (CEED) has been proposed in the field of power generation dispatch, which simultaneously minimizes both fuel cost and pollutant emissions. When the emission is minimized the fuel cost may be unacceptably high or when the fuel cost is minimized the emission may be high. A number of methods have been presented to solve CEED problems such as simplified recursive method [9], genetic algorithm [10-12], simulated annealing [13, 14], biogeography based optimization [15], differential evolution [16], particle swarm optimization [17, 18], and artificial bee colony algorithm [19, 20].

Recently, a new meta-heuristic search algorithm, called cuckoo search algorithm (CSA) [21, 22], has been developed by Yang and Deb. In this paper, cuckoo search algorithm has been used to solve CEED problem considering valve-point effect and transmission loss. Feasibility of the proposed method has been demonstrated on ten generator system. The results obtained with the proposed method were analyzed and compared with other optimization results reported in literature.

II. Problem Formulation

The CEED problem targets to find the optimal combination of load dispatch of generating units and minimizes both fuel cost and emission while satisfying the total power demand. Therefore, CEED consists of two objective functions, which are economic and emission dispatches. Then these two functions are combined to solve the problem. The CEED problem can be formulated as follows [11]:

$$F_T = Min\ f\left(FC, EC\right) \tag{1}$$

where F_T is the total generation cost of the system, FC is the total fuel cost of generators and EC is the total emission of generators.

2.1. Minimization of Fuel Cost

Mathematically, the fuel cost of each generating unit, considering the valve-point effects, is defined as the sum of a quadratic function and a sinusoidal function [11]. Total fuel cost of a power generating station can be expressed as:

$$FC = \sum_{i=1}^{n}\left(a_i P_i^2 + b_i P_i + c_i + \left|e_i \times \sin\left(f_i \times \left(P_i^{\min} - P_i\right)\right)\right|\right) \tag{2}$$

where P_i is the power generation of the ith unit; a_i, b_i, c_i, e_i, and f_i are fuel cost coefficients of the ith generating unit; and N is the number of generating units.

2.2. Minimization of Emission

The classical ED problem can be obtained by the amount of active power to be generated by the generating units at minimum fuel cost, but it is not considered as the amount of emissions released from the burning of fossil fuels. Total amount of emissions such as SO_2 or NO_X depends on the amount of power generated by until and it can be defined as the sum of quadratic and exponential functions and can be stated as [11]:

$$EC = \sum_{i=1}^{N}\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \exp(\delta_i P_i)\right) \tag{3}$$

where α_i, β_i, γ_i, η_i and δ_i are emission coefficients of the ith generating unit.

2.3. Combined Environmental Economic Dispatch (CEED)

CEED is a multi-objective problem, which is a combination of both economic and environmental dispatches that individually make up different single problems. At this point, this multi-objective problem needs to be converted into single-objective form in order to fulfill optimization. The conversion process can be done by using the price penalty factor [11]. However, the single-objective CEED can be formulated as shown in equation (4):

$$F_T = (w_1 * FC + w_2 * h * EC) \tag{4}$$

under the following condition,

$$w_1 + w_2 = 1 \ \text{ and } \ w_1, w_2 \geq 0 \tag{5}$$

where w_1, w_2 are weight factor and h is the price penalty factor.

2.4. Problem Constraints

There are two constraints in the CEED problem which are power balance constraint and maximum and minimum limits of power generation output constraint.

Power balance constraint:

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{6}$$

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

Generating capacity constraint:

$$P_{i\min} \leq P_i \leq P_{i\max} \tag{8}$$

Where P_D is total demand of system (MW); P_L is total power loss; $P_{i\ min}$ and $P_{i\ max}$ are minimum and maximum generation of unit i (MW); and B_{ij} is coefficients of transmission loss.

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 [21]. 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 [22].

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:

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

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:

$$\text{Lévy} \sim u = t^{-\lambda}, \left(1 < \lambda \le 3\right) \tag{10}$$

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 bellows,

1) Define the objective function $f(x), x = (x_1, \cdots, x_d)^T$
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)
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) Postprocess results and find the best solution among all.

IV. Simulation Results

The proposed techniques have been applied to a test power system consists of ten generators at 2000 MW power demand. Generation unit data has been taken from [23]. Simulations were performed in MATLAB R2010a environment on a PC with a 3 GHz processor.

1) Case I: Optimization of each of the two objectives individually

In this case, the fuel cost and the gas emission are minimized separately as a single objective functions. Minimizing each objective function individually is executed by giving full weight to the function to be optimized and neglecting others. Table I presents the results of economic dispatch when the objective is minimizing just the fuel cost (w_1=1, w_2=0). The fuel cost and the gas emission output of 10 unit system for 2000 MW are 111399.6196 \$/h and 4568.1135 lb/h respectively when the fuel cost is the optimized function. The power losses are 87.0297 MW.

Table II, presents the results of economic emission dispatch when the objective is minimizing just the gas emission (w_1=0, w_2=1). The fuel cost and the gas emission output of 10 unit system for 2000 MW are

116330.1110 $/h and 3912.3281 lb/h respectively when the gas emission is the optimized function. The power losses are 81.5877 MW.

2) Case II: Optimization of the fuel cost and gas emission simultaneously

In this case, the problem as multi-objective; two objectives are minimized simultaneously (the fuel cost and the gas emission objectives) by using the weighted factors w_1 = 0.5 and w_2 = 0.5. The multi-objective optimization problem can be converted to a single objective optimization problem by introducing weighted factors. Table III, presents the results of combined environmental economic dispatch when the objective is minimizing both fuel cost and the gas emission. The fuel cost and the gas emission output of 10 unit system for 2000 MW are 113412.6452 $/h and 4116.7288 lb/h respectively. The power losses are 83.9799 MW.

Table I Comparison of the best fuel cost results of each methods (P_D = 2000 MW)

Unit Output	ABC_PSO [23]	DE [16]	SA [14]	**CSA**
P1 (MW)	55	55	54.9999	54.9957
P2 (MW)	80	79.89	80	79.9708
P3 (MW)	106.93	106.8253	107.6263	106.0823
P4 (MW)	100.5668	102.8307	102.5948	100.6660
P5 (MW)	81.49	82.2418	80.7015	81.2701
P6 (MW)	83.011	80.4352	81.1210	84.0977
P7 (MW)	300	300	300	299.9494
P8 (MW)	340	340	340	340
P9 (MW)	470	470	470	470
P10 (MW)	470	469.8975	470	469.9977
Losses (MW)	87.0344	-	87.0434	**87.0297**
Fuel cost ($/h)	111500	111500	111498.6581	**111399.6196**
Emission (lb/h)	4571.2	4581	4584.8366	**4568.1135**

Table II Comparison of the best emission results of each methods (P_D = 2000 MW)

Unit Output	ABC_PSO [23]	DE [16]	SA [14]	**CSA**
P1 (MW)	55	55	54.9999	54.9980
P2 (MW)	80	80	80	79.8457
P3 (MW)	81.9604	80.5924	76.6331	81.6047
P4 (MW)	78.8216	81.0233	79.4332	81.5329
P5 (MW)	160	160	160	160
P6 (MW)	240	240	240	239.9867
P7 (MW)	300	292.7434	287.9285	293.1967
P8 (MW)	292.78	299.1214	301.4146	297.7226
P9 (MW)	401.8478	394.5147	412.4386	397.5370
P10 (MW)	391.2096	398.6383	388.9348	395.1634
Losses (MW)	81.5879	-	81.7827	**81.5877**
Fuel cost ($/h)	116420	116400	116386	**116330.1110**
Emission (lb/h)	3932.3	3923.4	3935.9769	**3912.3281**

Table III Comparison of CEED results of each methods (P_D = 2000 MW)

Unit Output	ABC_PSO [23]	DE [16]	NSGA-II [16]	**CSA**
P1 (MW)	55	54.9487	51.9515	55
P2 (MW)	80	74.5821	67.2584	79.6712
P3 (MW)	81.14	79.4294	73.6879	86.5432
P4 (MW)	84.216	80.6875	91.3554	83.4264
P5 (MW)	138.3377	136.8551	134.0522	142.6422
P6 (MW)	167.5086	172.6393	174.9504	160.5614
P7 (MW)	296.8338	283.8233	289.435	298.3308
P8 (MW)	311.5824	316.3407	314.0556	321.7533
P9 (MW)	420.3363	448.5923	455.6978	428.6680
P10 (MW)	449.1598	436.4287	431.8054	427.3834
Losses (MW)	84.1736	-	-	**83.9799**
Fuel cost ($/h)	113420	113480	113540	**113412.6452**
Emission (lb/h)	4120.1	4124.9	4130.2	**4116.7288**

V. Conclusion

In this paper, a cuckoo search algorithm has been applied to solve CEED problem of generating units considering the valve-point effect and transmission losses. The proposed technique has provided the global solution in the 10-generator system and the better solution than the previous studies reported in literature. Also, the equality and inequality constraints treatment methods have always provided the solutions satisfying the constraints.

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