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Cuckoo Search Algorithm for Solving Dynamic Economic Dispatch with Valve-Point Effects

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ABSTRACT
In this paper, a cuckoo search algorithm (CSA) is presented to solve the dynamic economic dispatch (DED) problem considering valve-point effects, the ramp rate limits and transmission losses. The practical DED problems have non-smooth cost function with equality and inequality constraints, which make the problem of finding the global optimum difficult when using any mathematical approaches. Cuckoo search algorithm is a new meta-heuristic algorithm. It is a nature-based searching technique which is inspired from the obligate brood parasitism of some cuckoo species by laying their eggs in the nests oh other host birds of other species. The effectiveness of the proposed algorithm has been verified on 10 unit generation system for a 24 h time interval. The results are compared with the results reported in the literature.

Keywords: *Cuckoo Search Algorithm, Dynamic Economic Dispatch, Non-Smooth Cost Functions, Ramp Rate Limits, Valve-Point Effects.*

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I. INTRODUCTION

The electrical power systems are interconnected in order to obtain the benefits of minimum generation costs, maximum reliability and best operational conditions, such as sharing of power reserve, improving the stability and operating on emergency situations. Thus, the optimization problem of the economic dispatch of electrical power system is relevant to accomplish requirements of quality and efficiency in power generation. Dynamic economic dispatch (DED) is one of important problems in modern power system operation and control, which is used to determine the optimal schedule of generating outputs on-line so as to meet the load demand at the minimum operating cost under various system and operating constraints over the entire dispatch periods. DED is an extension of the conventional economic dispatch (ED) problem that takes into consideration the limits on the ramp rate of generating units to maintain the life of generation equipment [1, 2].

Since the DED problem was introduced, several optimization techniques and procedures have been used for solving the DED problem with complex objective functions or constraints. There were a number of classical methods that have been applied to solve this problem such as gradient projection method, Lagrange relaxation, and linear programming [3-5]. Most of these methods are not applicable for non-smooth or non-convex cost functions. To overcome this problem, many stochastic optimization methods have been employed to solve the DED problem, such as genetic algorithm (GA) [6], simulated annealing (SA) [7], differential evolution (DE) [8, 9], particle swarm optimization (PSO) [10], hybrid EP and SQP [11], deterministically guided PSO [12], hybrid PSO and SQP [13], imperialist competitive algorithm (ICA) [14], and artificial immune system (AIS) [15]. Many of these techniques have proven their effectiveness in solving the DED problem without any or fewer restrictions on the shape of the cost function curves.

Recently, a new meta-heuristic search algorithm, called cuckoo search algorithm (CSA) [16, 17], has been developed by Yang and Deb. In this paper, cuckoo search algorithm has been used to solve the DED problem considering ramp rate limits, valve-point effects and transmission loss. Feasibility of the proposed method has been demonstrated on 10-unit generation system. The results obtained with the proposed method were analyzed and compared with other optimization results reported in literature.

II. PROBLEM FORMULATION

The objective of DED problem is to find the optimal schedule of output powers of online generating units with predicted power demands over a certain period of time to meet the power demand at minimum operating cost.

The fuel cost function of the generating unit is expressed as a quadratic function of real power generation. The objective function of the DED problem is

$$\min F_T = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(a_i P_{i,t}^2 + b_i P_{i,t} + c_i\right) \quad \text{for } i = 1,2,\cdots,N;\ t = 1,2,\ldots,T \tag{1}$$

where $F_{i,t}$ is the fuel cost of unit i at time interval t in \$/hr, a_i, b_i, and c_i are the cost coefficients of generating unit i, $P_{i,t}$ is the real power output of generating unit i at time period t in MW, and N is the number of generators. T is the total number of hours in the operating horizon.

The valve-point effects are taken into consideration in the DED problem by superimposing the basic quadratic fuel-cost characteristics with the rectified sinusoid component as follows:

$$\min F_T = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(a_i P_{i,t}^2 + b_i P_{i,t} + c_i + \left|e_i \times \sin\left(f_i \times \left(P_{i,\min} - P_{i,t}\right)\right)\right|\right) \tag{2}$$

where F_T is total fuel cost of generation in (\$/hr) including valve point loading, e_i, f_i are fuel cost coefficients of unit i reflecting valve-point effects. The fuel cost is minimized subjected to the following constraints:

2.1 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.

$$\sum_{i=1}^{N} P_{i,t} = P_{D,t} + P_{L,t} \tag{3}$$

where $P_{D,t}$ and $P_{L,t}$ are the load demand and transmission loss in MW at time interval t, respectively.

The transmission loss $P_{L,t}$ can be expressed by using ***B*** matrix technique and is defined by (4) as,

$$P_{L,t} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{i,t} B_{ij} P_{j,t} \tag{4}$$

where B_{ij} is coefficient of transmission loss.

2.2 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

$$P_{i,\min} \le P_{i,t} \le P_{i,\max} \tag{5}$$

where $P_{i,\,min}$ and $P_{i,\,max}$ are the minimum and maximum real power output of unit i in MW, respectively.

2.3 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 (6) and (7), respectively.

$$P_{i,t} - P_{i,t-1} \le UR_i \tag{6}$$

$$P_{i,t-1} - P_{i,t} \le DR_i \tag{7}$$

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 unit i (in units of MW/time period).

To consider the ramp rate limits and power output limits constraints at the same time, therefore, equations (5), (6) and (7) can be rewritten as follows:

$$\max\{P_{i,\min}, P_{i,t-1} - DR_i\} \le P_{i,t} \le \min\{P_{i,\max}, P_{i,t-1} + UR_i\} \tag{8}$$

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 [16]. 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 [17].

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

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

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 ∈ [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 CSA can be summarized as the pseudo-code shown in Table 1.

Table 1: Pseudo-code of CSA

Cuckoo Search Algorithm (CSA)
Define the objective function $f(x), x = (x_1, \cdots, x_d)^T$
Set *n*, p_a, and MaxGeneration parameters
Generate initial population of *n* available nests
while (t<MaxGeneration) or (stop criterion) **do**
Get a cuckoo (*i*) randomly by Lévy flights
Evaluate the fitness f_i
Randomly choose a nest (*j*) among n available nests
If $f_i > f_j$ **then**
Replace *j* by the new solution
end if
Abandon a fraction p_a of worse nests and new ones are built;
Keep the best solutions (or nests with quality solutions)
Sort the solutions and find the best current solution
end while
Post-process results and find the best solution among all.

IV. SIMULATION RESULTS

The DED problem was solved using the proposed CSA and its performance is compared with other methods reported in recent literature. The proposed technique has been applied to 10 unit generation system. The algorithm was implemented in MATLAB 7.1 on a Pentium IV personal Computer with 3.6 GHz speed processor and 2 GB RAM. The dispatch horizon is selected as one day with 24 dispatch periods of each one hour.

In this case, generator capacity limits, ramp rate constraints, valve-point effects and transmission losses are considered. The data for this system has been adopted from [18]. The load demand for each time interval over the scheduling period is given in Table 2. The optimal dispatch of real power for the given scheduling horizon using proposed CSA is given in Table 3. The best solution obtained through the proposed method is compared to those reported in the recent literature are shown in Table 4. The best total generation cost obtained using proposed method is $ 2463201.5515 and the computation time taken by the algorithm is 35.89 s. It clear from the table that the proposed method produces much better results compared to recently reported different method for solving DED problem.

Table 2: Load demand for 24 hours (10-unit system)

Time (h)	Load (MW)	Time (h)	Load (MW)	Time (h)	Load (MW)	Time (h)	Load (MW)
1	1036	7	1702	13	2072	19	1776
2	1110	8	1776	14	1924	20	2072
3	1258	9	1924	15	1776	21	1924
4	1406	10	2072	16	1554	22	1628
5	1480	11	2146	17	1480	23	1332
6	1628	12	2220	18	1628	24	1184

Table 3: Best scheduling of 10-unit system using CSA

Hour	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)
1	152.2008	136.8158	73.0000	93.0913	158.6836	141.8350	130.0000	120.0000	39.9884	10.0000
2	150.4166	135.0020	87.1379	79.7081	210.1409	156.0245	130.0000	119.9954	36.1179	27.9564
3	150.2812	136.5722	129.3693	162.3864	236.3364	159.8323	129.2991	119.3188	27.7000	35.3787
4	150.2348	135.0032	235.9837	169.3460	243.0000	157.8415	129.1039	120.0000	69.1458	31.8853
5	151.0766	135.0000	235.1316	238.2871	242.7723	159.8966	127.7673	120.0000	58.8404	50.5896
6	150.2153	135.0000	308.1900	300.0000	242.3233	160.0000	130.0000	120.0000	76.2533	54.0264
7	150.3032	176.6449	340.0000	300.0000	243.0000	160.0000	129.9988	120.0000	80.0000	55.0000
8	182.0258	224.3733	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
9	247.7199	318.8471	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
10	314.2653	414.2000	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
11	350.0713	460.0000	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
12	432.0750	460.0000	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
13	314.2600	414.2052	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
14	247.6880	318.8792	339.9999	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
15	182.0386	224.3605	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
16	150.2336	135.0000	287.3110	264.3420	243.0000	160.0000	130.0000	119.5583	67.3105	40.7912
17	151.2444	135.0000	227.4465	242.0031	243.0000	158.6499	129.1830	119.8545	57.9920	55.0000
18	150.2575	135.0000	334.5695	272.4905	243.0000	160.0000	129.9363	119.8802	78.4905	52.4593
19	181.9368	224.4625	340.0000	299.9999	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
20	314.2609	414.2044	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
21	247.7192	318.8478	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
22	150.0369	135.0000	321.0623	285.2577	242.0814	159.9601	129.5602	120.0000	78.0780	55.0000
23	150.6178	135.0613	198.2680	126.4879	243.0000	160.0000	128.8727	119.8881	48.4541	53.3644
24	150.4208	135.0071	114.8717	120.6707	243.0000	123.0423	129.9816	120.0000	32.6098	39.9140
Total generation cost ($) = 2463201.5515; Total power loss (MW) = 1315.4654										

Table 4: Comparison of cost and computing time

Method	Generation cost ($)	Computing time (s)
GA [15]	2,596,847.38	71.24
PSO [15]	2,5801,48.25	69.88
MBFA [15]	2,544,523.21	54.77
AIS [15]	2,500,684.32	49.82
CSA	2,463,201.55	35.89

V. CONCLUSION

In this paper, CSA has been successfully applied for solving the DED problem. The effectiveness of this algorithm is demonstrated for 10-unit generation system. The obtained results from the test systems have indicated that the proposed technique has a much better performance than other optimization methods reported in the literature. In addition, the results substantiate the robustness, precise convergence and efficiency of this optimization algorithm. The main advantage of CSA is a good ability for finding the solution. From the results obtained it can be concluded that CSA is a competitive technique for solving complex non-smooth optimization problems in power system operation.

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