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Cuckoo Search Algorithm For Solving Dynamic Economic Emission Dispatch Problem

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---*ABSTRACT*--

In this paper, a cuckoo search algorithm (CSA) is presented to solve the dynamic economic emission dispatch (DEED) problem. The practical DEED 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. The proposed algorithm is validated on 5-unit generation system for a 24 h time interval. The results proved the efficiency of the proposed method when compared with the other optimization algorithms reported in the literature.

***KEYWORDS** - Cuckoo search algorithm, dynamic economic emission dispatch, prohibited operating zones, non-smooth cost function*

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I. INTRODUCTION

The fundamental objective of dynamic economic dispatch (DED) problem of electric power generation is to schedule the committed generating unit outputs in order to meet the predicted load demand with minimum operating cost, while satisfying all system inequality and equality constraints [1, 2]. Therefore, the DED problem is a highly constrained large-scale nonlinear optimization problem. The valve-point effect introduces ripples in the heat-rate curves and make the objective function non-convex, discontinuous, and with multiple minima [3-5]. The fuel cost function with valve point loadings in the generating units is the accurate model of the DED problem [6, 7].

Nowadays strategically utilizing available resources and achieving electricity at cheap rates without sacrificing the social benefits is of major significance. The environmental pollution plays a major role as it had a major threat on the human society. Hence, it became compulsory to deliver electricity at a minimum cost as well as to maintain minimum level of emissions. Lowest emissions are considered as one of the objectives in combined economic and emission dispatch problems, along with cost economy. Atmospheric pollution due to release of gases such as nitrogen oxides (NO_X), carbon dioxide (CO_2), and sulphur oxides (SO_X) into atmosphere by fossil-fuel based electric power stations affects not only humans but also other forms of life such as birds, animals, plants and fish, while causes global warming too [8-11]. Generating units may have certain prohibited operating zones (POZs) due to faults in the machines themselves or instability concerns or the valve point effect. Hence, considering the effect of valve-points and POZs in generators' cost function makes the economic dispatch a non-convex and non-smooth optimization problem [12].

The dispatching of emission is a short-term option where the emission, in addition to fuel cost objective, is to be optimized. Thus, DEED problem can be handled as a multi-objective optimization problem and requires only small modification to include emission. Hence, the DEED problem can be converted to a single objective problem by linear combination of various objectives using different weights. The important characteristic of the weighted sum method is that different pareto-optimal solutions can be obtained by varying the weights [13]. In [14-16] the static economic dispatch problem with prohibited operating zones has been solved. A number of reported works has considered the prohibited operating zones in DED problem [17-20], however, the emission has not considered in these papers.

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 the DEED problem considering ramp rate limits, valve-point effects, prohibited operating zones, and transmission loss. Feasibility of the proposed method has been demonstrated on 5-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 DEED 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 both operating cost and emission simultaneously.

The objective function of the DEED problem can be formulated as follow:

$$F_T = w_1 * \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) + w_2 * h * \sum_{t=1}^{T}\sum_{i=1}^{N} E_{i,t}(P_{i,t}) \tag{1}$$

$$\text{for } i = 1,2,\cdots,N;\; t = 1,2,\ldots,T$$

where F_T is the total operating cost over the whole dispatch period, T is the number of hours in the time horizon, N is the total number of generating units, w_1 is weighting factor for economic objective such that its value should be within the range 0 and 1, and w_2 is the weighting factor for emission objective which is given by $w_2 = (1 - w_1)$, and h_i is the price penalty factor. $F_{i,t}(P_{i,t})$ and $E_{i,t}(P_{i,t})$ are the generation cost and the amount of emission for unit i at time interval t , and $P_{i,t}$ is the real power output of generating unit i at time period t.

The valve-point effects are taken into consideration in the DEED problem by superimposing the basic quadratic fuel-cost characteristics with the rectified sinusoidal component as follows [12]:

$$F_{i,t}(P_{i,t}) = \begin{pmatrix} a_i P_{i,t}^2 + b_i P_{i,t} + c_i + \\ \left|e_i \times \sin\left(f_i \times \left(P_{i,\min} - P_{i,t}\right)\right)\right| \end{pmatrix} \tag{2}$$

where the constant a_i, b_i, and c_i represents generator cost coefficients and e_i and f_i represents valve-point effect coefficients of the i-th generating unit.

Utilization of thermal power plant consuming fossil fuel is with release of high amounts of NO_X, they are strongly requested by the environmental protection agency to reduce their emissions. The NO_X emission of the thermal power station having N generating units at interval t in the scheduling horizon is represented by the sum of quadratic and exponential functions of power generation of each unit. The emission due to i-th thermal generating unit can be expressed as

$$E_{i,t}(P_{i,t}) = \left(\alpha_i P_{i,t}^2 + \beta_i P_{i,t} + \gamma_i + \eta_i \exp\left(\delta_i P_{i,t}\right)\right) \tag{3}$$

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

The minimization of the fuel cost and emission are subjected to the following equality and inequality constraints:

2.1 Power balance constraint

The total generated real power should be the same as total load demand plus the total line loss.

$$\sum_{i=1}^{N} P_{i,t} = P_{D,t} + P_{L,t} \tag{4}$$

where $P_{D,t}$ and $P_{L,t}$ are the 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 (5) as,

$$P_{L,t} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{i,t} B_{ij} P_{j,t} \tag{5}$$

where B_{ij} is the ij-th element of the loss coefficient square matrix of size N.

2.2 Generation limits

The real power output of each generators should lie between minimum and maximum limits.

$$P_{i,\min} \le P_{i,t} \le P_{i,\max} \tag{6}$$

2.3 Ramp rate limits

The ramp-up and ramp-down constraints can be written as (7) and (8), respectively.

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

$$P_{i,t-1} - P_{i,t} \le DR_i \tag{8}$$

where $P_{i,t}$ and $P_{i,t-1}$ are the present and previous real 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 real power output limits constraint at the same times, therefore, equations (6), (7) and (8) can be rewritten as follows:

$$\max\{P_{i,\min}, P_{i,t-1} - DR_i\} \le P_{i,t} \le \min\{P_{i,\max}, P_{i,t-1} + UR_i\} \tag{9}$$

2.4 Prohibited operating zones

The prohibited operating zones are the range of real power output of a generator where the operation causes undue vibration of the turbine shaft bearing caused by opening or closing of the steam valve. The prohibited operating zones of unit can be described as follows:

$$P_{i,t} \in \begin{cases} P_{i,\min} \le P_{i,t} \le P_{i,1}^{l} \\ P_{i,k-1}^{u} \le P_{i,t} \le P_{i,k}^{l}, \quad k = 2,3,\ldots, pz_i \\ P_{i,pz_i}^{u} \le P_{i,t} \le P_{i,\max},\ i = 1,2,\ldots, n_{pz} \end{cases} \tag{10}$$

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 serach (CS) algorithm represents a new metaheuristic optimization, which was insprired by the obigate brood parasitism of some cuckoo species by laying their eggs in the nests of host birds. Cuckoos usually choose the nest of a bird that has just laid its eggs so that they can be sure their eggs would hatch first because cuckoo eggs hatch earlier then their host eggs birds. In this optimization algorithm, each nest represents a potential solution [21].

Cuckoo search is based on three idealized rules [22]:

1) Each cuckoo lay one egg (a design solution) at a time, and dumps it in randomly chosen nest;
2) The best nests with high quality of eggs (better solutions) will be carried over to the next generations;
3) 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, it can simply either throw the egg a way or abandon the nest and find a new location to build a completely new one.

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 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
    Sort and find the current best
end while
Postprocess results and find the best solution among all.
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When generating new solution for $x^{(t+1)}$, say cuckoo i, a Levy flight is performed:

$$x_i^{(t+1)} = x_i^t + \alpha \oplus \text{Lévy}\,(\lambda) \tag{11}$$

where $\alpha > 0$ is the step size which sholud be related to the scale of the problem of interests. In most cases, the parameter $\alpha = 1$.

The product $\oplus$ means entry-wise multiplications. Levy flights fundamentally provide a random walk while their random steps are drawn from a Levy distribution for large steps:

$$\text{Lévy} \sim \text{u} = \text{t}^{-\lambda}, (1 < \lambda \le 3) \tag{12}$$

this has infinite varience with an infinite mean. Here the consecutive jumps/steps of a cuckoo fundamentally form a random walk process which obeys a power-law step-length distribution with a heavy tail.

IV. SIMULATION RESULTS

The feasibility of the proposed method is demonstrated on a 5-unit test system for the given scheduled time duration which is divided into 24 intervals. The 5-unit test system data with non-smooth fuel cost and emission function is taken from [23]. The load demand for 24 intervals and B-loss coefficients are taken from [23]. For this test system, the population size of nests (n), maximum number of iterations (MaxGeneration) and the value of probability (p_a) have been selected 20, 200 and 0.25 respectively.

The best solutions of the dynamic economic dispatch (DED), dynamic economic emission dispatch (DEED) and pure dynamic emission dispatch (PDED) are given in Tables 2, 3, and 4, respectively.

Table 2 shows hourly generation schedule, cost and emission obtained from DED problem. Table 4 shows hourly generation schedule, cost, and emission obtained from PDED problem. It is seen from Tables 2 and 4 that the cost is 42063.2959 $ under DED but it increases to 51961.8269 $ under PDED and emission obtained from DED is 22317.0928 lb but decreases to 17852.9736 lb under PDED. Table 3 shows hourly generation schedule, cost, and emission obtained from DEED problem. It can be seen that the cost is 43756.2275 $ which is more than 42063.2959 $ and less than 51961.8269 $, and emission is 19027.5370 lb which is less 22317.0928 lb and more than 17852.9736 lb.

Table 2: Hourly power schedule obtained from DEED (w1=1, w2=0)

H	P_1	P_2	P_3	P_4	P_5	Loss
1	10.0064	20.0000	30.0000	124.4550	229.5277	3.9891
2	46.0295	98.505	30.0052	124.9185	139.7680	4.2287
3	11.0327	98.8759	110.2523	210.0164	50.0000	5.1772
4	60.7904	98.4482	112.7657	124.8278	139.0026	5.8346
5	10.4440	96.2265	109.4258	209.8251	138.8549	6.7763
6	55.0887	98.4951	112.6682	209.8604	139.7556	7.8680
7	73.8389	98.4331	112.5174	209.7696	139.7578	8.3168
8	11.4458	99.2237	112.6936	210.3936	229.5098	9.2665
9	49.6688	98.5094	112.6556	209.8110	229.5234	10.1682
10	63.9981	98.5424	112.6698	209.8296	229.5197	10.5595
11	74.9388	103.3761	113.1339	209.9725	229.6200	11.0414
12	74.3870	124.9662	112.6441	209.7997	229.4740	11.7210
13	64.0735	98.5518	112.6638	209.7881	229.4820	10.5593
14	49.6323	98.5567	112.6467	209.8149	229.5179	10.1684
15	12.6068	98.5670	112.7040	209.8622	229.5182	9.2582
16	14.9034	20.0000	112.6765	209.8347	229.8600	7.2745
17	10.1732	97.4372	103.9571	124.2666	228.8990	6.7331
18	55.0591	98.6335	112.5933	209.8207	139.7619	7.8685
19	11.7525	99.1268	112.9299	209.8194	229.6336	9.2622
20	64.4697	98.5389	112.6596	209.5871	229.3028	10.5581
21	39.3484	98.5525	112.6723	209.8083	229.5202	9.9016
22	52.0803	98.5518	112.5956	209.8255	139.7435	7.7967
23	56.1966	98.4175	113.4387	124.9801	139.7261	5.7690
24	74.5916	98.5422	30.0031	124.8651	139.7662	4.7683
Total:Cost=42063.2959 $, Emission=22317.0928lb, Loss=194.8653 MW						

Table 3: Hourly power schedule obtained from DEED (w1=0.5, w2=0.5)

H	P_1	P_2	P_3	P_4	P_5	Loss
1	27.4541	98.5244	112.7361	124.9094	50.0001	3.6242
2	52.9022	98.5408	112.6749	124.9075	50.0009	4.0262
3	10.0331	93.0835	112.6763	124.9128	139.0491	4.7548
4	59.9749	98.5432	112.6710	124.9021	139.7443	5.8355
5	74.9923	99.0296	124.6007	125.5916	140.2368	6.4509
6	55.2032	98.4808	112.6943	209.7762	139.7129	7.8674
7	73.6338	98.5045	112.6555	209.7940	139.7289	8.3166
8	74.9925	98.5654	139.8314	209.8283	139.7565	8.9740
9	74.9934	100.1068	174.9996	210.0218	139.7930	9.9147
10	74.9175	114.3717	175.0000	209.8434	140.2252	10.3578
11	74.9803	98.5531	117.9527	209.9390	229.5796	11.0047
12	74.9781	98.5314	138.6933	209.8151	229.5006	11.5185
13	74.9923	114.6196	175.0000	209.9133	139.8341	10.3593
14	74.9992	100.1845	174.9977	209.8919	139.8412	9.9144
15	74.8529	98.7270	139.7175	209.8833	139.7943	8.9749
16	26.4855	98.5427	112.6785	209.7943	139.7363	7.2373
17	74.8128	99.4417	125.3592	125.0834	139.7534	6.4504
18	55.0977	98.5390	112.6716	209.8003	139.7593	7.8679

19	74.9628	98.5206	139.9055	209.8144	139.7703	8.9737
20	74.7803	115.0038	174.8973	209.9926	139.6873	10.3612
21	74.8973	98.5141	166.8038	209.7240	139.6980	9.6372
22	51.9998	98.5382	112.6852	209.8151	139.7581	7.7064
23	56.9066	98.5373	112.6669	124.9076	139.7522	5.7705
24	74.9993	98.6570	118.9570	124.9101	50.0207	4.5442
Total: Cost=43756.2275 $, Emission=19027.5370lb, Loss=190.5329 MW						

Table 4: Hourly power schedule obtained from DEED (w1=0, w2=1)

H	P_1	P_2	P_3	P_4	P_5	Loss
1	54.6786	58.2355	116.5716	110.5982	73.3640	3.4480
2	58.0671	62.3834	121.8514	117.9821	78/6015	3.8854
3	63.5264	69.0804	130.2204	129.7502	87.0639	4.6413
4	71.1205	78.4296	141.5515	145.8017	98.8903	5.7936
5	75.0000	83.2682	147.2406	153.9045	105.0175	6.4307
6	75.0000	93.4677	158.8135	170.4577	117.9160	7.6549
7	74.9999	97.2087	162.8575	176.3519	122.7053	8.1233
8	75.0000	103.1373	169.1991	185.3528	130.1922	8.8813
9	74.9993	111.5600	175.0000	197.6374	140.7169	9.9136
10	74.9996	115.3669	174.9910	203.3259	145.6538	10.3372
11	74.9988	119.7044	175.0000	209.5545	151.5754	10.8331
12	74.9998	124.9933	174.9974	217.4840	158.9978	11.4723
13	74.9999	115.2622	174.9990	203.2579	145.8175	10.3365
14	74.9998	111.3784	174.9995	197.8394	140.6965	9.9136
15	75.0000	103.1676	169.2498	185.2912	130.1728	8.8812
16	75.0000	87.7080	152.3790	161.2139	110.6544	6.9554
17	74.9999	83.2694	147.2401	153.9023	105.0190	6.4307
18	75.0000	93.4527	158.8131	170.4515	117.9375	7.6548
19	75.0000	103.0868	169.2306	185.4118	130.1521	8.8813
20	74.9984	115.1048	175.0000	203.2693	145.9634	10.3359
21	74.9998	108.7447	174.9269	193.7195	137.2267	9.6176
22	74.9999	92.8465	158.1036	169.4431	117.1850	7.5781
23	70.7034	77.9151	140.9390	144.9312	98.2387	5.7274
24	61.8834	67.0630	127.7206	126.2266	84.5138	4.4073
Total: Cost=51961.8269 $, Emission=17852.9736lb, Loss=188.1346 MW						

Table 5: Comparison results for 5 unit system

Weight	Method	Cost ($)	Emission (lb)
w1=1; w2=0	PSO [23]	47852	22405
	DE-SQP [24]	45590	23567
	CSA	42063.2959	22317.0928
w1=0.5; w2=0.5	PSO [23]	50893	20163
	DE-SQP [24]	46625	20527
	CSA	43756.2275	19027.5370
w1=0; w2=1	PSO [23]	53086	19094
	DE-SQP [24]	52611	18955
	CSA	51961.8269	17852.9736

Table 5 shows that, the efficiency of the proposed method compare with other method for DEED problem at different weighting factors. It can be seen that both fuel cost and emission less than other method reported in the literature.

V. CONCLUSION

In this paper, CSA has been successfully applied for solving the DEED problem. The effectiveness of this algorithm is demonstrated for 5-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. 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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