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Solution to Economic Load Dispatch Problem Using Cuckoo Search Algorithm

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***Abstract*: Economic Load Dispatch is the most important area of power system operation and planning. It is a deputize problem of the optimal power flow (OPF). The main objective of ELD problem is to diminish the overall fuel cost of generating units while simultaneously satisfying the equality, inequality and other constraints. Minimization of fuel cost only is not satisfactorily therefore emission constraints are also considered to minimize the pollutants form thermal units. The power system with large number of generating units is unable to provide a fast and vigorous solution using conventional methods. Thus in this paper, ELD problem is unravelled using a new metaheuristic nature- inspired algorithm called as Cuckoo Search Algorithm (CSA). The viability of proposed method is tested on numerous test systems like 3, 6, 10 & 13 unit systems and results obtained are compared with other techniques presented in literature. Simulation results clearly show that CS provides accurate solution with high convergence rate.**

***Keywords*: economic dispatch, cuckoo search algorithm**

1. INTRODUCTION

As Unit Commitment & Load Forecasting, the economic load dispatch (ELD) is also a crucial part of modern power system. The purpose of the ED is to find the optimum generation among the existing units, such that the total cost of generating units is minimized while satisfying the power balance equations and various other constraints in the system simultaneously [1]. For any load demand the ELD problem provide power output of each unit in MW and also calculate the overall fuel cost of generating units. The thermal plant releases various pollutants in the atmosphere during generating electricity. Thus to minimize the fuel cost is not the only single objective therefore in this paper we also consider emission constraints in order to minimize the emissions. The fuel cost curve is a smooth convex curve but due to insertion of valve point loading this fuel cost curve become non-linear and the problem become more complex. Valve point loading is also considered in this paper. Economic dispatch analysis has been studied by many researchers using diverse methods. Previous methods include various mathematical procedures such as Newton Raphson, Gradient-based method, Lambda iteration & Dynamic programming [2,3] which doesn't provide fast and global solution and the problem complexity increases. Thus the power system optimization problem need algorithm with faster rate of convergence, global solution provision and ability to handle very large complexity. Various artificial intelligent techniques such as the Genetic Algorithm (GA) [4], Artificial bee colony[5], Gravitational search algorithm [6], Pattern Search (PS) [7], Firefly algorithm[8], Evolution Programming (EP), Particle Swarm Optimization, Differential evolution [9, 10], Tabu search [11], have been efficaciously used to solve power optimization problem. In this paper an appropriate and robust technique is used to solve economic dispatch problem i.e. Cuckoo Search Method (CS) [12]. It is a new metaheuristic search algorithm, developed by Yang and Deb in 2009.

2. PROBLEM FORMULATION

The ED problem may be stated as to curtail the fuel cost of generator units under several constraints. Mathematically, it may expressed as-

A) Economic dispatch problem (Minimization Of Fuel Cost)

Fuel cost model is given as

$Fi\ (Pi) = a_iP_i^2 + b_iP_i + c_i$ (1)

$\text{Min } F = \sum_{i=1}^{N} Fi(Pi)$

$= \sum_{i=1}^{N} aiPi^2 + biPi + ci$ (2)

Subjected to following constraints-

$\sum_{i=1}^{N} Pi - Pd - Pl = 0$ (3)

and $P_{imin} \leq P_i \leq P_{imax}$ (4)

where,

a_i , b_i , c_i are cost coefficients of generator i

P_i = real power output of i[th] generator

P_d= total load demand

P_l = transmission losses

B = coefficient of transmission losses

$P_l = \sum_{i=1}^{N} \sum_{j=1}^{N} Pi\ Bij\ Pj + \sum_{i=1}^{N} Boi\ Pi + Boo$ (5)

A) Economic dispatch problem with valve point effect

By insertion of valve point loading effect, the incremental fuel cost curve become more real and it thus increases non-linearity and as well as no. of local optima in the results.

Fuel cost now is expressed as-

$\dot{F}i(Pi) = Fi(Pi) + |\, e_i \sin (f_i\ (P_{imin} - P_i))|$ (6)

$\dot{F}i(Pi) = aiPi^2 + biPi + ci + |\, e_i \sin (f_i\ (P_{imin} - P_i))|$ 7

e_i and f_i are constants of valve point effect

Now overall cost to be minimized is-

$\text{Min } F = \sum_{i=1}^{N} \dot{F}i(Pi)$ (8)

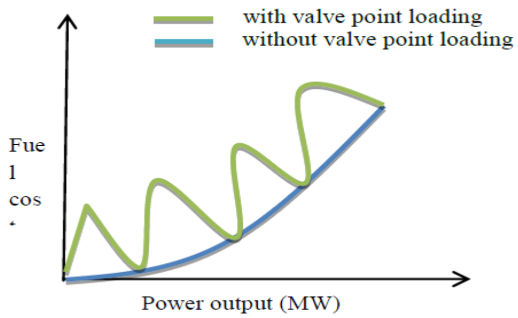


Fig 1.1 Ripples in the Cost-Function due to Valve Point Loading

A) Emission dispatch problem (minimization of emissions from generator units i.e. NOx & SOX)

1.) Fuel cost for economic dispatch ($/hr)

$$F1 = \sum_{i=1}^{N} Fi(Pi) = \sum_{i=1}^{N} aiPi^2 + biPi + ci \qquad (9)$$

2.) Fuel cost for emission dispatch (kg/hr)

$$F2 = \sum_{i=1}^{N} Fxi(Pi) = \sum_{i=1}^{N} \alpha iPi^2 + \beta iPi + \gamma i \qquad (10)$$

where α, β, γ are the coefficients of emissions

3. CUCKOO SEARCH METHOD

Cuckoo search is an optimisation algorithm based on cuckoo bird's behaviour. It is developed by Xin-Se Yang & Suash Deb in 2009.

First step is to initialize the population which consist of cuckoos. Tis population contain eggs which lay them into the host bird's nest. Some of these eggs which are quite similar to the host bird's eggs have more chance to grow up and become the young cuckoos. Other eggs which are recognized by host bird are either thrown away or it simply vacates its nest and construct new one somewhere else.

Basically it consist or 3 rules -

1) Each cuckoo lays one egg at a time, and put them into host nest.
2) Best nests with high class of eggs (solutions) will carry over to the next generations.
3) The number of available host nests is fixed, and a host can discover an egg laid by cuckoo with probability pa ∈ [0 1].

Simply cuckoo search method can be applied to various optimization problems. Yang & Suash Deb discovered that performance of cuckoo search can be improved usin levy's flight instead of simple random walks.

3.1 Lévy Flight

In nature, animals search for food in a random or quasi-random manner. Generally, the searching path of an animal is efficiently a random walk because the next move is centred on both the current location and the changeover possibility to the next location. The chosen direction implicitly depends on a probability, which can be presented mathematically. Various studies have shown that the flight behavior of many animals and insects determines the typical features of Lévy flights [17]. A Lévy flight is a random walk in which the step-lengths are scattered according to a heavy-tailed probability distribution. After a large number of steps, the distance from the origin of the random walk tends to a stable distribution. The random walks can also be linked with the similarity between a cuckoo's egg and the host's egg which can be tricky in implementation. The step size determines how far a random walker can go for a fixed number of iterations.

For maximization problem, the excellence or fitness of a solution can simply be proportional to the value of the objective function. For ease, we can use the following simple representations that each egg in a nest represents a solution, and a cuckoo egg represents a new solution. When engendering new solutions x^(t+1)for, say, a Cuckoo i, a Levy flight is performed

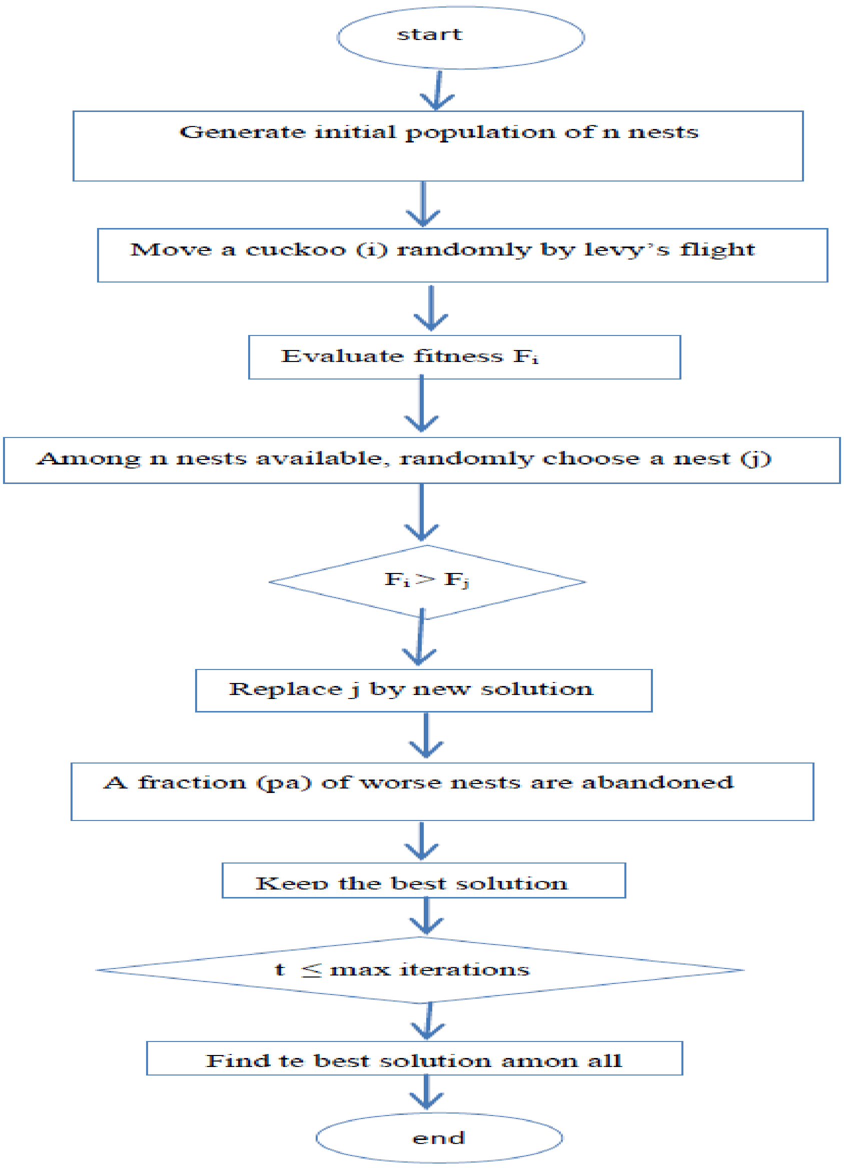
$$xi^{(t+1)} = xi^{(t)} + \alpha \oplus levy\ (\lambda) \qquad (11)$$

where α > 0 is the step size which should be related to the scales of the problem of interests. In most cases, we can use α =1. The product ⊕ means entry wise multiplications. This entry wise product is similar to those used in PSO. The Levy flight fundamentally provides a random walk while the random step length is drawn from a Levy distribution ,

$$levy\ u = t^{(-\lambda)} \quad (1 < \lambda < 3) \qquad (12)$$

which has a boundless variance with an infinite mean. Levy walk around the best solution achieved so far, this will speed up the local search [18].

3.2 Flowchart of CS



4. NUMERICAL RESULTS

***4.1 Case 1*:** The proposed method is tested on 3, 6 & 10 unit systems for an economic load dispatch. All the systems are consider ignoring losses and without valve point effect.

1) *3 Unit System:* The fuel cost coefficients are given in table I. The load demand is 850 MW. The total fuel cost calculated with proposed method is 8194.35 $/hr. This cost is compared with other techniques mentioned in literature [16].

Table.1 Fuel cost coefficients

Unit	Min	Max	a($/MW^{2}h)	b($/MWh)	c($/h)
1	50	200	0.004820	7.97	78
2	100	400	0.001940	7.85	310
3	100	600	0.001562	7.92	561

Table.2 Comparison of proposed method with others for 3 unit system

Unit power output	CS	PSO	CPSO	WIPSO	MRPSO
P1	393.16	415.21	327.29	387.50	37.62
P2	334.60	209.95	400	327.40	324.68
P3	122.22	143.82	122.70	137.60	137.38
T.Power O/P	850	850	850	850	850
Total cost	8194.3	8200.7	8197.16	8200.215	8196.14
Time (sec)	0.091	0.3689	0.3561	0.4792	0.3506

2) ***6 Unit System****:*This is an IEEE standard 30 bus systems with 6 generating units. The fuel cost coefficients of 30 bus system are given in [9]. The load demand is 283.4 MW. The total fuel cost computed with proposed method is 765.87563 $/hr.

Table.3 Comparison of proposed method with others for 6 unit system

Unit power output	CS	GA	EP	PSO	DE
P1	185.94	176.18	173.30	185.28	177.10
P2	46.48	40.37	50.75	53.92	50.96
P3	18.95	26.88	20.92	21.94	21.73
P4	10.01	18.48	22.63	10.00	9.12
P5	10.00	16.79	12.23	10.00	10.80
P6	12.00	12.00	12.00	12.00	12.54
Total cost	765.87	798.94	797.00	799.35	797.27

3) 10 Unit System: It is a 10 unit system with load demand of 1036 MW. The fuel cost coefficients are given in [16].The total cost computed with cuckoo search method is 27811.643 $/hr and it is compared with other techniques such as PSO, MRPSO, CPSO etc.

Table.4 Comparison of proposed method with others for 10 unit system

Unit power o/p	CS	PSO	CPSO	WIPSO	MRPSO
P1	174.31	203.09	215.03	203.09	225.01
P2	162.37	171.21	165.03	171.21	157.016
P3	124.30	126.97	136.04	126.97	126.97
P4	64.41	60	75.03	59.03	71.02
P5	128.78	89.74	112.01	89.74	119.76
P6	159.76	89.09	82.22	89.09	89.09
P7	128.70	130	123.02	131.24	121.01
P8	48.82	101.71	66.89	101.719	68.03
P9	30.019	50.035	44.87	50.0356	39.02
P10	14.51	13.95	16.03	13.9021	19.03
Total cost	27811.64	28295.02	28297.46	28291.8	28245.5
Time (sec)	0.104	0.476	0.539	1.117	0.355

4.2 Case 2: In this case the proposed method is tested on 3 & 13 unit system for an economic load dispatch. Both the systems are consider ignoring losses and with valve point effect.

1) 3 Unit System: The fuel cost coefficients are same as given in table I. The load demand is 850 MW.

The total fuel cost calculated with proposed method is 8053.4007 $/hr. The valve loading coefficients are given below in table IV [6].

Table.5 Valve loading coefficients

Unit	**1**	**2**	**3**
e	150	200	300
f	0.063	0.042	0.0315

Table.6 Comparison of proposed method with others for 3 unit system with valve point loading

Units	**Proposed Method (C.S)**
1	393.1698
2	122.2264
3	334.6037
Total cost ($/hr)	8053.4007

Table.7 Comparison of proposed method with others for 3 unit system with valve point loading

Method	**Cost ($/hr)**
Proposed method (CS)	8053.40
GSA [6]	8234.10
GA [6]	8222.07
EP [6]	8234.07
MFEP [6]	8234.07
IPSO [13]	8234.067
PSO [13]	8234.073

1) 13 Unit System: It is a 13 unit system with load demand is 2520 MW. The fuel cost coefficients are given in [6] [11]. The total cost obtained is 22360.84 $/hr.

Table.8 Results obtained for 13 unit system with VPL

Unit power o/p	**CS**	**Unit power o/p**	**CS**
P1	647.98	P8	128.45
P2	349.84	P9	134.69
P3	347.42	P10	56.47
P4	162.83	P11	90.39
P5	164.59	P12	84.87
P6	138.08	P13	76.47
P7	137.88	Total cost	22360.84

Table.9 Comparison of proposed method with others for 13 unit system with valve point loading

Method	**Cost ($/hr)**
Proposed method (CS)	22360.84
GSA [6]	24164.25
EP-SQP [6]	24266.44
SA [6]	24070.91
PSO-SQP [6]	24261.05
GA [11]	24400
TSA [11]	24314.75
DTSA [11]	24169.95
ITS [11]	24080.55

4.3 Case 3: In this case the proposed method is tested on 3 unit system for an emission dispatch i.e. to minimize the pollutants from thermal plant. The fuel cost coefficients are given in [11].The load demand varies from 200-400 MW.

Table.10 Emission coefficients

Unit	α(kg/MW²h)	β(kg/MWh)	γ(kg/h)
1	0.0126	-1.355	22.983
2	0.01375	-1.249	137.370
3	0.00765	-0.805	363.704

Table.11 Comparison of proposed method with others

	Emission (kg/hr)	
Load	**Proposed method (CS)**	**ITS [11]**
200	446.300	521.0815
250	472.183	583.7942
300	515.744	679.637
350	576.986	762.187
400	655.907	878.576

5. CONCLUSION

This paper boon a new method to solve ED problem. The solution of ELD problem includes minimization of fuel cost, emission cost & scheduling generator units. While solving ELD the power balance equation and various other constraints must be satisfied. The proposed method (Cuckoo Search method) is tested on 3, 6, 10 & 13 unit systems for solving economic dispatch problem with and without valve point effect as well as for emission dispatch. The total fuel cost and emission cost obtained by CS method is found to be less as compared to other methods given in literature. Also its computation time is less as compared to other techniques. This proved that CS method has ability to provide global solution & high convergence rate for small as well as large scale systems. Thus this method is proved to be more proficient, robust and is widely used in real world applications now-a-days.

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