International Journal of Engineering Trends and Technology (IJETT) – Volume 4 Issue 6- June 2013

Solving Combined Economic and Emission Dispatch using Cuckoo Search

Upasana Sapra

#P.G. Student & Electrical Engg. Deptt. & R.G.P.V University
MITS, Gwalior, India

***Abstract*— This paper presents an application of a new meta-heuristic approach called Cuckoo Search (CS) for solving Multi-objective CEED problem. Combined Economic and Emission Dispatch problem determines optimum power generation schedule while minimizing fuel cost and emission simultaneously. Cuckoo Search is inspired from the obligate brood parasitic strategy of cuckoo species in combination with the lévy flights behavior of birds. To validate the effectiveness & feasibility of the approach, it has been examined on three different standard test cases. Simulation results obtained are also compared with other reported methodology. The comparison confirms the superiority, fast convergence and proficiency of the algorithm.**

***Keywords*— Combined Emission and Economic Dispatch (CEED), Fuel cost, Emission, Cuckoo Search (CS).**

I. INTRODUCTION

Combined Economic and Emission Dispatch (CEED) problem allocate optimal power generation among the committed units which minimizes fuel cost as well as the amount of emission while satisfying all the operational constraints of the system. The generation of electricity from fossil fuel releases several contaminated elements, such as Sulphur Dioxide (SO_2), Nitrogen Oxides (NO_x), and Carbon Dioxide (CO_2) into atmosphere which pollute the environment. Atmospheric pollution affects all the forms of life and also causes global warming. Due to increasing concern over the environment and the passage of US Clean Air Act amendments of 1990, utilities are forced to modify their strategies for power generation not only at minimum cost but also at minimum emission level [1].

Several strategies such as Genetic Algorithm (GA) [2,3], Simple Recursive approach [4], Multi-Objective Evolutionary Algorithms(MOEA) [5], Refined Genetic Algorithm (RGA) [6], Particle Swarm Optimization (PSO) [7], Biogeography Based Optimization (BBO)[8], Differential Evolution (DE) [9], Non-Dominated Sorting Genetic Algorithm (NSGA-II) [10], Artificial Bee Colony (ABC) [11], ABC-PSO [12], Gravitational Search Algorithm (GSA) [13] and Parallel Synchronous Particle Swarm Optimization (PSPSO) [14] have been proposed to solve various complex CEED problems.

Here, a new meta-heuristic technique Cuckoo Search [15-16] is implemented to solve multi-objective CEED problem. Cuckoo Search is based on the obligate brood parasitic behaviour of cuckoo species in combination with the Lévy flight behaviour of birds. The success or failure of CS approach depends upon its ability to set-up a proper trade-off between intensification and diversification. Intensification is the ability of an algorithm to search around the current best solutions and select the best solution whereas diversification expands the problem search space efficiently by randomization.

In order to validate the effectiveness of CS approach to optimize objective function, three test cases are discussed and compared in this paper. Three test system of three unit, six unit and fourteen unit system with smooth cost and emission function with and without power loss are considered here along with generator capacity constraints and power balance constraints.

The rest of the paper is organized as follows: the problem formulation of Combined Economic and Emission Dispatch (CEED) problem is described in Section-II. Section-III explains the Cuckoo Search (CS) algorithm. Section-IV depicts the implementation of CS for solving CEED problem. Section-V presents the simulation results for different standard test cases. Comparative study is discussed in section-VI. Finally, conclusion is derived in section-VII.

II. PROBLEM FORMULATION

The objective of Combined Economic and Emission Dispatch (CEED) problem is to determine the optimal power generation schedule among the committed units which minimizes the fuel cost as well as the amount of emission while satisfying all equality and inequality constraints of the system. The objective function is expressed mathematically as:

$$TC = \min \sum_{i=1}^{N_g} f_i(F(P_i), E(P_i)) \tag{1}$$

where, TC is the total production cost, $F(P_i)$ is the fuel cost of i^{th} thermal units in \$/hr, $E(P_i)$ is the total amount of emission of i^{th} thermal units in kg/hr or ton/hr and N_g is the number of generators in the system.

A. *Minimization of Fuel Cost*

The smooth fuel cost function of thermal generating unit is expressed as a quadratic function. Mathematically,

$$F(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

where, a_i, b_i *and* c_i are the fuel cost coefficients of i^{th} thermal unit, $F(P_i)$ is fuel cost of i^{th} thermal units in \$/hr, P_i is the power generation output of i^{th} thermal unit; P_i^{min} and P_i^{max}

are the lower and upper power generation limits for i^{th} thermal unit.

B. Minimization of Emission

Thermal power stations are major causes of atmospheric pollution. In this study, Nitrogen Oxides (NO_x) emission is considered. The smooth emission level function from each generator can be described as:

$$E(P_i) = \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{4}$$

E (P_i) is the total amount of emission in kg/hr or ton/hr, α_i, β_i and γ_i are emission curve coefficients of i^{th} thermal unit.

C. Multi-objective Optimization Using Price Penalty factor approach

A Multi-objective CEED problem deals with the optimal power generation scheduling that minimizes two objectives of Economic Dispatch (ED) and Economic Emission Dispatch (EED) simultaneously. This bi-objective problem is converted into a single objective problem with the help of Price Penalty factor approach as:

$$\min TC = u * F(P_i) + (1-u) * h * E(P_i) \tag{6}$$

The value of u shows a relative significance between the two objectives. Normally, weights are selected in such a way that their arithmetical sum is equal to one. The weighting factor u, can take different number between 0 and 1. A set of solutions obtained from a set of different values for u are known as Pareto optimal solutions. When u=1, the problem becomes purely of Economic Dispatch (ED) that minimizes fuel cost only while at u=0, the problem is converted into Economic Emission Dispatch (EED) which minimizes only emission. When u varies from 0 to 1, the fuel cost decreases whereas emission increases.

Hence, *h* is defined as the ratio of average fuel cost to average emission for maximum power capacity of plant. A practical way of determining *h* is given in [17].

D. Constraints

1) Equality Constraints:

$$\sum_{i=1}^{N_g} P_i - P_D - P_L = 0 \tag{10}$$

P_D represents the load demand (MW), P_L are the transmission power loss (MW). P_L is obtained using Loss-coefficient matrix as:

$$P_L = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i B_{ij} P_j \tag{11}$$

2) Inequality Constraints:

Real power generation should be within minimum and maximum values.

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{12}$$

P_i^{min} and P_i^{max} is the minimum and maximum power generation capacity for i^{th} thermal unit.

III. CUCKOO SEARCH ALGORITHM

Cuckoo Search (CS) is a stochastic global search algorithm formulated by Yang and Deb [15-16]. It is inspired from the breeding strategy of some cuckoo species by laying their eggs in the nest of host birds.

Cuckoo bird searches for a nest where they could lay their eggs. As cuckoo eggs would hatch earlier as those of host birds, so they choose a nest where host bird has just laid its eggs. When a cuckoo egg is hatched, it instantly expels the host bird’s eggs so as to receive all the food brought in. If host bird discovers cuckoo egg then either it throw away those alien eggs or abandon its nest or build a new nest somewhere. Some breeds of cuckoos have adapted to lay their eggs which mimic the eggs of host birds. This characteristic decreases the probability of their eggs being abandoned and thus increases their reproductivity. In simulation, each nest represents a potential solution. CS idealized this breeding behavior of cuckoo species for various optimization problems in three steps:

1. Each cuckoo lays only one egg in the randomly chosen nest.
2. The best nests with better proficiency will carry to the next generation.
3. Here the availability of host nests is fixed and probability $p_a \epsilon$ [0, 1] represents the possibility of alien egg to be discovered by host bird.

The new nest i.e. new solutions x_i^{t+1} are generated by the host by the Lévy flight method [18].

$$x_i^{t+1} = x_i^t + \alpha \oplus Levy(\beta) \tag{13}$$

where $\alpha > 0$, represents the step size of the concern problem. The product $\oplus$ means entry wise multiplications.

$$\alpha = \alpha_o (x_j^t - x_i^t) \tag{14}$$

where α_0 is constant, while the term in the bracket represent the difference of two random solutions. This mimics that fact that similar eggs are less likely to be discovered and thus new solutions are generated by the proportionality of their difference.

Normally, Lévy flights represent a random way of food searching used by birds and animals. It is suggested that the step size should be L/100, where L is the size of space to be searched. Selection of larger step size would lead new solutions to go out of search space. The generation of random walks by Lévy flights can be achieved either by randomization through Lévy distribution or by normal distribution. By Lévy distribution, the step length can be derived as:

$$\text{Lévy} \sim u = t^{1-\beta} \quad (0<\beta<2) \tag{15}$$

which has an infinite variance and infinite mean. Here, β=1.5.

A fraction of worse nests can be thrown away with probability (p_a) so that new nests can be built by random walk or mixing. The mixing of eggs can be performed by random permutation according to the similarity/difference of the host eggs. A scheme for the calculation of step size is discussed in detail [19] can be summarized as:

$$s = \alpha_0 (x_j^t - x_i^t) \oplus Levy(\beta) \sim 0.01 * \frac{u}{|v|^{1/\beta}} (x_j^t - x_i^t) \qquad (16)$$

where, u and v are drawn from normal distribution. That is:

$u \sim N(0, \sigma_u^2)$ & $v \sim N(0, \sigma_v^2)$

$$\sigma_u = \left\{ \frac{\Gamma(1+\beta)\sin(\pi\beta/2)}{\Gamma[(1+\beta)/2\beta 2^{\beta-1/2}]} \right\}^{1/\beta}, \sigma_v = 1 \qquad (17)$$

Γ represents the standard gamma function.

$$\Gamma(z) = \int_0^\infty t^{z-1} e^{-t} dt$$

where, z=k is a integer, we have Γ(k)= (k-1)!.

IV. IMPLEMENTATION

The computational process of CS can be described in the following steps:

Step 1: Initialize the number of population, *n* of host nests through objective function (1) as $f(x)$, $x=(x_1, x_2 \ldots\ldots x_d)^T$ within generation range (12). Specify the capacity of each generator, cost characteristics, emission coefficients, power demand, loss coefficients matrix. Set the value of probability, p_a and maximum number of iterations.

Step 2: While the iteration value is less than the maximum number of iterations, the function will generate a cuckoo randomly by Lévy flight using (13-15). Since each value of population set represents the power generation output which acts as decision variables for CEED.

Step 3: Estimate the fitness F_i of the generated solution. In CEED problem, fitness value signifies the overall fuel cost and emission for i^{th} thermal units which is evaluated with the help of (1).

Step 4: Choose a nest among *n* (say *j*) randomly and calculate its fitness (F_j) as in Step 3.

Step 5: Perform selection procedure between F_i and F_j based on their fitness values. If the fitness F_i is more than the fitness F_j then replace *j* by new solutions.

Step 6: A fraction of worse nests (not so good solutions) are discarded and new ones are built by Lévy flights according to (13-14) and (16-17).

Step 7: As the new solutions are accepted, rank the solutions and find the current best solutions.

V. SIMULATION RESULTS

To assess the efficiency and performance of CS, it is applied to three standard test systems of three unit, six unit and fourteen unit system. This algorithm is implemented using MATLAB Software 7.8 and the system configuration is Intel core i3 processor with 2.27 GHz and 3 GB RAM. The simulation is performed for 20 repeated trials with 500 iterations per trial.

A. *Description of Test systems*

1) *Test system I:Three unit system:*

This test case consists of three thermal generator units with NO_x emission and power loss. The cost coefficients, emission coefficients, load demands, power loss matrix and operating limits of generators are taken from [14]. The best compromising fuel cost ($/hr) and Emission (kg/hr) obtained by CS method and their comparison with other reported methods such as Genetic Algorithm (GA) [14], Particle Swarm Optimization (PSO) [14] are shown in Table-I. The optimal power generation scheduling for all generators obtained at 20 repeated trials is listed in Table-II. A Cost-Emission trade-off curve for three unit test system at 400MW, 550MW and 700MW is shown in *"Fig.1"*, *"Fig.2"*and *"Fig.3"*.

TABLE I. COMPARISON OF TEST RESULTS FOR THREE UNIT SYSTEM

P_D (MW)	Performance	GA	PSO	PSPSO	CS
400	**Fuel Cost ($/hr)**	20838.313	20839.149	20837.605	20837.48577
	Emission (kg/hr)	202.265	202.735	200.230	200.23984
	Simulation Time (sec)	0.206	0.253	0.177	0.0458
550	**Fuel Cost ($/hr)**	27905.107	27907.314	27904.350	27903.98049
	Emission (kg/hr)	383.614	384.361	381.210	381.21735
	Simulation Time (sec)	0.214	0.269	0.186	0.046987
700	**Fuel Cost ($/hr)**	35465.394	35467.062	35463.663	35463.57986
	Emission (kg/hr)	653.267	653.504	651.585	651.58841
	Simulation Time (sec)	0.227	0.289	0.192	0.04847

TABLE II. OPTIMAL POWER GENERATION SCHEDULING FOR THREE UNIT SYSTEM

Unit Power Output (MW)	**Load Demand (MW)**		
	400	**550**	**700**
P_1	102.22683	142.19953	182.42069
P_2	154.04782	212.05897	271.39819
P_3	151.13969	209.95822	269.54973
Fuel cost ($/hr)	20837.48577	27903.98049	35463.57986
Emission (kg/hr)	200.23984	381.21735	651.58841
P_L**(MW)**	7.41434	14.21671	23.36862

2) *Test system II: Six unit system:*

A six unit thermal generating units with NO_x emission is considered here. The unit cost coefficients, emission coefficients, load demands and operating limits of generators have been adopted from [3]. Comparison of results with γ-iteration [4], Recursive [4], PSO [4], DE [4], Simple Recursive [4] and GA [3] is listed in Table-III. For 20 repeated trials, the obtained result in terms of optimum power output along with load demand is shown in Table IV. A cost-emission trade-off curve at various load demands is illustrated in *"Fig. 4"*, *"Fig.5"*, *"Fig.6"*, *"Fig.7"*, *"Fig.8"* and *"Fig.9"*.

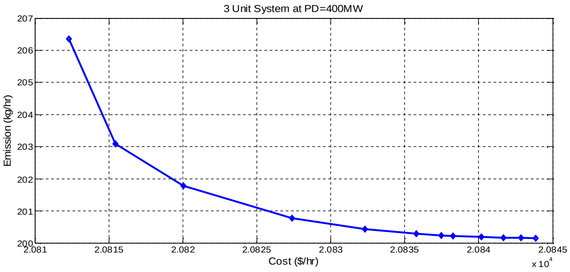

Fig. 1. Cost-Emission Trade-off curve for 3 unit system at PD=400 MW

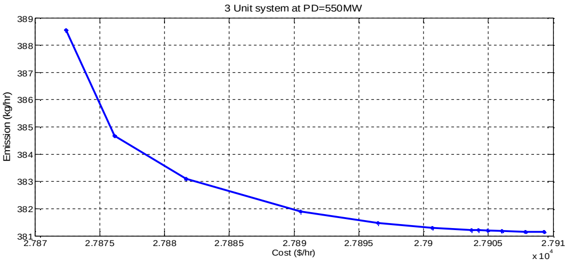

Fig. 2. Cost-Emission Trade-off curve for 3 unit system at PD=550 MW

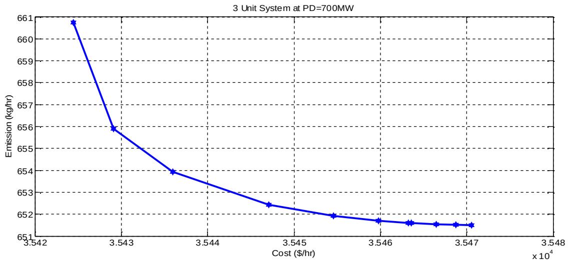

Fig. 3. Cost-Emission Trade-off curve for 3 unit system at PD=700 MW

3) *Test system III: fourteen unit system:*

An IEEE-118 Bus system which includes 14 generating units with NO_x emission is considered here. The input data for this system is taken from [20]. The load demand is set to be 950 MW. The obtained result in terms of optimum power output, fuel cost ($/hr) and Emission (kg/hr) is shown in Table-V. The cost-emission trade-off curve for 14-unit system at 950MW is shown in *"Fig. 10"*.

B. Determination of parameters for CS method

The following procedure has been adopted to determine optimum value of population (n) and probability (p_a). Different population size was undertaken 10, 20, 50, and 100. For each population, probability (p_a) is varied from 0.05 to 0.5 for 6-unit system for 500 MW which is shown in Table-VI. The simulation is performed at 20 repeated trials with 500 iterations per trial for all combinations. Based on the results obtained in Table-VII, population size (n) =20 and probability (p_a) =0.25 are observed to give the best compromise result which is much less than the previously reported result.

TABLE III. COMPARISON OF TEST RESULTS FOR SIX UNIT SYSTEM

PD (MW)	**Performance**	**γ-iteration [4]**	**Recursive [4]**	**PSO [4]**	**DE [4]**	**Simple Recursive [4]**	**GA [4]**	**CS**
500	**Fuel Cost ($/hr)**	27,092.5	27,092.5	27,092.5	27,098.1	27,092.5	27,089.45	**27084.08859**
	Emission (kg/hr)	261.635	261.634	262.225	261.859	261.634	261.3307	**260.65638**
600	**Fuel Cost ($/hr)**	31,628.7	31,628.6	31,634.9	31,629.2	31,628.6	31,626.79	**31625.26340**
	Emission (kg/hr)	338.993	338.992	339.820	339.065	338.992	338.4397	**337.77405**
700	**Fuel Cost ($/hr)**	36,314.0	36,313.9	36,314.2	36,314.0	36,313.9	36,310.80	**36307.25096**
	Emission (kg/hr)	434.380	434.380	434.605	434.453	434.380	433.6409	**433.26490**
800	**Fuel Cost ($/hr)**	41,148.4	41,148.3	41,160.3	41,152.6	41,148.3	41,144.47	**41143.62921**
	Emission (kg/hr)	547.797	547.796	547.844	547.802	547.796	546.7831	**546.38774**
900	**Fuel Cost ($/hr)**	46,131.8	46,131.8	46,160.6	46,152.6	46,131.8	46,124.54	**46121.69005**
	Emission (kg/hr)	679.241	679.241	679.724	679.283	679.241	678.2906	**677.85970**
1100	**Fuel Cost ($/hr)**	56546.4	56546.2	56556.7	56546.6	56546.2	56546.2	**56539.68670**
	Emission (kg/hr)	996.224	996.218	996.672	996.222	996.218	994.218	**993.94270**

TABLE IV. OPTIMAL POWER GENERATION SCHEDULING FOR SIX UNIT SYSTEM

Unit Power Output (MW)	**Load Demand (MW)**					
	500	**600**	**700**	**800**	**900**	**1100**
P_1	27.03748	37.39861	47.84760	58.84201	69.75570	92.36278
P_2	12.65131	25.86138	39.08190	53.00908	66.70854	94.91109
P_3	87.49980	103.28325	118.98162	134.53739	150.04468	180.74842
P_4	90.07136	105.03321	119.95601	134.75949	149.55722	178.94189
P_5	144.09373	166.52026	188.99292	210.95699	233.14380	277.02662
P_6	138.64632	161.90328	185.13996	207.89504	230.79004	276.00921
Fuel cost ($/hr)	**27084.08859**	**31625.26340**	**36307.25096**	**41143.62921**	**46121.69005**	**56539.68670**
Emission (kg/hr)	**260.65638**	**337.77405**	**433.26490**	**546.38774**	**677.85970**	**993.94270**

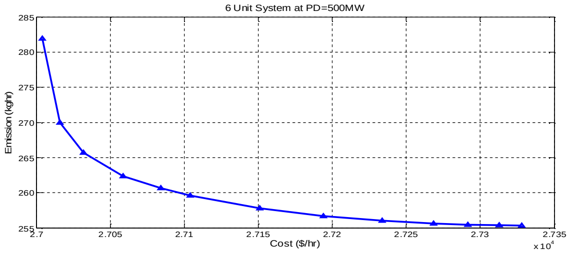

Fig. 4. Cost-Emission Trade-off curve for 6 unit system at PD=500 MW

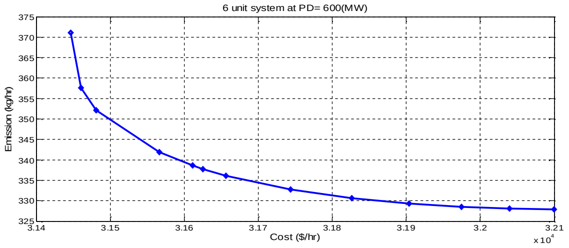

Fig. 5. Cost-Emission Trade-off curve for 6 unit system at PD=600 MW

C. Effect of population size on CS Algorithm

The effect of population size on CS algorithm is considered here. Depending upon this analysis, the following CS parameters have been used: population size of host nests, n=20, probability (p_a) =0.25 and maximum number of iteration=500. The value of minimum, maximum, average fuel cost and emission along with simulation time at each specified population is listed in Table-VII. Analysis from Table-VII deduces that convergence rate is very less sensitive to the parameter variation. This implies that fine adjustment is not needed for any given problem. Few parameters make this algorithm less complex and more powerful.

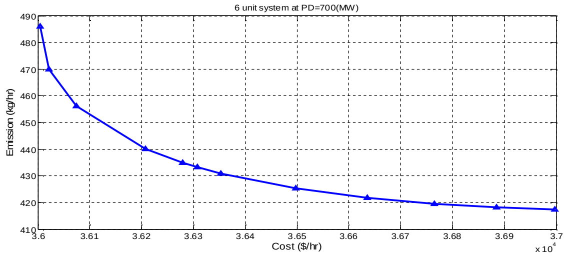

Fig. 6. Cost-Emission Trade-off curve for 6 unit system at PD=700 MW

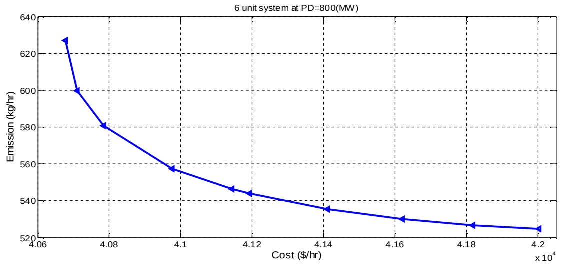

Fig. 7. Cost-Emission Trade-off curve for 6 unit system at PD=800 MW

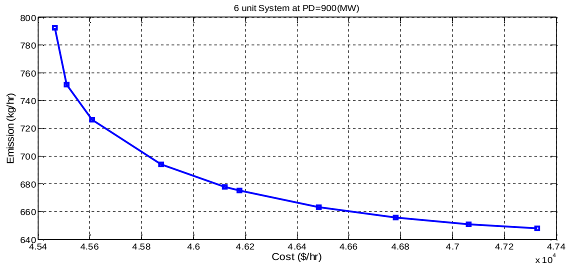

Fig. 8. Cost-Emission Trade-off curve for 6 unit system at PD=900 MW

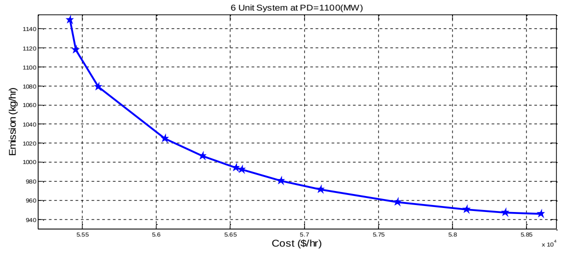

Fig. 9. Cost-Emission Trade-off curve for 6 unit system at PD=1100 MW

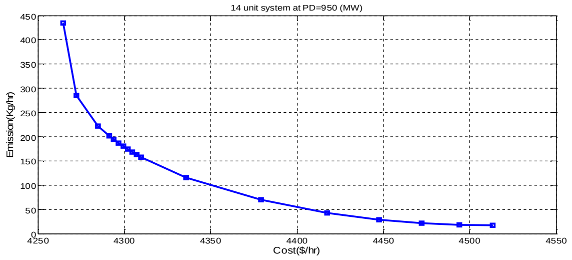

Fig. 10. Cost-Emission Trade-off curve for 14 unit system at PD=950 MW

TABLE V. RESULT FOR FOURTEEN UNIT SYSTEM AT PD=950MW

Unit Power Output (MW)	u=0	u=0.1	u=0.2	u=0.3	u=0.4	u=0.5	u=0.6	u=0.7	u=0.8	u=0.9	u=1
P_1	70.70983	73.85897	77.51654	81.81616	86.77337	92.34919	99.05708	103.70075	108.46558	109.31723	109.33220
P_2	50.00000	50.00000	50.00000	50.000	51.69202	55.61630	60.70446	65.39020	71.53537	77.64983	89.39291
P_3	77.37363	74.76585	71.76193	68.26314	63.94028	58.28115	51.19966	50.00000	50.00000	50.00000	50.00000
P_4	88.23810	86.91441	85.35421	83.488891	81.00608	77.39805	72.64202	61.95614	50.00000	50.00000	50.00000
P_5	66.56786	66.49842	66.39042	66.22428	65.82838	64.89074	63.40013	57.85498	50.00000	50.00000	50.00000
P_6	50.0000	50.00000	50.00000	50.000	50.00000	50.00000	50.00000	50.00000	50.00000	50.00000	50.00000
P_7	72.12381	69.76974	67.06213	63.91388	60.03831	54.99086	50.00000	50.00000	50.00000	50.00000	50.00000
P_8	71.18651	69.24426	66.97565	64.29099	60.91932	56.42921	50.67347	50.00000	50.00000	70.43530	50.0000
P_9	72.70301	73.94804	75.39429	77.09458	78.97583	80.87423	83.03652	82.27375	79.80770	73.85500	53.33220
P_{10}	88.44643	89.78863	91.28745	92.96815	94.64469	95.98361	97.20916	93.90200	87.99289	59.54299	53.33220
P_{11}	50.000	50.00000	50.00000	50.000	50.00000	52.39890	55.54962	57.64030	59.89994	159.19966	57.57472
P_{12}	71.18651	75.69956	81.02534	87.40588	95.03517	104.15025	115.66927	127.28188	142.29852	50.00000	187.03577
P_{13}	71.46429	69.51211	67.23205	64.53402	61.14656	56.63750	50.85860	50.00000	50.00000	50.00000	50.00000
P_{14}	50.000	50.00000	50.00000	50.000	50.00000	50.00000	50.00000	50.00000	50.00000	50.00000	50.0000
Fuel cost ($/hr)	**4513.24991**	**4493.95006**	**4472.17548**	**4447.46000**	**4417.39843**	**4379.24476**	**4335.84055**	**4309.77050**	**4284.81819**	**4272.34791**	**4264.51282**
Emission (kg/hr)	**17.42371**	**18.32922**	**21.67763**	**28.82778**	**42.95165**	**70.03234**	**115.96477**	**157.40991**	**221.78924**	**285.03079**	**434.97532**

TABLE VI. EFFECT OF PARAMETER VARIATION ON FUEL COST ($/HR) AND EMISSION (KG/HR)

Population, (n)			**10**	**20**	**50**	**100**
Probability, (p_a)	**0.05**	**Fuel cost ($/hr)**	27084.08862	27084.08862	27084.08861	27084.08897
		Emission (kg/hr)	260.65640	260.65641	260.65640	260.656
	0.15	**Fuel cost ($/hr)**	27084.08861	27084.08861	27084.08867	27084.08864
		Emission (kg/hr)	260.65640	260.65640	260.65640	260.65641
	0.25	**Fuel cost ($/hr)**	27084.08863	**27084.08858**	27084.08864	27084.08860
		Emission (kg/hr)	260.65640	**260.65638**	260.65640	260.65640
	0.4	**Fuel cost ($/hr)**	27084.08862	27084.08862	27084.08894	27084.08892
		Emission (kg/hr)	260.65640	260.65639	260.65637	260.65641
	0.5	**Fuel cost ($/hr)**	27084.08861	27084.08742	27084.07963	27084.09334
		Emission (kg/hr)	260.65640	260.65647	260.65693	260.65613

TABLE VII. EFFECT OF POPULATION SIZE ON A SIX GENERATOR SYSTEM AT 500(MW) (P_A=0.25)

Population, n		10	**20**	50	100
Simulation Time (sec)		0.996	**0.887**	1.90	2.98
No. of trials		20	**20**	20	20
Minimum	**Fuel Cost ($/hr)**	27084.08861	**27084.08742**	27084.08963	27084.0886
	Emission (kg/hr)	260.65640	**260.65638**	260.65640	260.65640
Maximum	**Fuel Cost ($/hr)**	27084.08863	**27084.08862**	27084.08894	27084.09334
	Emission (kg/hr)	260.65642	**260.65640**	260.65693	260.65641
Average	**Fuel Cost ($/hr)**	27084.088618	**27084.08837**	27084.086898	27084.089694
	Emission (kg/hr)	260.6564	**260.65650**	260.65651	260.65657
Standard Deviation	**Fuel Cost ($/hr)**	0.00053131	**0.00000836**	0.0040650	0.0020447
	Emission (kg/hr)	0.000353	**0.00000**	0.00024072	0.0001927

VI. COMPARATIVE STUDY

1) Solution Quality

It is depicted from Table-I and III that the value of fuel cost and Emission obtained by CS method for 3-unit and 6-unit at various load demands is less than the other methods. Table-V shows that the fuel cost and emission obtained for 14-unit

IEEE-118 bus system at various values of u. These obtained solutions are known as pareto-optimal solutions. Optimal power generations and Best Compromise Solution (set of solution for which both fuel cost and emission minimizes simultaneously) for 3- unit, 6–unit and 14-unit systems at different load demands are shown in II, IV and V. This emphasizes the potential of CS to give better solution quality. Hence, it is seen from above observation that CS has better proficiency and fast convergence characteristic in solving multi-objective CEED problem.

2) *Computational Efficiency*

Table-II and IV shows best compromising results obtained by CS method for 3 and 6-units at various load demands which is less as compared to other results in reported literature. From Table-VII and Table-I, it is clear that the average cost achieved for 6-unit generator at 500 MW is lower and the average simulation time for 20 repeated trials is also less. Hence it can be concluded that CS algorithm is computationally more efficient than other methods in terms of speed and quality of solution.

3) *Robustness*

CS is a stochastic search technique, so randomness in the results is reasonable. Many trials are therefore carried out to find the best results. CEED is a real time problem so it is required that every step should provide a value that is close enough to optimum value which is clearly seen in Table-VI. The result obtained in Table-VII depicts that at different population size there is minute change in the value of cost and emission which signifies the robustness and superiority of algorithm.

VII. CONCLUSIONS

A novel meta-heuristic technique for optimization is successfully employed to solve different CEED problems. Promising results are obtained which are presented in the paper.

CS has demonstrated excellent performance while dealing with various emission problems. The basic concept behind CS is the obligate brood parasitic behavior of cuckoo species and the objective function is expressed in terms of eggs laid by cuckoo. The obtained results have better quality solutions, fast convergence characteristics and robustness in satisfying the objective function. Comparison of result ensures its better exploitation capability over the other reported methodology. On the basis of limited analysis and comparative study, it can be concluded that CS approach can have better solution quality and computational efficiency.

ACKNOWLEDGMENT

The authors are thankful to the Director, Madhav Institute of Technology and Science, Gwalior (M.P), India for providing support and facilities to carry out the research work.

REFERENCES

[1] El- Keib AA, Ma H, JL Hart, "Economic Dispatch in view of the Clean Air Act of 1990," *IEEE Trans Power Syst*, Vol.9, No. 2, pp.972–978, 1994.

[2] Y.H. Song, R. Morgan, D. Williams, "Environmentally constrained Electric Power Dispatch with Genetic Algorithms," *Evolutionary Computation, IEEE International Conference*, vol.1, pp.17, Dec. 1995.

[3] U. Güvenç, ''Combined Economic and Emission Dispatch solution using Genetic Algorithm based on similarity crossover," *Scientific Research and Essays*, vol.5, no. 17, pp. 2451–2456, 2010.

[4] R. Balamurugan and S. Subramanian, "A Simplified Recursive Approach to combined economic emission dispatch," *Electric Power Components and Systems*, vol. 36 number 1, pp. 17–27, 2008.

[5] M. Abido, "Environmental/Economic Power Dispatch using Multi-objective Evolutionary Algorithms," *IEEE Trans. Power Syst*. vol.18, no. 4, pp.1529–1537, 2003.

[6] M. Sudhakarn, S.M.R Slochanal, R. Sreeram and N. Chandrasekhar, "Application of Refined Genetic Algorithm to Combined Economic Emission Dispatch," *J. Institute of Engg. (India)*, vol-85, pp.115-119, Sep.2004.

[7] M. Abido, "Multi-objective Particle Swarm Optimization for Environmental/Economic Dispatch problem," *Electr. Power Syst. Res.* vol.79, no.7, pp. 1105–1113, 2009.

[8] A. Bhattacharya, P. Chattopadhyay, "Application of Biogeography-Based Optimization for solving Multi-objective Economic Emission Load Dispatch problems," *Electr. Power Compon. Syst*., vol.38, no. 3, pp.340–365, 2010.

[9] M. Basu, "Economic Environmental Dispatch using Multi-objective Differential Evolution," *Applied Soft Computing*, vol.11 pp.2845–2853, 2011.

[10] S. Dhanalakshmi, S. Kannan, K. Mahadevan, S. Baskar, "Application of modified NSGA-II Algorithm to Combined Economic and Emission Dispatch problem," *Electrical Power and Energy Systems*, vol.33, pp. 992–1002, 2011.

[11] G.P .Dixit, H.M. Dubey, M. Pandit, B. K. Panigrahi, "Artificial Bee Colony Optimization for Combined Economic and Emission Dispatch," *International Conference on Sustainable Energy and Intelligent System," IEEE Conference*, pp 340-345, July 2011.

[12] E.D. Manteaw, N.A. Odero, "Combined Economic and Emission Dispatch solution using ABC_PSO Hybrid algorithm with valve point loading effect," *International Journal of Scientific and Research Publications*, vol. 2, Issue 12, pp 1-9, December, 2012.

[13] U. Guvenc, Y. Sonmez, S. Duman, N. Yoruderen, "Combined Economic and Emission Dispatch solution using gravitational search algorithm," *Turkey: Science Iranica*, vol. 19, issue 6, pp 1754-1762, December, 2012.

[14] H. Hamedi, "Solving the Combined Economic Load and Emission Dispatch problems using new Heuristic Algorithm," *Electrical Power and Energy Systems*, vol.46, pp. 10–16, 2013.

[15] X.S. Yang, S. Deb, "Cuckoo search via Lévy flights," *in: Proc. Of World Congress on Nature & Biologically Inspired Computing (NaBIC), India. IEEE Publications*, USA, pp. 210-215, December, 2009.

[16] X.S. Yang and S. Deb, "Engineering Optimization by Cuckoo Search," *Int. J. Mathematical Modeling and Numerical Optimization*, vol. 1, no. 4, pp. 330–343, 2010.

[17] P. Venkatesh, R. Gnanadass, and N. P. Padhy, "Comparison and Application of Evolutionary Programming Techniques to Combined Economic and Emission Dispatch with Line Flow Constraints," *IEEE Transactions on Power Systems*, vol. 18, no. 2, pp. 688-697, May 2003.

[18] X.S. Yang, "Nature-Inspired Metaheuristic Algorithms," *Luniver Press*; 2008.

[19] X.S. Yang and S. Deb, "Multi-objective Cuckoo Search for design optimization," *Computers & Operations Research*, vol.40 pp.1616–1624, 2013.

[20] L.H. Wu, Y.N. Wang, X.F. Yuan and S.W. Zhou, "Environmental/Economic Power Dispatch Problem using Multi-objective Differential Evolution Algorithm", *Electric Power Systems Research*, vol. 80, pp. 1171–1181, 2010.