Analysis of Practical Constraints using Hybrid Cuckoo Search Algorithm

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ABSTRACT— In this paper a proposed Hybrid Cuckoo Search Algorithm (HCSA) is used to solve optimal power flow problem. The evolutionary techniques are based on the randomness of the values within its variable limits. Hence choosing best starting solution value and obtaining best final solution within less number of iterations is one of the challenging tasks. In this the conventional Cuckoo Search Algorithm (CSA) is combined along with the real coded Genetic Algorithm (GA) cross over operation to improve the effectiveness of solution. In reality solution of objective optimal power flow with satisfying equality and inequality constraints along with additional constraints of ramp-rate limit and prohibited operating zone limits (POZ) needs a lot of practice. The complete procedure is solved on IEEE-30 bus systems with the supporting results.

Keywords— Generation fuel cost; Emission; Total power loss; Hybrid Cuckoo Search;

I. INTRODUCTION

The continuous research in developing evolutionary algorithms increases the effectiveness of the solution in terms of objective function value, computational time, convergence characteristics etc. As the power system is a network connected with various generating units, loads, shunt compensators and tap setting transformers etc., and needs to satisfy many objectives simultaneously. As the fuel prices are increasing day by day, it is necessary to operate the generating units at optimum levels to minimize the fuel cost with satisfying the operating and physical constraints [1, 2]. It is imposed by the Clear Air Act amendments to modify the generating units operating strategies to minimize the emission of polluted gases [3]. In power system, minimizing of transmission real power losses is one of the objective functions for the effective reactive power dispatch. Since minimization of loss objective function tends to rise in generator voltages, which results in decrease of the reactive power reserve capacity during contingencies [4].

There are several optimization techniques implemented recently to solve many electrical problems, some of them like Fuzzy Strategies (FS) [5], Genetic Algorithms (GA), Differential Evolution (DE), Evolutionary Programming (EP), Particle Swarm Optimization (PSO), Tabu Search (TS), Simulated Annealing (SA), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Cat Swarm Optimization (CSO) have been suggested [6-14]. Because which have highest number of successions in solving single objective optimization problems. These techniques are not applicable to solve multi-objective OPF problem, as these problems has many solutions instead of single solution. So obtaining an optimal solution for this type of problem necessitates the importance of multi-objective optimization methods such as Penalty function method, weighted sum method, Stochastic Search Techniques (MOSST) [15], Multi-objective Evolutionary algorithm (MOEA) [16], Strength Pareto Evolutionary Algorithm (SPEA) [17], Non-dominated Sorting Genetic Algorithm (NSGA-II) [18], Niched Pareto Genetic Algorithm (NPGA) [19], e-constraint method [20], and Fitness sharing multi objective methods[21].

Xin-She Yang et. al. [22], he initiated to formulate a most recent meta-heuristic algorithm, called Cuckoo Search Algorithm (CSA), for solving optimization problems. The CSA could yields promising results and increases the performance of the optimization technique. Improved cuckoo search algorithm to find global optimized solution is proposed in [23]. To solve unconstrained optimization problem and reliability problems using CSA are referred in [24, 25]. Complex valued cuckoo search algorithm is presented in [26]. Economic load dispatch problem is solve using CSA is discussed in [27, 28]. A conceptual comparison of the PSO, DE, ABC, and CSA are highlighted in [29]. In most of the literature it is practiced the single-objective optimization problems using CSA.

The main contribution of this paper is that, conventional Cross over based methodology is adapted with the proposed Hybrid Cuckoo Search Algorithm (HCSA) to minimize power system operation objectives such as generation fuel cost, emission and losses whiles satisfying equality and inequality constraints along with the presence of ramp-rate and prohibited operating zone limits. The obtained numerical results support that the proposed method can yield better results than the existing methods.

II. PROBLEM FORMULATION

The non linear constrained mathematical problem can be formulated as follows

$$\text{Minimize } [A_m(x,u)] \quad \forall\, m = 1,2,\ldots\ldots,J \tag{1}$$

Subject to

$$g\,(x,u) = 0 \tag{2}$$

$$h\,(x,u) \leq 0 \tag{3}$$

where 'g' and 'h' are the equality and inequality constraints respectively and 'x' is a control vector of dependent variables like slack bus active power generation , PQ bus voltage magnitudes and generator reactive powers and vector ‘u’ consist control variables like real powers and voltages of generators, transformer tap ratios and shunt compensation . ‘J’ is the number of objective functions.

1) Fuel cost objective

The optimal allocation of the real powers generated by the generating units at power stations should be organized in a most economic way to meet the existing load on a give system can be considered as economic load dispatch problem. The simplified quadratic cost expression for ith unit for real power output of subjected to different constraints can be expressed as [8]

$$F_i\left(P_{G_i}\right) = a_i P_{G_i}^2 + b_i P_{G_i} + c_i$$

where are the fuel cost-coefficients of generators. The total generation fuel cost ( ) of all ‘ ’ number of units can be mathematically expressed as

$$A_1 = min\ (F_T) = \sum_{i=1}^{N_G} F_i\left(P_{G_i}\right) \qquad \$/h \qquad (4)$$

2) Emission objective

In practical, minimizing generation cost is not only sufficient but also it is necessary to decrease the pollutions caused by the emission of polluted gases (SOX, NOX, COX) becoming mandatory for generation units. The emission generated can be approximated as [19]

$$A_2 = \min\left(E\left(P_{G_i}\right)\right) = \sum_{i=1}^{N_G}\left(\alpha_i + \beta_i P_{G_i} + \gamma_i P_{G_i}^2 + \xi_i \exp^{(\lambda_i P_{G_i})}\right) \quad ton/h \qquad (5)$$

where ‘are emission coefficients of the generator.

3) Transmission loss objective

The system active power loss in transmission lines must be less to get safer operation. This objective can be expressed as

$$A_3 = \min(TPL) = \sum_{i=1}^{N_{line}} P_{Loss,i} \qquad (6)$$

where is the real power loss in ith line.

While minimizing the objectives it must satisfy the following equality and inequality constraints along with the ramp-rate and POZ limits. These constraints can be expressed as

i). Equality constraints

$$\sum_{i=1}^{N_G} P_{G_i} - P_{Demand} - P_{Loss} = 0$$

$$\sum_{i=1}^{N_G} Q_{G_i} - Q_{Demand} - Q_{Loss} = 0$$

where P_l and are total real and reactive power demands and its corresponding total power losses.

ii) In-equality constraints

The self restricted constraints satisfied within OPF are

Generator bus voltage limits:

$$V_{G_i}^{min} \le V_{G_i} \le V_{G_i}^{max}; \qquad \forall$$

Generator real power limits:

$$P_{G_i}^{min} \le P_{G_i} \le P_{G_i}^{max}; \qquad \forall$$

Transformers tap setting limits:

$$T_i^{min} \le T_i \le T_i^{max}; \quad i = 1,2,3, \ldots n_t \ (\text{total number of taps})$$

Capacitor reactive power generation limits:

$$Q_{C_i}^{min} < Q_{ci} < Q_{C_i}^{max}; \quad i = 1,2 \ldots\ldots n_c \ (\text{total number of VAr sources})$$

Transmission line flow limit:

$$S_{l_i} \le S_{l_i}^{max}; \qquad i = 1,2,3, \ldots\ldots\ldots l$$

Generator reactive power limits:

$$Q_{G_i}^{min} \le Q_{G_i} \le Q_{G_i}^{max};$$

Bus voltage magnitude limits:

$$V_i^{min} \le V_i \le V_i^{max}; \qquad i = 1,2,3, \ldots\ldots\ldots N_{load}$$

III. HYBRID CUCKOO SEARCH ALGORITHM (HCSA)

HCSA is population based evolutionary computation technique. Main steps of HCSA can be described as follows.

i) Initialization

Randomly generate a specified number of populations for each control variable is given by

$$x_{pq} = x_q^{min} + rand(0,1) \times \left(x_q^{max} - x_q^{min}\right) \qquad (8)$$

Where, $p = 1,2, \ldots \ldots, n \ \& \ q = 1,2,$

$$n = Number\ of\ host\ nests\ \&\ m = Number\ of\ control\ variables$$

Population vector is of size generated and it is used for evolutionary operations.

ii) Levy flights

Levy flight operation is used in CSA compared to other techniques. A initial population of host nests is generated and then the population of solution is subjected to repeated cycles of search process of cuckoo bird. The cuckoo randomly chooses the nest position to lay egg is given in equations (9) and (10). for cuckoo, while generating new solutions levy flight is performed [22]

$$x_i(t+1) = x_i(t) + S_{pq} \times \alpha \oplus Levy\ (\lambda) \qquad (9)$$

Where

α is generated randomly between -1 and 1

$\oplus$ gives entry wise multiplication

S_{pq} is step size.

Hence step size is calculated as

$$S_{pq} = x_{pq}^{t} - x_{fq}^{t}$$

Where $p, f = 1,2, \dots \dots ., n \;\&\; q = 1,2, .$

$$Levy\,(\lambda) = \left| \frac{z(1+\lambda) \times \sin\left(\frac{\pi \times \lambda}{2}\right)}{z\left(\frac{1+\lambda}{2}\right) \times \lambda \times 2^{\left(\frac{\lambda-1}{2}\right)}} \right|^{1/\lambda} \quad ; \; 1 < \lambda \leq 3 \qquad (10)$$

Some of the new solutions should be generated by levy walk around the best solution obtained so far, which will speed up the local search.

Above levy flight equation gives modified variables

in the population vector i.e, belongs to nest

and control variable. Here old variable is

modified with respect to neighborhood’s nest, and the egg laid by cuckoo is evaluated.

iii) Cross over

Once population of random set of points is created, a reproduction operator can be used to select good population. Recently efficient crossover operator have been designed for searching process [6]

$$x_{pq}^{new} = (1 - \lambda_{cross}) \times x_{1q}^{ref} + \lambda \times x_{pq}^{old} \qquad (11)$$

Where ‘ ’ is random number between 0 and 1

Modified value of is obtained by the crossover of old value and its reference value. After getting new values of control variables for total number of nests, whose limits has to check if control variable obtained is beyond its maximum limit equate it to maximum and below its minimum limit equate it to minimum otherwise keep the value same as obtained.

iv) Selection

For this work sorting and ranking process is used. By comparing fitness vector obtained randomly and after performing crossover process. Now fitness vector is obtained for new population, the fitness vector with minimum fitness value will be memorized. Now the fitness vectors in which fitness values are ranked from lower to higher value. Then lowest fitness value and its corresponding population value are treated as best, and best population vector is considered for the next generation.

v) Stopping criteria

The number of iterations is equals to the specified maximum number of iterations. Then stop the process.

IV. RESULT ANALYSIS

The Case-A problem is solved using existing PSO, CSA along with the proposed HCSA and the corresponding optimal settings of eighteen control variables are considered and tabulated in Table.2.

Table.2. OPF solution for fuel cost minimization of IEEE-30 bus system

CONTROL VARIABLES	Existing methods			Proposed HCSA
	TS [10]	PSO	CSA	
PG1(MW)	176.04	178.5558	170.7789	173.6794
PG2(MW)	48.76	48.6032	48.3696	44.4255
PG5(MW)	21.56	21.6697	18.3135	22.9575
PG8(MW)	22.05	20.7414	32.6057	25.953
PG11(MW)	12.44	11.7702	10	13.221
PG13(MW)	12	12	12	12
VG1(p.u.)	1.0500	1.1	1.1	1.1
VG2(p.u.)	1.0389	0.9	1.0567	1.0499
VG5(p.u.)	1.0110	0.9642	1.0912	1.0877
VG8(p.u.)	1.0198	0.9887	1.0725	1.0985
VG11(p.u.)	1.0941	0.9403	1.0465	1.1
VG13(p.u.)	1.0898	0.9284	1.1	1.1
T6-9(p.u.)	1.0407	0.9848	1.0531	1.0323
T6-10(p.u.)	0.9218	1.0299	1.007	1.0151
T4-12(p.u.)	1.0098	0.9794	1.0395	0.9793
T28-27(p.u.)	0.9402	1.0406	0.9707	1.0588
QC10(MVAr)	-	9.0931	30	30
QC24(MVAr)	-	21.665	6.7556	5.4662
Cost ($/h)	802.29	803.4548	802.7283	802.2545
Emission (ton/h)	-	0.3701	0.3508	0.3557
TPL (MW)	-	9.9403	8.6677	8.8364

From Table.2, it is observed that the generation fuel cost is minimized with the proposed HCSA method in comparison to existing methods. The proposed HCSA method gives lesser generation fuel cost with respect to the below mentioned existing methods is given in Table.3.

Table.3. Summary of test results for generation fuel cost

S. No	*Method*	*Generation cost ($/h)*
1	*EP [33]*	*802.907*
2	*TS/SA [34]*	*802.788*
3	*ITS [35]*	*804.556*
4	*IEP [36]*	*802.465*
5	*SADE_ALM [37]*	*802.404*
6	*MDE-OPF [38]*	*802.376*
7	*GA [39]*	*803.050*
8	*Gradient method [40]*	*802.430*
9	*Proposed HCSA*	*802.2545*

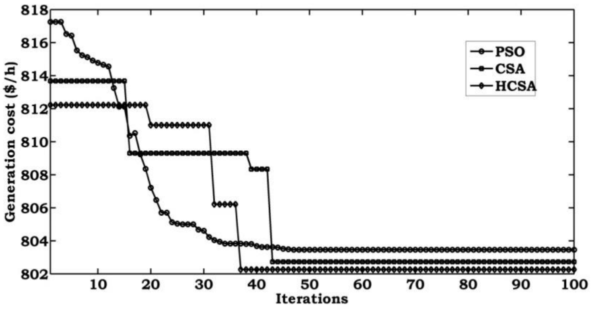

Figure.1. Convergence characteristics for fuel cost of Case-A in IEEE-30 bus system

The convergence characteristics of the proposed method along with the existing methods can be observed in Figure.1 and it is very clear that, the proposed method started with best starting value and reached final solution with less number of iterations as compared with the existing PSO and CSA methods.

The same analysis is carried out for Case-B, Case-C and Case-D with the proposed HCSA of generation fuel cost as an objective. Further the same analysis is extended for emission and total power loss objectives with HCSA. The detailed results for three objectives with four different cases are tabulated in Table.4. It is observed from Table.4, the three objective values are increasing from Case-A to Case-D with inclusion of additional constraints. Generation fuel cost has increased from 802.2545 $/h to 804.5419 $/h of Case-A to Case-D. Similarly, it is also observed that emission has increased from 0.205168 ton/h to 0.205432 ton/h and total power loss from 3.292898 MW to 4.200394 MW.

From Table.4, the following observations have been noticed:

- While minimizing fuel cost in Case-B, the generators at 5,8,11 and 13th buses are following down ramp rate and remaining generators at 1st and 2nd are following up ramp rate. Because of this, it is observed that 13th bus generator increases its generation by 16.66% when compared to Case-A. Hence generation fuel cost has increased by 0.061%.
- In Case-C, it is observed that except slack generator all the remaining generators are operating below the POZ lower limit with respect to generation fuel cost.
- In Case-D, because of ramp rate and POZ limits the generators at 5,11, 13th buses are following down ramp rate and operating below the POZ lower limit, while the remaining generators are following up ramp rate and equal or above the POZ upper limit.
- In Case-D, it is also noticed that in addition to 13th bus generator in Case-B, the generator at 8th bus has increased its generation by 15.59% as compared with Case-A. Hence generation fuel cost is increased by 0.285%.
- While minimizing emission, except slack generator, remaining generators are following up ramp rates and above the POZ upper limit. The slack generator is following down ramp rate.
- When compared with cost minimization case, most of the emission is minimized because of decrease in generation at slack bus.

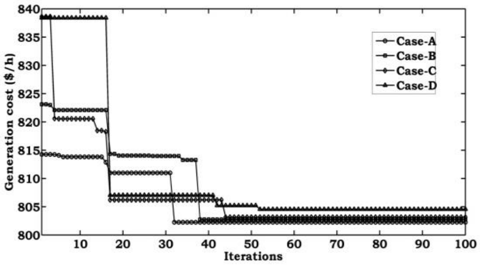

Figure.2. Convergence characteristics for fuel cost of four cases with HCSA in IEEE-30 bus system

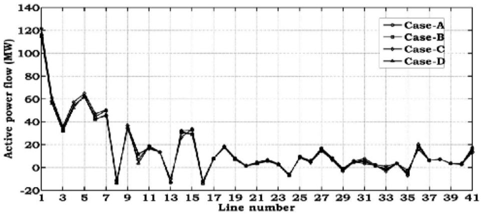

Figure.3. Active power flow variation for fuel cost of four cases with HCSA in IEEE-30 bus system

From Figure.2, it is observed that, with the proposed method started with best starting value and number of iterations taken are increased from Case-A to Case-D. The active power flow variation for the four cases is shown in Figure.3. It is observed that, active power in lines nearer to the 8th and 13th bus generators is increased due to increase its in active power generation. Similarly the active power flow in the lines nearby the remaining generators is decreased as the generation is decreased.

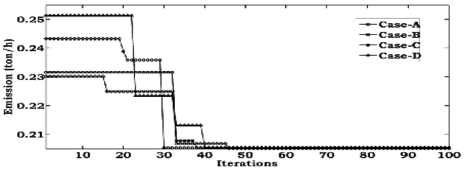

Figure.4. Convergence characteristics for emission of four cases with HCSA in IEEE-30 bus system

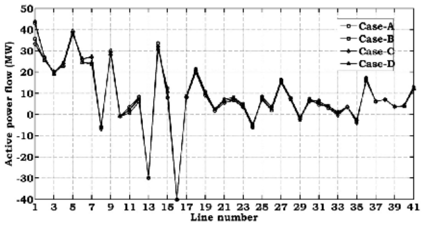

Figure.5. Active power flow variation for emission of four cases with HCSA in IEEE-30 bus system

CONTROL VARIABLES	**Generation cost**				**Emission**				**Total power loss**			
	CASE – A	**CASE – B**	**CASE – C**	**CASE – D**	**CASE – A**	**CASE – B**	**CASE – C**	**CASE – D**	**CASE – A**	**CASE – B**	**CASE – C**	**CASE – D**
P_{G1}(MW)	173.6794	173.6482	182.528	170.3015	61.2243	70.0002	58.9585	70.7823	51.6551	51.8926	52.2447	66.3574
P_{G2}(MW)	44.4255	47.8984	50	46.2831	71.327	61.995	73.2217	61.2402	80	80	80	75.4412
P_{G5}(MW)	22.9576	22.663	17.811	19	50	50	50	50	50	50	50	50
P_{G8}(MW)	25.953	21.4386	21.0547	30	35	35	35	34.9987	35	35	35	35
P_{G11}(MW)	13.221	13	10	13	30	30	30	30	30	30	30	30
P_{G13}(MW)	12	14	12	14	40	40	40	40	40	40	40	30.8018
V_{G1}(p.u.)	1.1	1.0701	1.1	1.0625	1.0243	1.1	1.1	1.1	1.1	1.0165	0.976	1.1
V_{G2}(p.u.)	1.0499	0.9337	0.9987	1.0122	0.9	1.1	0.9824	1.1	1.0996	1.0013	0.9	0.9017
V_{G5}(p.u.)	1.0877	1.0084	1.0214	1.0013	0.9609	1.082	0.9	1.0975	1.0641	0.9916	0.9499	0.9
V_{G8}(p.u.)	1.0985	1.1	1.1	1.1	0.9516	1.098	1.1	1.098	1.1	1.0354	0.9455	1.1
V_{G11}(p.u.)	1.1	1.1	1.0922	0.9	1.0837	1.1	1.1	0.9	0.9038	0.9	1.1	1.0286
V_{G13}(p.u.)	1.1	1.1	1.1	1.0985	0.9	0.9647	1.1	1.0059	0.9	1.1	1.0681	1.0989
T_{6-9}(p.u.)	1.0323	0.9606	1.1	0.9	0.9521	1.0987	1.0964	1.1	0.9002	0.9038	0.9	0.9883
T_{6-10}(p.u.)	1.0151	0.9	0.9	0.9	0.9	1.1	0.9	1.1	1.1	0.9	0.926	0.9707
T_{4-12}(p.u.)	0.9793	0.9438	0.9	0.9067	0.9	0.9033	1.0547	1.0063	0.9	0.9	0.9	1.0468
T_{28-27}(p.u.)	1.0588	0.9	0.9	0.9	0.9038	0.9643	0.961	1.0681	0.9511	0.9	0.9	1.0234
Q_{C10}(MVAr)	30	20.3867	29.8425	29.9968	30	30	5.1962	30	13.1375	29.6273	5.0569	27.0536
Q_{C24}(MVAr)	5.4662	5	8.7863	5	6.3343	5.0012	12.8994	5	17.1374	6.3343	24.549	28.0595
Cost ($/h)	**802.2545**	**802.7423**	**803.1519**	**804.5419**	953.0761	936.8423	955.6316	935.8656	968.0326	968.5997	969.4415	939.689
Emission (ton/h)	0.3557	0.3555	0.3831	0.3475	**0.2052**	**0.2053**	**0.2053**	**0.2054**	0.2072	0.2072	0.2072	0.2102
TPL (MW)	8.8364	9.2482	9.9936	9.1846	4.1514	3.5952	3.7802	3.6211	**3.2929**	**3.4925**	**3.8447**	**4.2004**

Finally it is also observed that additional constraints have non considerable effect on emission minimization. The convergence characteristic for four cases is shown in Figure.4. From Figure.4, it is observed that, with the proposed method started with best starting value and number of iterations taken are increased from Case-A to Case-D. It is also observed that the final converged value is almost similar in all cases.

It is observed from Figure.5, that the active power flow in line-1 connected between buses 1 and 2 is increased from 35.6905 MW in Case-A to 43.8066 MW in Case-D i.e 8.1161 MW, this is because of the effect of ramp-rate effect on slack generator and POZ effect on 2nd bus generator.

From Table.4, while minimizing total power loss, the generation at slack bus is increased from 51.6551 MW in Case-A to 66.3574 MW in Case-D i.e 14.7023 MW due to this the active power losses are increased from 3.2929 MW to 4.2004 MW i.e 0.9075 MW. This increase is because of the effect of ramp-rate limit on 2nd generator and POZ effect in 13th generator. The convergence characteristics for the four case when minimizing total power loss is shown in Figure.6

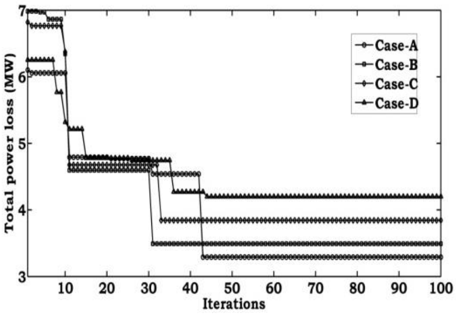

Figure.6. Convergence characteristics for total power loss of four cases with HCSA in IEEE-30 bus system

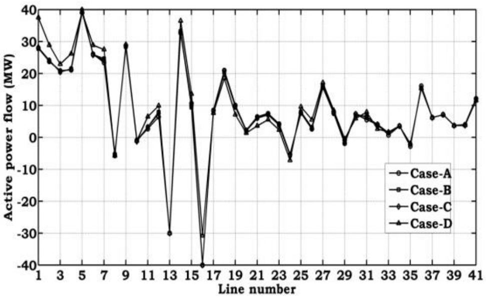

Figure.7. Active power flow variation for total power loss of four cases with HCSA in IEEE-30 bus system

The active power flow variation for four cases while minimizing total power loss is shown in Figure.7. It is observed from this figure, the active power flow in the lines nearby 2nd and 13th generators is decreased because of the additional constraints.

V. CONCLUSIONS

In this paper, HCSA algorithm has been proposed to optimize most warranted power system objectives such as fuel cost, emission and power loss objectives. The optimization problem is solved while satisfying conventional equality, in-equality constraints and practical constraints such as ramp-rate and POZ limits. The proposed algorithm has proven its effectiveness by starting iterative process with good initial function value and reaches final best value in less number of iterations when compared to existing methods. The proposed method works without considering the nature of the objectives and can be used to optimize any number of objectives. Standard electrical test IEEE-30 bus systems are tested with supporting numerical results.

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