Optimal Power System Planning with Renewable DGs with Reactive Power Consideration

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ABSTRACT

This paper analyses the optimal power system planning with DGs used as real and reactive power compensator. Recently planning of DG placement reactive power compensation are the major problems in distribution system. As the requirement in the power is more the DG placement becomes important. When planned to make the DG placement, cost analysis becomes as a major concern. And if the DGs operate as reactive power compensator it is most helpful in power quality maintenance. So, this paper deals with the optimal power system planning with renewable DGs which can be used as a reactive power compensators. The problem is formulated and solved using popular meta-heuristic techniques called cuckoo search algorithm (CSA) and particle swarm optimization (PSO). the comparative results are presented.

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1. INTRODUCTION

Expansion planning of power system with renewable resources for placing DGs in future for satisfying the increase in demand is proposed by Partha kayal in 2014 with multi-objective consideration. Raj Kumar in 2011 discussed about the multi-objective based planning of DG placement. Using impact indices does this. The bus which give more impact for DG placement is identified and placed there. [1,2]. Generator dispatch problems are solved with multi objective in [3]. Placement of wind and solar alone with its mathematical static model is implemented by kayal [4]. This improves the voltage stability and power loss minimization. The Evolutionary algorithms plays an important role in placement problems as it is easy to consider more constraints and fast solution. [5,6]. Previous works deals with only real power [7]. In this paper cuckoo search algorithm [8] is used for the first time in optimal expansion planning of DGs with renewable energy resources with reactive power consideration. And the problem of the minimization is solved by Partha kayal [1] is modified with solving method by using CSA and PSO to get better voltage profile and voltage stability factor and reduced loss. This paper is organised as follows , Section II talks about the the problem formulation.Section III talks about the Pseudo code and Flowchart,Section IV talks about the Results and Discussion, followed by the Conclusion and References.

2. PROBLEM FORMULATION

(i) Total cost of renewable DGs due to installation, operation and maintenance,

$$Cost_{DG\ ren} = \sum_{i=2}^{N}\sum_{j\in type} IC_{ij} * n_i * l_i + (\sum_{i=2}^{N}\sum_{j\in type} OMC_{ij} * P_{DG\ ren\ ij} * n_i * l_i) * CPV \quad (1)$$

Where
$IC_{ij} - Inverstment\ cost\ type\ 'j' renewable\ DGat\ bus\ 'i'$

$OMC_{ij} - Operation\ and\ maintenance\ cost\ of\ type\ 'j' renewable\ DGat\ bus\ 'i'$
$n_i - number\ of\ DG\ unit\ connected\ at\ bus\ 'i'$
$l_i - location\ variable\ at\ bus\ 'i' (0\ or\ 1)$
$P_{DG\ ren\ ij} - Power\ generated\ by\ type\ 'j'\ DG\ at\ bus\ 'i'$
$N - number\ of\ buses\ in\ the\ network$
$CPV - cumulative\ present\ value$

$$CPV = \frac{(1-PV^{N_y})}{(1-PV)} \quad (2)$$

Here,
Present value of cost

$$PV = \frac{1+\frac{IF}{100}}{1+\frac{IR}{100}} \quad (3)$$

Where,
$IF - Inflation\ rate$
$IR - interest\ rate$
$N_y - Number\ of\ year\ in\ planning\ horizon$

(ii) Total benefit that can be achieved from operation of distribution network with renewable DGs is given by,

$$Benefit_{DG\ ren} = \{(\sum_{i=2}^{N}\sum_{j\in type}(P_{DG\ ren\ ij} + Q_{DG\ ren\ ij}) * n_i * l_i) + \Delta Ploss_{DG\ ren}\} * C_{hr} * 8760 * CPV \quad (4)$$

$\Delta Ploss_{DG\ ren} - Power\ loss\ due\ to\ allocation\ of\ renewable\ DGs$
$C_{hr} - Cost\ of\ electricity$
Benefit to cost ratio

$$BCR_{DG\ ren} = \frac{Benefit_{DG\ ren}}{Cost_{DG\ ren}} \quad (5)$$

DISCO benefited more when $BCR_{DG\ ren} > 1$

(iii) Voltage stability factor
Due to the placement of DGs in power system changes the voltage profile so there is a need for improving the voltage profile, the below equation shows the VSF for any bus i+1in the distribution network,

$$VSF_{i+1} = (2V_{i+1} - V_i) \quad (6)$$

Here,
$V_i - voltage\ magnitude\ at\ bus\ i$
$V_{i+1} - voltage\ magnitude\ at\ bus\ i+1$
VSF for the entire network is given by

$$VSF = \frac{\sum_{i=1}^{N-1} VSF_{i+1}}{(N-1)} \quad (7)$$

(iv) Network security index
Security of the network also should be considered on placement of DG

$$LL_i = \frac{L_{MVA,i}}{L_{MVA_{max,i}}} \quad (8)$$

Network security index can be formulated as below

$$NSI = \frac{\sum_{i=1}^{N-1} LL_i}{(N-1)} \quad (9)$$

Low value is better.
So,
the objective function is represented as

$$minimize\ f\left(P_{DG\ ren\ ij}, n_i, l_i\right) = -BCR - VSF + NSI \quad (10)$$

with respect to equality constraints,

$$P_{slack} + \left(\sum_{i=2}^{N} \sum_{j\in type} P_{DG\ ren\ ij} * n_i * l_i\right) - \sum_{i=2}^{N} P_{D,i} - P_L = 0 \quad (11)$$

$$Q_{slack} - \sum_{i=2}^{N} Q_{D,i} - P_L = 0 \quad (12)$$

Inequality constraints,
Generation limit at bus i

$$P_{DG\ ren\ ij} * n_{i\ min} \leq P_{DG\ ren\ ij} * n_i \leq P_{DG\ ren\ ij} * n_{i\ max} \quad (13)$$
$$Q_{DG\ ren\ ij} * n_{i\ min} \leq Q_{DG\ ren\ ij} * n_i \leq Q_{DG\ ren\ ij} * n_{i\ max}$$

Here $Q_{DG\ ren\ ij} = P_{DG\ ren\ ij} * \tan(\cos^{-1}(PF))$

Bus voltage tolerance constraint at bus i

$$V_{i,min} \leq V_i \leq V_{i,max} \quad (14)$$

Line capacity constraint of line connecting bus i and bus j

$$S_{ij} \leq S_{ij}^{max} \quad (15)$$

Where S_{ij} and S_{ij}^{max} are actual and maximum line power flow in MVA

Both Particle Swarm Optimization and the Cuckoo Serch Algorithms are used for the solution which is explained in the form of flowchart abd pseudo code in the following section.

3. PSEUDO CODE AND FLOWCHART

The PSO technique the position of each particle corresponds to the solution variables which get updated in each particle movement. A comprehensive pseudo code of PSO based OPF is given below, For each particle i = 1......S

a. do:
b. Initialize the particle's position with a uniformly distributed random vector: xi ~ U(blo,bup), where blo and bup are the lower and upper boundaries of the search-space.
c. Initialize the particle's best known position to its initial position: pi ← xi.
d. If (f(pi)<f(g)) update the swarm's best known position:g←pi.
e. Initialize the particle's velocity: vi ~ U(-|bup-blo|,|bup-blo|).
f. Until a termination criterion is met (e.g. number of iterations performed, or a solution with adequate objective function value is found), repeat:
g. For each particle i =1,...,S do:
h. For each dimension d=1,...,n do:
i. Pick random numbers: rp, rg~U(0,1)
j. Update the particle's velocity: vi,d←ωvi,d+ φprp(pi,d-xi,d) + φg rg(gdxi,d)
k. Update the particle's position: xi←xi+vi
l. If (f(xi) <f(pi)) do:
m. Update the particle's best known position: pi←xi.

n. If (f(pi) < f(g)) update the swarm's best known position: g←pi.
o. Now g holds the best found solution.
p. The parameters ω, φp, and φg are selected by the practitioner and control the behaviour and efficacy of the PSO method,

For simplicity, flow chart of PSO algorithm is given in Figure 1

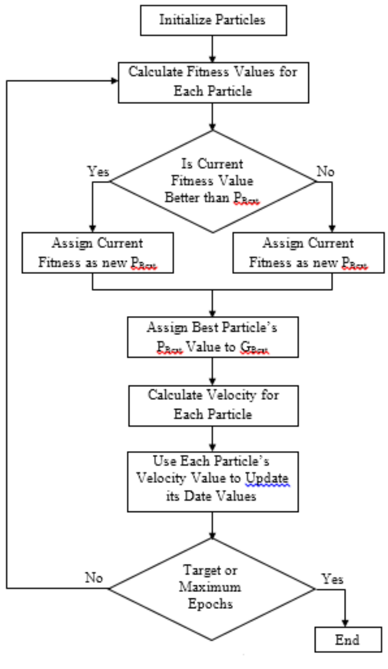

Figure 1. Flowchart of Particle Swarm Optimization

Cuckoo bird lays eggs in communal nests. If the host bird finds the different eggs in its nest it may push down the eggs or it may abandon the nest and build new nest. The cuckoo bird selects the nest of host to lay eggs with similarity in shape and color of eggs to that of host eggs. This increases the probability of hatching cuckoo eggs. And also, cuckoo bird's eggs hatches faster compared to host bird eggs. And also, chicks can mimic the host bird sound for getting food from it. This concept is made as mathematical equation and the concept of search of levy flights which make 90 degrees turn leading to scale free search makes this algorithm more reliable. The procedure of Cuckoo search algorithm is shown as below.

For simplicity in describing new Cuckoo Search, we now use the following three idealized rules:

1) Each cuckoo lays one egg at a time, and dump its egg in randomly chosen nest;
2) The best nests with high quality of eggs will carry over to the next generations;
3) The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability pa ∈ [0, 1].

In this case, the host bird can either throw the egg away or abandon the nest, and build a completely new nest. For simplicity, this last assumption can be approximated by the fraction pa of the n nests are replaced by new nests (with new random solutions

The pseudo code for cuckoo algorithm is briefly given below:

```
begin
          Objective function f(x), x = (x1,...,xd)T
            Generate initial population of
            n host nests xi (i = 1,2,...,n)
 while (t <MaxGeneration) or (stop criterion)
            Get a cuckoo randomly by L´evy flights
            evaluate its quality/fitness Fi
            Choose a nest among n (say, j) randomly
 if (Fi>Fj),
            replace j by the new solution;
```

end
A fraction (pa) of worse nests are abandoned and new ones are built;
Keep the best solutions (or nests with quality solutions);
Rank the solutions and find the current best
end while
Post process results and visualization
end
The flow chart cuckoo algorithm is given below:

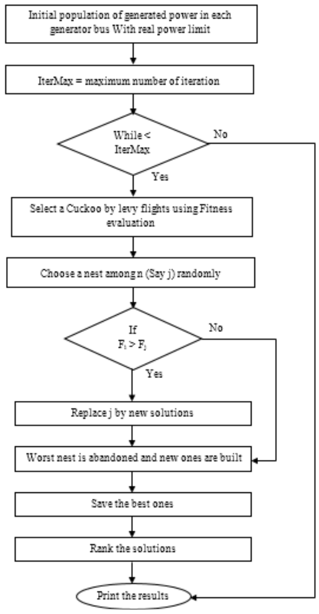

Figure 2. Flowchart of Cuckoo Search Algorithm

4. RESULTS AND ANALYSIS

The test system used here is Indian 28 distributed bus system [2] (appendix II). The minimization of Equation (10) is implemented with PSO algorithm and CSA algorithm. The number of DG installed is taken constant (N=6) as 6. And the problem is solved for 10 years (yr) duration (N_{yr}=10). The types of DGs are chosen as Solar, Wind and biomass. Here type '1' is solar, type '2' is wind and type '3' is biomass. And it works for reactive power support also. The power factor considered here is 0.9. Appendix 1 shows the parameters used for it [1].

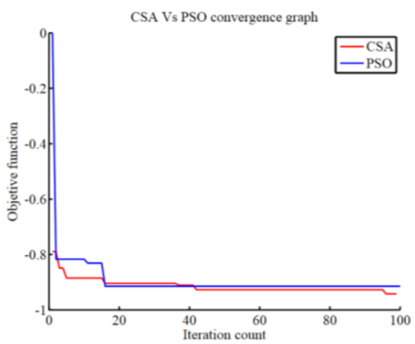

Figure 3. Convergence Graph of CSA and PSO

Figure 4 shows the convergence graph of CSA and PSO algorithm with same objective function. Here total number of population is taken as 60 and iteration count as 100 for both the algorithm. The above graph shows the performance of CSA in red line and PSO in blue line. For 100 iteration CSA gives better minimum objective function. Both satisfies the constraints.

Table 1. Results of PSO Algorithm

Bus	nos.	type	Size (MW)	Size (MVar)	IC in Rs	OMC in Rs/yr	TC Rs/yr
26	6	3	1.2	0.6	789742.3831	121067.5073	910809.8904
3	4	2	0.5	0.2	159081.0395	25083.8983	184164.9378
9	3	3	0.6	0.3	197435.5958	30266.87683	227702.4726
15	5	3	1	0.5	548432.2105	84074.65787	632506.8684
24	3	2	0.375	0.2	89483.0847	14109.6928	103592.7775
25	4	3	0.8	0.4	350996.6147	53807.78103	404804.3957
		Total	4.475	2.2	2135170.928	328410.4142	2463581.342

Table 2. Results of CSA Algorithm

Bus	nos.	type	Size (MW)	Size (MVar)	IC in Rs	OMC in Rs/yr	TC Rs/yr
14	5	3	1	0.5	548432.2105	84074.65787	632506.8684
20	3	2	0.375	0.2	89483.0847	14109.6928	103592.7775
19	4	3	0.8	0.4	350996.6147	53807.78103	404804.3957
26	6	3	1.2	0.6	789742.3831	121067.5073	910809.8904
13	5	3	1	0.5	548432.2105	84074.65787	632506.8684
7	6	2	0.75	0.4	357932.3388	56438.77118	414371.11
		Total	5.125	2.5	2685018.842	413573.0681	3098591.91

Table 3. Comparison with PSO Vs CSA

	loss in MW	BCR	VSF	NSI	Final obj	Time in sec	TC in Rs.
CSA	0.0552	0.114	0.9996	0.1711	-0.9424	721.623107	3098591.91
PSO	0.075	0.1206	0.9996	0.2056	-0.9146	174.759907	2463581.342
Conventional method [1]	0.044	0.1383	0.9589	0.4024	-	-	-

Table 1 shows the results of PSO algorithm with position, numbers, type, IC, OMC and TC. Table 2 shows the results of CSA algorithm with position, numbers, type, IC, OMC and TC. Table 3 shows the comparative results of CSA Vs PSO with TC (Total Cost), Time taken, final objective value, NSI, VSF, BCF and Loss in MW.

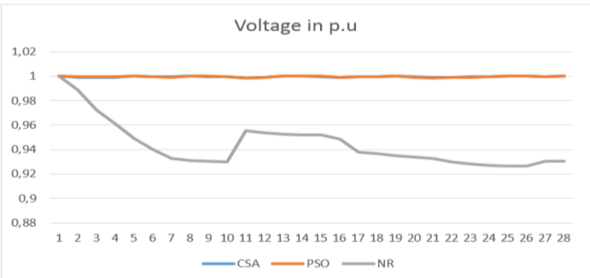

Figure 4. Voltage Profile of Indian 28 Bus System for with Renewable DG Placed Optimally with CSA, PSO and Without Renewable DG with NR (Newton-Raphson) Method

5. COMPARISON WITH CONVENTIONAL METHOD FROM [1]

CSA algorithm gives better voltage profile, NSI, VSF and BCR value compared to PSO algorithm and conventional method used in [1]. And vottage profile nears the value of 1 p.u as shown in Figure.4. But

PSO algorithm gives lesser cost and lesser time taken for solving the algorithm. So, the total cost of the renewable Dgs per year is less in PSO and more in CSA.

6. CONCLUSION

The real and reactive power supplied by using DG placement. For Indian 28-bus system expansion planning is conducted for 10-year duration to identify the total cost, Network security index and loss reduction and to improve the voltage stability factor, benefit cost ratio. Traditional PSO algorithm and cuckoo search algorithm is used to solve this problem. And comparatively CSA gives better VSF, NSI and voltage profile compared to PSO. And PSO gives lesser cost and lesser time to solve the problem. So, for implementation choice of algorithm can be chosen based on the real-time requirement.

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APPENDIX I

Technical and Economic Data of Wind and Solar based Renewable Dgs

DG technology	Commercial size (kW)	Plant factor (%)	Investment cost (Rs/kW)	Operating and maintenance cost (Rs/kW-year)
Solar photovoltaic (PV)	20	25	350000	4818
Wind turbine	125	20	75000	11826
Biomass	200	60	100000	15330

APPENDIX II

Indian 28-bus Distribution System Base MVA = 1 MW; Base Voltage = 11 KV

Bus no.	Power demand in MW	From bus	To bus	R in p.u	X in p.u
1	0.0504	1	2	0.009744	0.006777
2	0.02	2	3	0.014843	0.010174
3	0.0504	3	4	0.010793	0.007397
4	0.02	4	5	0.015298	0.010463
5	0.0504	5	6	0.012595	0.008628
6	0.0504	6	7	0.015744	0.010785
7	0.0504	7	8	0.009893	0.006777
8	0.02	8	9	0.005397	0.003694
9	0.02	9	10	0.009446	0.006471
10	0.08	4	11	0.023331	0.009686
11	0.054	11	12	0.009785	0.004058
12	0.054	12	13	0.008281	0.003438
13	0.02	13	14	0.00376	0.001562
14	0.0504	14	15	0.004512	0.001876
15	0.0504	5	16	0.021074	0.008744
16	0.0128	6	17	0.011289	0.004686
17	0.0128	17	18	0.006769	0.00281
18	0.0504	18	19	0.012793	0.005306
19	0.0504	19	20	0.011289	0.004686
20	0.02	20	21	0.029355	0.012182
21	0.0504	7	22	0.012793	0.005306
22	0.0128	22	23	0.009025	0.003744
23	0.08	23	24	0.007521	0.003124
24	0.0128	24	25	0.00376	0.001562
25	0.0504	25	26	0.003008	0.001248
26	0.0504	8	27	0.004512	0.001868
27	0.0504	27	28	0.002256	0.000934
28	0				