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Optimal Sizing and Placement of Shunt Capacitor in Radial Distribution System using Cuckoo Search Algorithm

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***Abstract*—In the present work static and variable shunt capacitors are sized and placed in the given radial distribution system. Cuckoo Search Algorithm (CSA), used as an optimization algorithm for both placing and sizing. Placement of capacitors improves the voltage profile of the system. Static Capacitor (SC) is placed for 50 percent load condition and Variable Capacitor (VC) is placed for varying load condition. The SC and VC are placed and validated for IEEE-33, bus test systems and on 22, 29 bus practical system.**

***Index Terms*— Capacitor Placement, cuckoo search algorithm, voltage stability, loss reduction.**

I. INTRODUCTION

At present each individual is dependent on the power system, and it should be made sure that power system should be stable and reliable. One of the important parameter of power system network is voltage; the voltage in the system must be maintained in permissible limit. A conventional method to improve voltage stability in the system is by placing the capacitor in the network, which also helps in reactive power management, which helps in loss reduction in the system.

Distribution sector is the most critical among the power system as it is connected to power consumers. Distribution system losses which are termed as AT&C losses are eventually high. It is suggested in [8] that an initiatives must be taken in distribution sector and these initiatives shall be noted as, loss reduction, capacitor placement in all levels, network reconfiguration, 100% metering, and load management etc. One of the major problems in Indian distribution system is loss reduction, which shall be achieved by the capacitor placement.

Number of literatures discusses n number of methods for reducing the distribution system losses, which are through, capacitor placement, network reconfiguration, distributed generator placement etc. All these method requires an optimization algorithm, lot many algorithms has been introduced, few proved to be reliable in the power system optimization. For optimization we have mathematical model, heuristic, Meta heuristic

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approaches.
CSA [1] has been developed by simulating the brood characteristics of a species of bird named cuckoo, the CSA algorithm is simple due to less parameters, easily used to solve, complex, multi objective, non linear problems. There are few optimization algorithms which are proven to be reliable to solve the power system problems. Comparison of CSA with GA, PSO in [2-3], PSO, ABC, DE in [4,5,7], HSA in [6]. These literatures suggest that CSA is robust and reliable compared to the other conventional algorithms.
To assure an optimal place and rating of shunt static and shunt variable capacitor, CSA has been used. The proposed method is tested on IEEE test system and 22, 29 real time system. It is noted that proposed method shall be implemented to improve voltage profile of the system.The backward forward method is used for distribution system load flow analysis, which is stated in [9].

II. METHODOLOGY

The main objective of capacitor allocation is to minimise the losses in the system, to improve the voltage profile in the system with respect to the system constraints. The objective function is defined below

$$PL^D = \sum_{i=1}^{N}\sum_{j=1}^{N}[\propto_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}(Q_iP_j + P_iQ_j)] \quad (1)$$

Where, $\propto_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

Subject to the constraints:
Voltage constraint

$$V_{min} \leq V_i \leq V_{max} \quad (2)$$

The voltage limits at each bus must lie within 0.95$\leq V_i \leq 1.05$ pu.

Capacitor reactive power constraints
Static capacitor constraint

$$0 \leq Q_{ci} \leq Q_{ci-50\,\%\,max} \quad (3)$$

Variable capacitor constraint

$$0 \leq Q_{ci} \leq Q_{ci-100\,\%\,max} \quad (4)$$

Maximum Total Compensation

$$\sum_{i=1}^{N} Q_c\,(i) \leq \sum_{i=1}^{N} Q_D\,(i) \quad (5)$$

Here, Q_{ci} is the capacitor installed at i^{th} bus and its maximum isQ_{ci-max}.The maximum value of the capacitor should not exceed the reactive power demand. The above conditions are noted to be same for both static and variable capacitors.

Power balance

$$P_{Slack} = \sum_{i=1}^{N} P_D\,(i) + \sum_{j=1}^{N} P_L\,(j)$$

$$Q_{Slack} + \sum_{i=1}^{N} Q_C\,(i) = \sum_{i=1}^{N} Q_D\,(i) \sum_{j=1}^{N} Q_L\,(j) \quad (6)$$

The real and reactive power balance must be retained in the network.

Overall Power Factor

$$0.9 \leq PF \leq 1 \quad (7)$$

Static and variable shunt capacitor: The capacitor placement is done, in the power system network, based on the reactive power demand. The static shunt capacitor is placed based on the 50- percent load demand e, static capacitor is placed in the network using CSA, after placing static capacitor in the network, and the system data is updated with the static capacitor. CSA technique is used for optimization of both the static and variable capacitor. Variable shunt capacitors are placed for varying load from 60-percent to 110- percent, with a 10 percent increment. Static capacitor is fixed, and it does not depend upon the variation in the load. But variable capacitor rating and place varies as per the variation in the load condition.

Over view Of Cuckoo Search Algorithm: Cuckoo search (CS) is the latest Meta heuristic algorithm inspired by species of cuckoos developed in 2009. CS is similar to genetic Algorithm and Particle swarm Optimization as it is also a population based algorithm, elitism similar to Harmony Search Algorithm. For the random walk it uses levy flights which is heavy tailed and large. The parameters in CS are fewer make the search simpler, n, α, pa are the variables of CS.

Global optimal results are obtained using CSA, different values of α and pa are used and it is found that, α=.25 and pa=0.5 are suited for the present problem, and optimal results are obtained at these values.

In summary the pseudo code for CSA for static and variable capacitors are given below:

1. Generate initial population, i.e n host nests.
2. Certain constraints need to evaluate until the results are converged.
    - Calculate fitness function
    - Select a host nest
    - Calculate its fitness function
    - Compare and keep the best nests
    - Find the optimal fitness value and obtain the results
3. This is initially done for 50 percent load, and the obtained optimal size and place are considered to be static capacitor. Once SC is placed in the network the power system data is updated, and LF is run for the updated system.
4. Step 2, is now repeated to place variable capacitor, in the network for varying load conditions.

The procedure of CSA based algorithm to place OCP is shown in Fig.1

The size of the capacitor selection completely depends upon the reactive power required at the load level, which shall be taken as maximum level of Qc. The variation of the load is made in steps of 10, from 50-110 so that, the variation in the variable capacitor and the position of them shall be noted, based on the variation in the variable capacitor the size of the switching capacitor shall be noted. The maximum load is chosen to be 110% above which the line overloading condition.

III. Results And Discussions

In this paper CSA based algorithm is utilized to select optimal location and to size shunt static capacitor and shunt variable capacitor. In order to test the effectiveness of the algorithm, the performance has been tested on various distribution system, such as IEEE 69 bus test system and 22, 29bus practical distribution system. Evaluated for varying load condition, here critical buses are identified based on voltage constraints, and it could be seen that the voltage profiles has been improved after capacitor placements without calculating any index, for the given system.

The optimal capacitor placement OCP is tested for IEEE- 33 bus test system, and it is noted that results are acceptable; the proposed algorithm is now implemented on the practical distribution system. It is implemented on 22, 29 bus distribution system data of Mysore, Karnataka. The single line diagram of the system is given below.

IEEE 33 bus radial distribution system

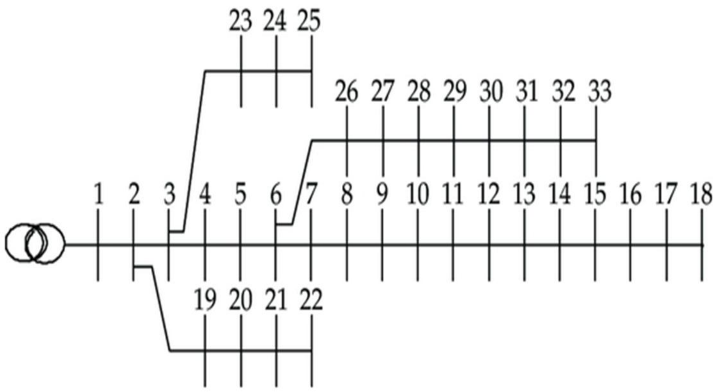

Fig 2: IEEE-33 bus Radial Distribution System

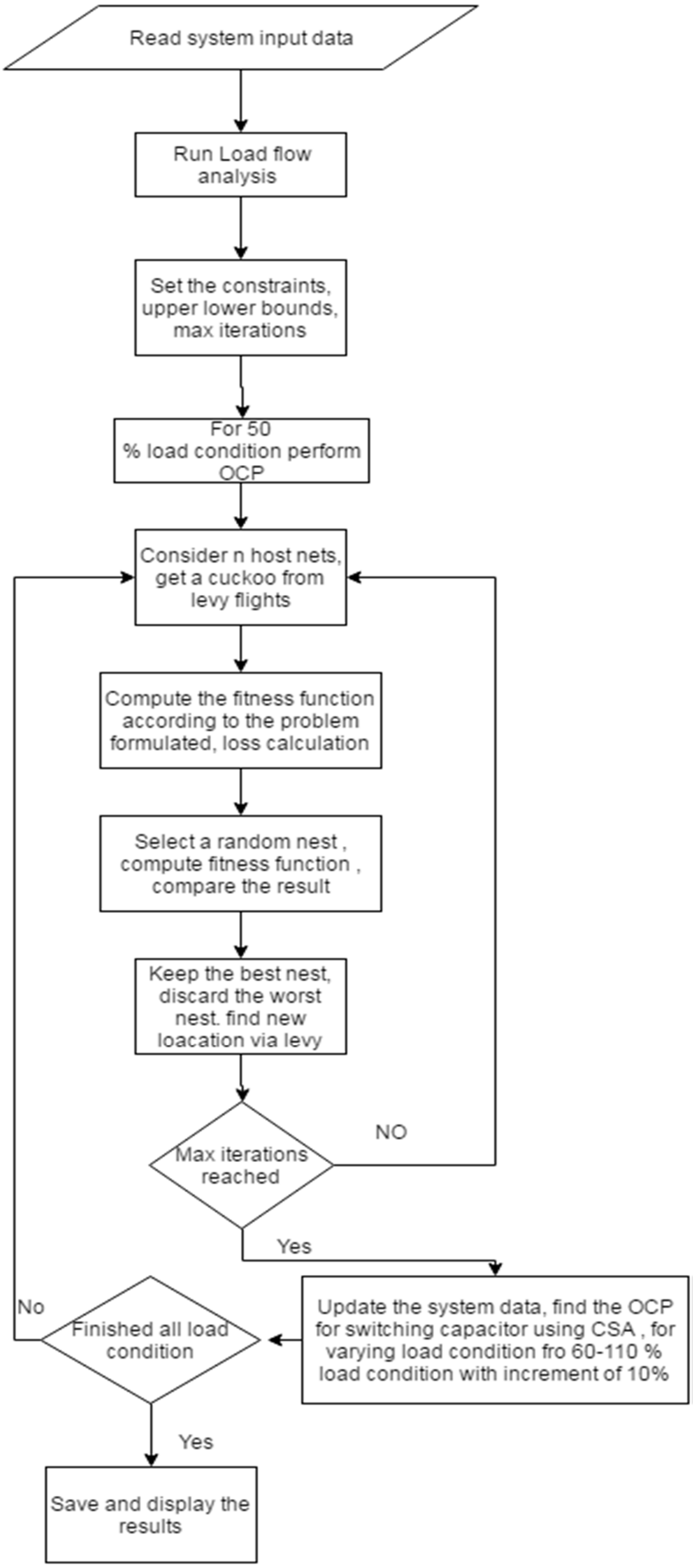

Fig.1 CSA flow chart implemented for an OCP

22 bus radial distribution system

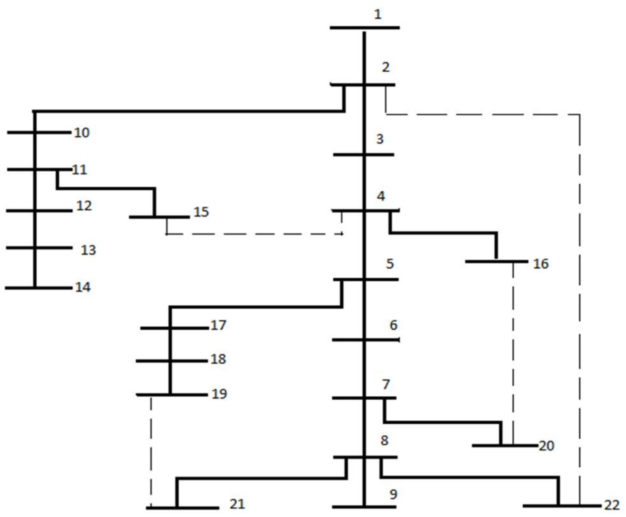

Fig 3: 22 bus Radial Distribution System

29 bus radial distribution system

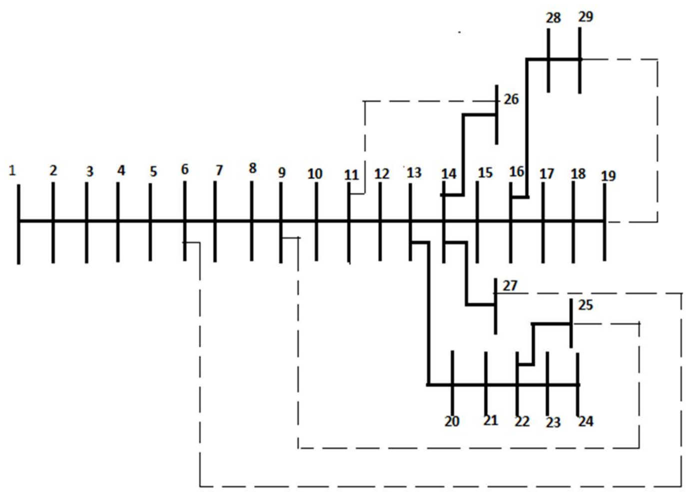

Fig 4: 29 bus Radial Distribution System

TABLE I: RESULTS OF OCP

33 bus test system	**OC place and size** $Q_c, MVAr$	P_{loss}, kW, Before	P_{loss}, kW, After
SC for 50% load	30, 0.7463	78.74	35.6
VC for 60% load	8 , 0.3848	116.16	49.9
70% load	8 , 0.5225	162.1	68.9
80% load	8 , 0.6617	217.28	91.6
90% load	8 , 0.8714	282.5	118.2
100% load	29, 0.8992	360.43	147.7
110% load	29 , 1.0657	449.9	180.7

TABLE II: RESULTS OF OCP

22 bus test system	OC place and size $Q_c, MVAr$	P_{loss}, kW, Before	P_{loss}, kW, After
SC for 50% load	7 , 0.2680	2.4	2
VC for 60% load	12 , 0.1543	3.4	2.9
70% load	5 , 0.2078	4.6	3.9
80% load	5 , 0.2402	6.1	5.1
90% load	5 , 0.3037	7.7	6.5
100% load	5 , 0.3673	9.5	8.0
110% load	5 , 0.4312	11.6	9.7

TABLE III: RESULTS OF OCP

29 bus test system	OC place and size $Q_c, MVAr$	P_{loss}, kW, Before	P_{loss}, kW, After
SC for 50% load	13, 0.4455	9.76	8.2
VC for 60% load	16, 0.1238	14.1	11.8
70% load	16 , 0.1935	19.3	16
80% load	16 , 0.2634	25.3	21
90% load	16 , 0.3337	32.2	26.7
100% load	14, 0.4438	40.07	33.1
110% load	14 , 0.5249	48.7	40.2

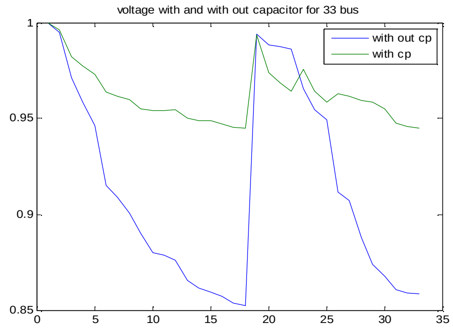

Fig 5: 33 bus, voltage comparisons

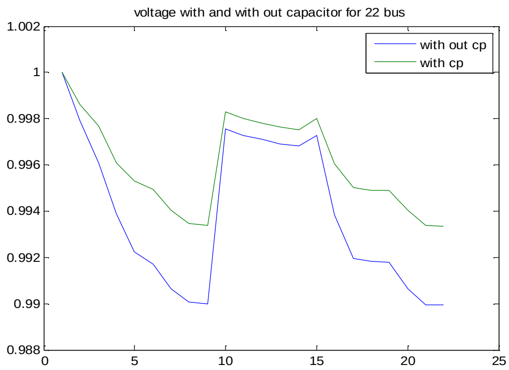

Fig 6: 22 bus, voltage comparisons

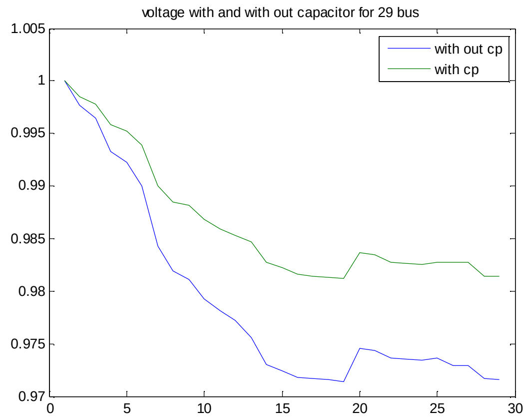

Fig 7: 29 bus, voltage comparisons

For all the three systems are evaluated for fixed/static capacitor placement and variable/ switch capacitor placement. And it is noted that placement of switching as well as fixed capacitor has more benefit compared to placing a single capacitor in the network.

The loss reduction is observed to be 20% at 100 percent loading conditions. It is noted that for a IEEE 33 bus test system variable capacitor varies from 0.39-1.07MVAr, and position to be varied 8 till 90% load and 29 for 100 and 110% load condition. Similarly for 22 bus system it is from 0.15 – 0.43MVAr at bus 12 and 5, for 29 bus system 0.12-0.53MVAr at bus 16 and 14. In all the three cases the variable capacitor MVAr varies in all load condition but the position remains same for 60-90% load condition and the bus number remains same for 100 & 110% of system load.

CSA has better benefits compared to the nature inspired algorithms; the comparison is given in [6], where CSA is compared with GA, PSO and HSA for IEEE 33 bus test system. The voltage profiles of the above systems with and without OCP are given.

The voltage profile of each system before and after placement of capacitor is shown in figure 5, & 7. It is been noted that the voltage profile is improved in all the three test cases.

IV. Conclusions

Cuckoo search shall be used as one of the optimization algorithm in power system utility. Without using any performance index or voltage indices OCP using CSA is capable to obtain the best results to maintain voltage profile in the system. Though Capacitor placement is a conventional according to APDRP [8], capacitor placement is one of the solutions to improve voltage profile and loss of the distribution system.

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