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Multi-Objective Capacitor Allocations in Distribution Systems using Cuckoo Search Algorithm

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Abstract:

This manuscript presents an approach to allocate capacitors along radial distribution network using cuckoo search (CS) algorithm. The objective function is to enhance voltage profile, power loss reduction and to achieve maximum net yearly savings. However the effectiveness to reduce power loss can be achieved if the capacitor is placed in suitable location with appropriate size. In general high potential buses for capacitor placement in distribution systems or initially identified using loss sensitivity factors. However, the loss sensitivity factor method may not always indicate the appropriate placement. In proposed approach the cuckoo search algorithm identifies optimal sizing and placement and takes the final decision for optimal location within the number of buses nominated. The CS-Algorithm is tested for IEEE-34, IEEE-69 and IEEE-94 bus radial distribution systems and it is capable of generating high quality solutions with good convergence characteristics.

Keywords: Cuckoo search algorithm, Loss sensitivity factor,Radial distribution system.

1 Introduction

The power loss in distribution system corresponds to about 70% of the total loss in electrical power systems .The loss that occur in distribution systems, such as power loss in the cables, over head lines, distribution transformers and bus bars. Generally, one of the approach to minimize the power losses in the distribution is to install the capacitors. It operates by supplying reactive power into the system, by placing the capacitors in suitable location with appropriate size. The common objectives to be achieved are: to improve the power factor, reducing the power losses, minimizing the cost and improving bus voltage profile.

Reactive power addition can be beneficial only when correctly applied. The correct application means choosing the correct position and size of the reactive power support. It is not possible to achieve zero losses in a power system, but it is possible to keep the losses to a minimum to reduce the system overall cost. Several optimization techniques that assist in solving problems that were previously problematic have been proposed and developed in the last decade. To attain a loss reduction factor in distribution systems it is necessary to use effective and efficient computational tools that allows quantifying the losses in each different network element for system losses reduction.

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Since, the optimal capacitor placement is a combinatorial optimization problem, one of the techniques used to determine the location of capacitor is sensitivity analysis. This technique works by selecting a node that has high value of power loss reduction when reactive power supplied to that node. Several numerous methods for solving this problem with a view to minimizing losses have been suggested in the literature based on both traditional methods and heuristic approaches. Several heuristic methods have been in the past such as Ant colony optimization based algorithm [8], PSO [3 & 9],ABC[1],fuzzy algorithm[4] to solve capacitance placement optimization problems

In this article, the CS-based algorithm is used to ascertain to optimize size and select optimum locations of capacitors. High potential buses for capacitor placement are identified by the observations of LSF with weak voltage buses. The proposed methods improves the voltage profile and reduce system loses in addition to maximize yearly net savings. The method has been tested and validated on a variety of radial distribution systems and the detailed results are presented.

2 Modeling Of Objective Function

The objective of capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints [1]. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is described as:

f=min(COST) (1)

f=min(yearly power loss cost + yearly capacitor cost) (2)

cost of yearly power loss = $K_p.P_{loss}$ (3)

yearly capacitor cost = $\sum^{n}_{i=1} K_i^c Q_i^c$ (4)

where n = no. of candidate locations

K_p=equivalent annual capacitor installation cost.

Subject to the satisfaction of the Active and Reactive power flow balance equations and set of inequality constraints shown below as

The voltage magnitude at each bus must be maintained within its limits for all load levels and is expressed as

$V_{i,\min} \leq |V_i| \leq V_{i,\max}$, i=1...N. (5)

The injected reactive power constraint must be within their permissible ranges at each candidate bus and is expressed as

$Q^{\min}_{Ci} \leq Q_{Ci} \leq Q_{Ci}^{\max}, \forall i \in NB$. (6)

The apparent power flow through line Sl is restricted by its maximum rating limit as

$S_{li} \leq S_{li}^{rated} \forall i \in n$. (7)

Compensation by using a capacitor bank is limited to the total load reactive power demand

$$\sum_{i-1}^{N_B} Q_C(i) \leq \sum_{j-1}^{n_l} Q_D(j) \quad (8)$$

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3 Loss Sensitivity Analysis

Optimal locations of capacitor placements are selected buses that can be determined using loss sensitivity factors[11]. The estimation of these buses helps in reduction of the search space for optimization procedure[10]. A distribution line with an impedance R+jX and a load of P+jQ connected between P and Q buses is given below figure 1.

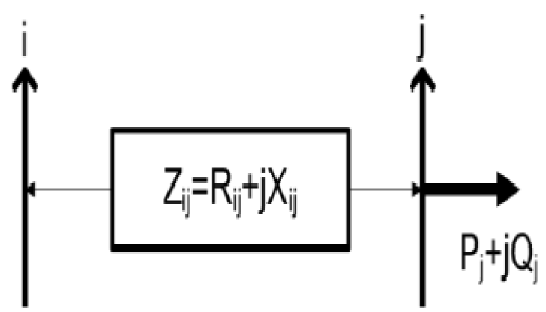

Figure 1: Distribution line with P & Q Buses

Active power loss in i[th] line between i-j buses can be expressed as shown in below

$$P_{ij-loss} \propto \frac{(P_j^2+Q_j^2)}{|V_j|^2}.R_{ij} \quad (9)$$

Thus, the sensitivity analysis actor is a derivative of the power loss with reactive power , as indicated in below

$$\frac{\partial P_{ij-loss}}{\partial Q_j} \propto \frac{2\,Q_j}{|V_j|^2}.R_{ij} \quad (10)$$

Loss Sensitivity Factor ($\partial Plineloss$ / $\partial Qeff$) are calculated from load flow analysis of the given system and the values are arranged in descending order for all the lines of the system. The descending order will decide the sequence in which the buses are to be considered for compensation [11]. If the nominal voltage (i.e. V[i]/0.95) at a bus in the sequence list is greater than 1.01 then such bus needs no compensation. At these buses of position vector , normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given as below

$$Norm[i] = |A[i]|/0.95 \quad (11)$$

Where V[i] is the base voltages of the corresponding IEEE bus. The 'Norm[i]' decides whether the buses need reactive compensation or not. The buses whose norm[i] using eq (11), value is less than 1.01 can be selected as the candidate buses for capacitor placement. The candidate buses are stored in 'candidate bus' vector. It is to be noted that the "loss sensitive factors" decide the sequence in which buses are to be considered for capacitor placement and Norm[i] decides whether the buses needs Reactive power compensation or not. If Norm[i] is greater than 1.01 such bus needs no reactive power compensation and that bus will not to be listed in "candidate bus" vector. The "candidate bus" vector gives the information about places for the capacitor placement. [6] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.

4 Cuckoo Search Algorithm

The cuckoo search algorithm is an optimization technique developed by Xin-

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She Yang and Saush Deb in the year 2009. This algorithm is inspired by some species of a bird family called cuckoo, because of their special life style and due to their reproduction approach. They lay their eggs in the nests of other birds and also remove the existing eggs, which increases the hatching probability of their own eggs. Also, some of the host birds are able to combat this parasites behavior of cuckoos and either they throw out the discovered alien eggs or they build their nests in a new locations. Some birds are so specialized that they have the characteristic of mimicking the color and the pattern of the egg which the reduce the chances of egg being left out there by increasing their productivity. The timely sense of eggs laying of cuckoo is quite interesting.

CS-Algorithm one the modern nature inspired meta-heuristic approaches. CS algorithm is based on the obligate brood parasitic behavior of some cuckoo species. For simplicity is describing the CS the following three basic rules are:

1. Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest.
2. The best nests with high quality of nests carried over to the next generations.
3. The number of available host nests is fixed, and the egg of cuckoo is discovered by the host bird with a probability of pa. in the range of [0,1].

In this case the host bird can either abandon or throw the egg away from the nest so as to build a completely new nest in a new location.

4.1 Algorithm for capacitor placement and sizing using CS algorithm

Step1: Perform the load flow to fond initial power losses without any reactive power compensation .the losses value will be the first fitness value for the algorithm.

Step2: Set all the parameters of cuckoo search such as : No of host nests (n=100), Maximum number of iterations(niter=100), probability (pa=0.3) for the worst nest.

Step3: Randomly initialize the solutions Nest(i,:) = LB+(UB-LB).* rand(size(LB)) get the best objective function.

Step4: A fraction of worst nests are abandoned and replaced by the constructing new nests with discovery rate of alien eggs (pa)

K = rand (size(nest)) > pa

Step size = rand * (nest (rand (n),:) – nest(rand(n),:)

new_nest = nest + step-size.*K

Step5: Evaluate this set of solutions

Step6: Find the best objective so far

Step7: The iteration count is incremented and if the iteration count is not reached maximum then go to step 4.

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Step8: Repeat the procedure till the end of the iterations and get the value of best objective function

Step9: The capacitor sizes corresponding to maximum net savings gives the optimal capacitor locations and results are printed.

5Test Cases And Results

5.1 34-Bus test sytem

This 34-bus test system has 4-lateral radial distribution system which is shown in Fig 2. The data of the system obtained from [13]. The rated line voltage of the system is 11kV and the total load of the system is (4636.5+j2873.5) Kva. Using base LF to candidate the potential buses for capacitor placement and based on LSF values; {19,22,20,21,23,24,25,26 &27}.

In all calculations, for all test cases, the following constants are assumed and applied as shown in Table1.

Table1: Constants used in computation of net saving/ year

S. No	Parameter description	Value
1	Average energy cost (Ke)	Rs 3.6/kW h
2	Depreciation factor (α)	20%
3	Purchase cost (Cp)	Rs 1500/kVAR
4	Installation cost (Ci)	Rs96000/location
5	Operating cost (Co)	Rs18000/year/location
6	Hours per year (T)	8760

The net savings are calculated using

Net Savings Year = Total Cost of Energy Reductions−σ.*{Cost of Installations + Cost of Purchase}−Operating cost/year (12)

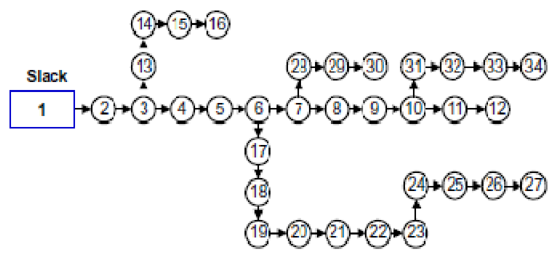

Fig 2:Single line diagram of a 34-bus radial distribution network

The proposed CS algorithm can reduce peak real losses to 160.51 kw (i.e percentage of reduction is 27.35%) with total reactive compensation of 2300 kVAr allocated at buses of 9,19,25 with ratings of 832,702 and 766KVAR respectively. The net yearly saving is Rs 17018.00. the voltage profile, reduction of Active and Reactive power loss and annual net savings are indicated in table 2.

Table2: results of 34 bus system

Point of comparison	Without OCP	With OCP Proposed approach
Vmin(P.U.)a	0.9416	0.9495
Vmax (P.U.)a	0.9941	0.9950

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Ploss(kW)	221.7373	160.51
Qloss (kVAr)	65.2230	47.05
Reductions in Ploss%	-	27.61
Reductions in Qloss%	-	27.86
Net savings per year in Rs		11,69,400

The voltage index of 34-bus radial distribution system without and with compensator and convergence curve of power loss using CS-Algorithm in depicted in Fig 3 and Fig 4 respectively.

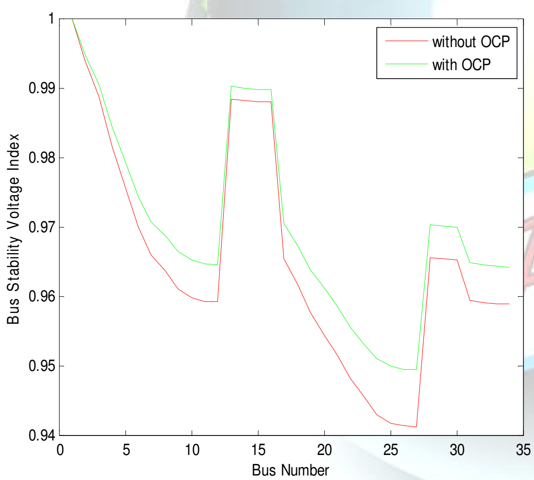

Fig 3: Voltage Profile of 34 Bus System Before and After Compensation

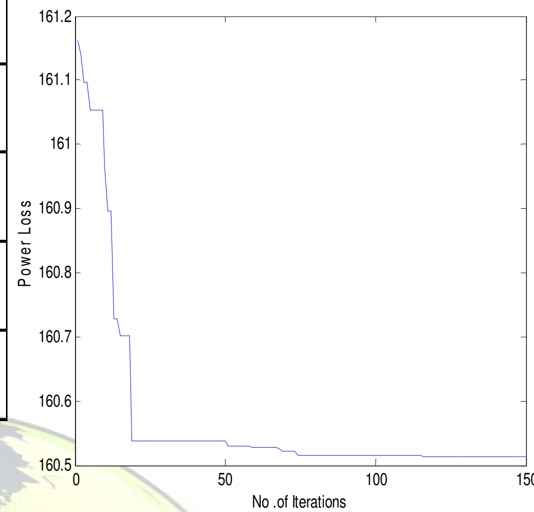

Fig4: convergence curve of power loss in34 – bus system

5.269-Bus test sytem

This is a large scale radial distribution system with 69 buses. The line and bus data of this system are taken from [15]. This system consists of four feeders with 68 branches, a total peak load of 4.47 MW and 3.06 MVAr and its corresponding loss of 227.53 kW. The base values of the system are 100 MVA and 12.66 KVwhich is shown in Fig 5.

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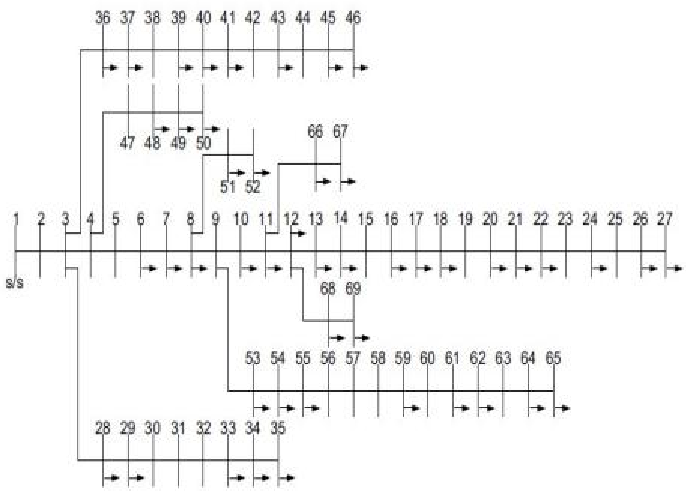

Fig 5: Single line diagram of the 94-bus radial distributionsystem

The proposed CS algorithm can reduce peak real losses to 146.8062 KW (i.e percentage of reduction is 34.02%) with total reactive compensation of 2300 KVAR allocated at buses of 17,10 and 50 with ratings of 869,687 and 744KVAR respectively. The net yearly saving is Rs17,10,960. The voltage profile, reduction of Active and Reactive power loss and annual net savings are indicated in table3.

Point of comparison	Without OCP	With OCP Proposed approach
Vmin(P.U.)a	0.8684	0.9154
Vmax (P.U.)a	0.9942	0.9968
Ploss(KW)	225.0028	146.8062
Reductions in Ploss %	-	34.02
'et Saving per ear in Rs	-	17,10,960

he voltage index of 94-bus radial ribution system without and with ipensation and convergence curve of ver loss using CS algorithm in depicted in 6 and Fig 7 respectively.

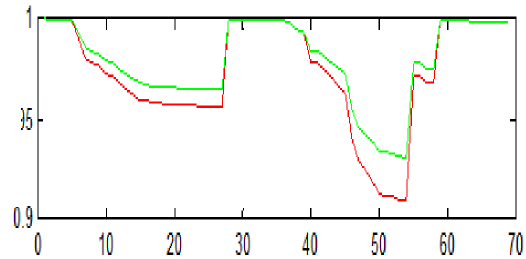

Fig 6: voltage profile of 69 bus system before and after compensation

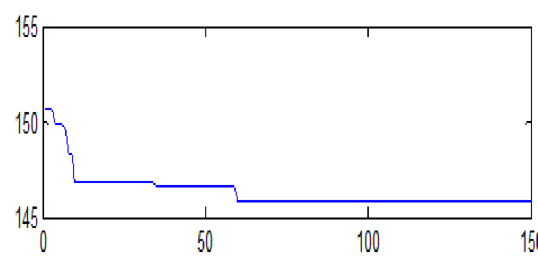

Fig 7: convergence curve of power loss in 94 – bus system

5.394-Bus test sytem

This proposed approach has been applied to an actual radial distribution system with 94 nodes the network layout,including line data and load data obtained from [7], this network consists of 22-lateral radial branches with total loads of

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(4797+j2323.9)kva which is shown in Fig 8.The bus voltages constraints are (1 P.U.) have been proposed in this test case with 15 kV voltage level. The most likely buses for capacitor placements as identified byLSF indicators are {11, 10, 90, 18, 8, 21, 54, 52, 15, 9, 83, 20, 16, 24….}.

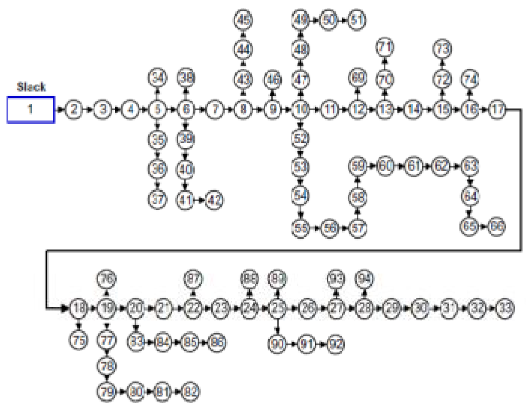

Fig 8: Single line diagram of the 94-bus radial distributionsystem

The proposed CS algorithm can reduce peak real losses to 268.1667KW (i.e percentage of reduction is 25.98%) with total reactive compensation of 2300 KVAR allocated at buses of 20,10 and 58with ratings of 913,942 and 645KVAR respectively. The net yearly saving is Rs 21,24,600. The voltage profile, reduction of Active and Reactive power loss and annual net savings are indicated in table 4.

Table 4: results of 94 bus system

Point of comparison	Without OCP	With OCP Proposed approach
Vmin(P.U.)a	0.8484	0.9072
Vmax (P.U.)a	0.9950	0.9970
Ploss(KW)	362.8578	268.5530
Qloss (KVAR)	504.042	373.5053
Reductions in Ploss %	-	25.98
Reductions in Qloss %	-	25.89
Net Saving per year in Rs	-	21,24,600

The voltage index of 94-bus radial distribution system without and with compensation and convergence curve of power loss using CS algorithm in depicted in Fig 8 and Fig 9 respectively.

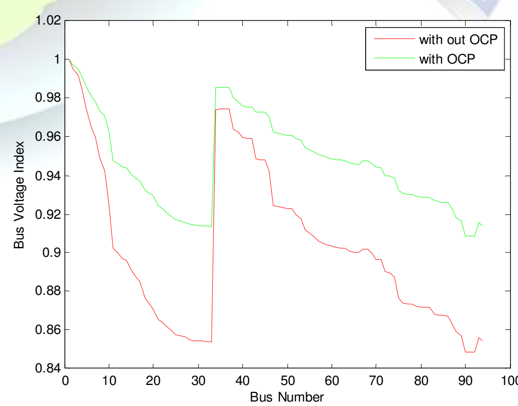

Fig 8: voltage profile of 94 bus system before and after compensation

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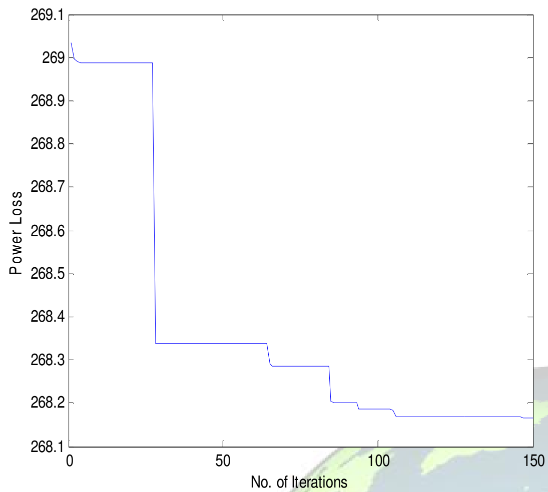

Fig 9: convergence curve of power loss in 94 – bus system

6 CONCLUSIONS

The cuckoo search algorithm has been applied to solve the problem of capacitor allocations (sizing and placement)to maximize the net annual savings and to improve system voltage profile. The numerical results shows that improvement in active and reactive power loss reductions, bus voltage profile enhancements while maximizing the annual net savings. The results obtained via the proposed CS-Algorithm are preferable to the other methods in terms of the quality of the solution and convergence characterstics.

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