Comparison between ABC and CS Algorithms with respect to Capacitor Allocations in Radial Distribution Networks to Minimize of Power Loss

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Abstract - *This manuscript presents an approach to allocate capacitors along radial distribution network using Cuckoo Search (CS) algorithm and Artificial Bee Colony (ABC) 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 approaches the cuckoo search algorithm and artificial bee colony algorithms identifies optimal sizing and placement and takes the final decision for optimal location within the number of buses nominated. The both algorithms are tested on IEEE-34 and IEEE-94 bus radial distribution systems and found that CS algorithm is capable of generating high quality solutions with good convergence characteristics compared to ABC algorithm.*

***Key Words*: Cuckoo search algorithm (CS), Artificial Bee Colony algorithm (ABC), Loss sensitivity factor, Net savings, 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 approaches 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 value to reduce the system overall cost. Many 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.

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 [1 & 8], PSO [3 & 9], fuzzy algorithm [4] to solve capacitance placement optimization problems.

In this article, the ABC and CS-based algorithms are 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 additionally 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 = $\sum n_i = K_{ic} * Q_{ic}$ (4)

Where n = no. of candidate locations

K_p=equivalent annual capacitor installation cost.

K_{ic} is the annual capacitor installation cost, and, i = 1, 2. . , n

Q_{ic} is the Reactive power compensation at each location.

Subjected to the satisfaction of the Active and Reactive power flow balance equations and set of inequality constraints shown below as [2],

2.1 Voltage Limit Constraint

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

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

2.2 Reactive Compensation Limit

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

$Qc_{imin} \le Qc_i \le Qc_{imax}$, ∀i ∈NB. (6)

2.3 Line Capacity Limit

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

$Sl_i \le Sl_{irated}$ ∀i ∈n. (7)

2.4 Maximum Total Compensation

From practical limitations, maximum compensation by using a capacitor bank is limited to the total load reactive power demand

$$\sum_{i=1}^{N_B} Q_C(i) \le \sum_{j=1}^{n_l} Q_D(j).$$

(8)

3. LOSS SENSITIVITY ANALYSIS

Optimal locations of capacitor placements are selected buses, that can be determined using loss sensitivity factors [3]. The estimation of these buses helps in reduction of the search space for optimization procedure [1]. The LSF may be able to estimate which bus will have the highest loss reduction when reactive compensation is put in place in the distribution feeder network. 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.

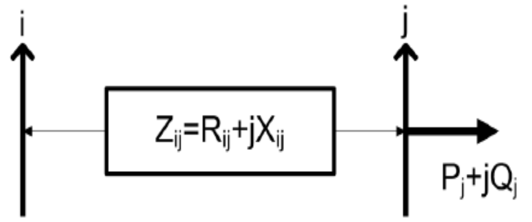

Fig 1: Distribution line with P & Q Buses

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

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

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

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

(10)

3.1. Candidate bus selection using Loss Sensitivity Factor

Loss Sensitivity Factor ($\partial P_{lineloss} / \partial Q_{eff}$) 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 (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 e.q (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.

4. CUCKOO SEARCH ALGORITHM

The cuckoo search algorithm [6] is an optimization technique developed by Xin-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 [10]. 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 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.

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.

5. ARTIFICIAL BEE COLONY ALGORITHM

The ABC algorithm was planned by Karaboga for optimizing numerical issues in 2005 [14]. It simulates the intelligent search behavior of honey bees warms. It's a really straightforward, robust and population based random improvement algorithmic program. The ABC algorithm has three phases: employed bee, onlooker bee and scout bee. In the employed bee and the onlooker bee phases, bees exploit the sources by native searches with in the neighborhood of the solutions hand-picked based on deterministic selection in the employed bee phase and the probabilistic choice within the onlooker bee section. In the scout bee phase which is an analogy of abandoning exhausted food sources within the search method, solutions that are no longer useful for search progress are abandoned, and new solutions are inserted instead of them to explore new regions within the search area.

The process of finding the food begins with scout bees randomly determines the location of food area. Status of scout bees modified to employed bees once they found the food sources within the food area. Supported on information from all food sources, the employed bees return to hive to exchange information with onlooker bees in the dancing area. In this area, they're going to perform a special dance that called as waggle dance and duration of the dancing depends on the richness of food. The particular position of a food source corresponds to a probable solution to the optimization problem and the quantity of nectar found in a food source represents the quality (fitness) of the associated solution.

5.1. Algorithm for capacitor placement and sizing using ABC algorithm

The main steps of the ABC algorithm in the form of Pseudo-code are given below

Step 1: Randomly generated initial population, Xij consisting of capacitor size and location.

Step 2: Evaluate the population

Step 3: Evaluate the fitness value for each employed bee using the below eq (12)

$$\text{Fitness} = \frac{1}{1+\text{power loss}} \quad (12)$$

Step 4: initialize cycle=1

Step 5: Generate new solutions (food positions) vij in the neighborhood of Xij for the employed bees using the formula

$$v_{ij} = x_{ij} + \varphi_{ij}\left(x_{ij} - x_{kj}\right) \quad (13)$$

(k is a solution in the neighborhood of i) and evaluate them.

Step 6: Calculate the probability values Pi for the solutions xij by means of their fitness values using Eq (14)

$$p_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i}. \quad (14)$$

In order to calculate the fitness values of solutions, the following Eq. is employed;

$$fit_i = \begin{cases} \frac{1}{1+f_i} & \text{if } f_i \geq 0 \\ 1+|f_i| & \text{if } f_i < 0 \end{cases}. \quad (15)$$

Normalize Pi values into [0, 1]. fit_i obtained separately for each individual ith solution through Eq. 15.

Step 7: Produce the new solutions (new positions) vij for the onlookers from the solutions x_{ij} selected depending on P_i and evaluate them

Step 8: Apply the greedy selection process between previous and new Fitness_i.

Step 9: Determine the abandoned solution, if it exists, and replace it with a new randomly produced solution x_{ij} for the scout using below e q

$$x_{ij} = Q_{Cj}^{\min} + rand(0,1).\left(Q_{Cj}^{\min} - Q_{Cj}^{\max}\right). \quad (16)$$

Step 10: Memorize the best food source position (solution) achieved so far.

Step 11: Cycle = Cycle + 1

Step 12: Until Cycle = MCN.

6. TEST CASES AND RESULTS

6.1. 34-Bus test System

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

Control parameters adopted for the ABC algorithm for finding the optimal capacitor sizes are Qmin=50 kvar, Qmax=1500 kvar, pa=0.3, conlony size=60, mcn=100 and limit is 30 and for CS algorithm No of host nests (n=100), Maximum number of iterations(niter=100), probability (pa=0.2 to 0.5) for the worst nest.

The net savings are calculated using

Net Savings Year = Total Cost of Energy Reductions−σ.*{Cost of Installations + Cost of Purchase}−Operating cost/year (17)

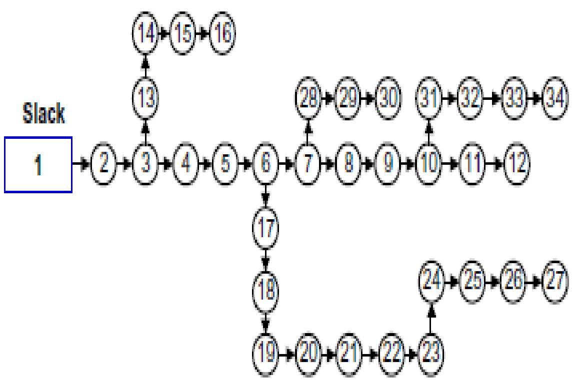

Fig 2: Single line diagram of a 34-bus radial distribution network

The proposed ABC-based approach can reduce peak real losses to 165.07 kW with total reactive compensation of 2200 KVAR allocated at buses of 20, 9 and 25 with ratings of 880 KVAR, 667 KVAR and 653 KVAR respectively and CS algorithm can reduce peak real losses to 160.51 kw (i.e percentage of reduction is 27.61%) with total reactive compensation of 2300 kVAr allocated at buses of 9, 19, 25 with ratings of 792,672 and 736 KVAR respectively. The capacitor allowable range is from 50 kVAr to 1500 kVAr with step of 1.5kVAr. Top three nodes are selected as candidate locations to reduce the search space and then the amount to be injected in the selected nodes is optimized by ABC and CS algorithms.

Table 2 shows a comparison of the proposed methods according to power losses reduction, annual net savings, capacitor location, size as well as total size of capacitor. Based on the obtained results, it can be clearly see that the CS method outperformed other method i.e ABC in term of quality solution.

The bus connected capacitor banks improves power factor and reduces current flow through the feeder lines, transformers etc. This will reduce power losses in the distribution system. Moreover reactive power compensation value used in this analysis is high hence more will be the power loss reduction.

Table2: Summary of Results for 34 Bus Systems

Point of comparison	Uncompensated	Compensated by	
		ABC algorithm	CS- algorithm
Vmin(P.U.)a	0.9416	0.9495	0.9496
Vmax(P.U.)a	0.9941	0.9950	0.9950
Ploss(kW)	221.7373	165.07	160.51
Qloss (kVAr)	65.2230	48.49	46.05
Reductions in Ploss%	-	25.55	27.61
Reductions in Qloss%	-	25.65	29.39
Net savings per year in Rs	-	10,92,000	11,69,400
Capacitor location	-	20,9,25	9,19,25
Capacitor size in KVAR	-	880,667,653	792,672,736
Total KVAR	-	2200	2200

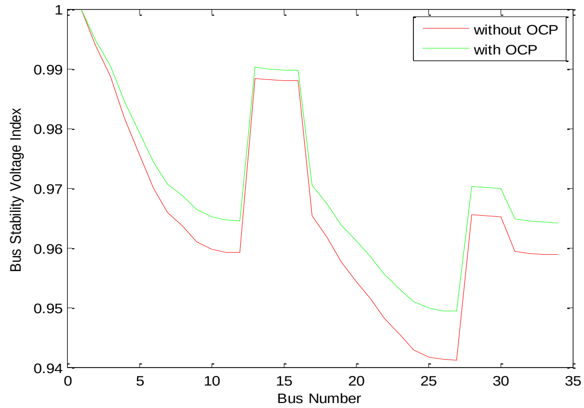

Fig 3: Voltage Profile of 34 Bus System Before and After Compensation

The voltage index of 34-bus radial distribution system without and with compensation using proposed algorithms are nearly same which is depicted in Fig 3 and the convergence curve of power loss using ABC and CS algorithms shown in figures separately in Fig 4 and Fig 5 respectively.

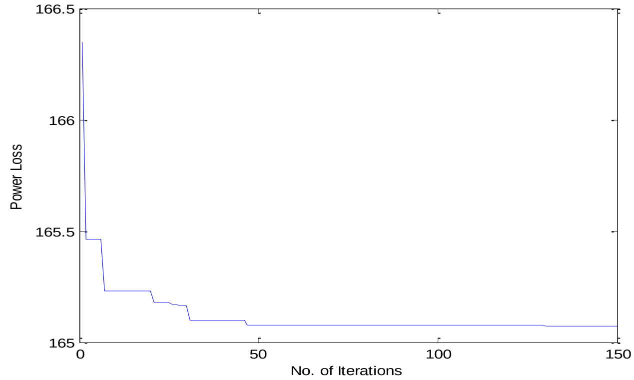

Fig 4: convergence curve of power loss in 34 – bus system using ABC algorithm

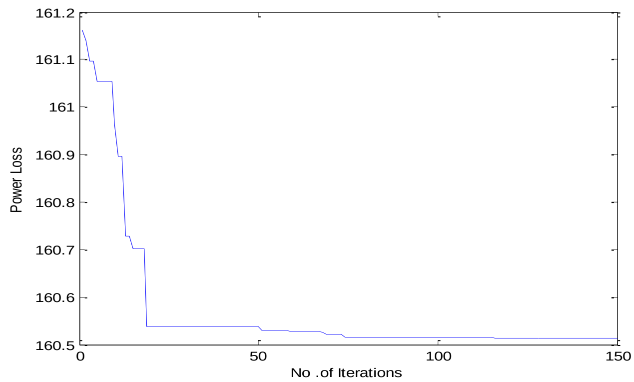

Fig5: convergence curve of power loss in 34 – bus system using CS algorithm

6.2 94-Bus test system

The proposed approaches have 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 (4797+j2323.9) kva which is shown in Fig 6.

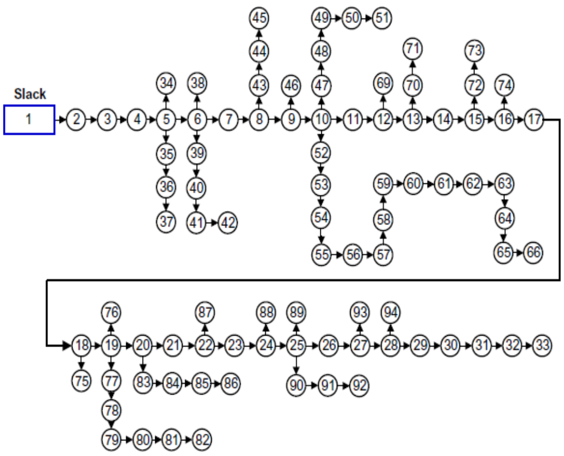

Fig 6: 94-bus radial distribution system

The proposed ABC algorithm can reduce peak real losses to 269.5530 KW with total reactive compensation of 2300 KVAR allocated at buses of 12, 21 and 54 with ratings of 620,770 and 910 KVAR respectively and the CS algorithm can reduce peak real losses to 266.55 KW (i.e percentage of reduction is 26.54%) with total reactive compensation of 2300 KVAR allocated at buses of 20, 10 and 58with ratings of 913, 942 and 645 KVAR respectively. Table 3 shows a comparison of the proposed methods according to power losses reduction, annual net savings, capacitor location, size as well as total size of capacitor.

The voltage index of 94-bus radial distribution system without and with compensation using proposed algorithms are nearly same which is depicted in Fig 7.

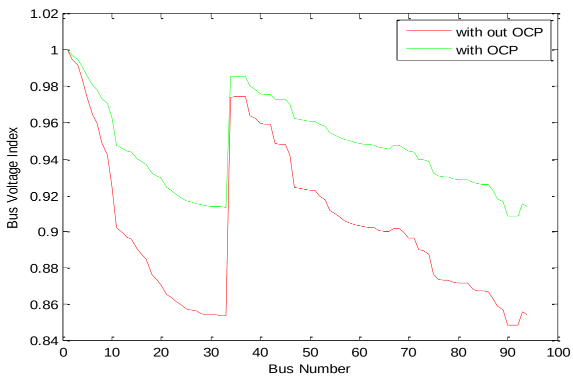

Fig 7: voltage profile of 94 bus system before and after compensation

Table 3: Summary of Results for 94 Bus Systems

Point of comparison	Uncompensated	Compensated by	
		ABC algorithm	CS- algorithm
Vmin(P.U.)a	0.8484	0.9073	0.9074
Vmax(P.U.)a	0.9950	0.9970	0.9972
Ploss(KW)	362.857	269.5530	266.55
Qloss (KVAR)	504.042	373.5053	370.50
Reductions in Ploss %	-	25.71	26.54
Reductions in Qloss%	-	25.89	26.49
Net Saving per year in Rs	-	19,96,800	21,24,600
Capacitor location	-	12,21,54	20,10,58
Capacitor size in KVAR	-	620,770,910	913,942,645
Total KVAR	-	2300	2300

The convergence curve of power loss using ABC and CS algorithms shown in figures separately in Fig 8 and Fig 9 respectively. These convergence curves can be obtained by plotting power loss v/s No of iterations.

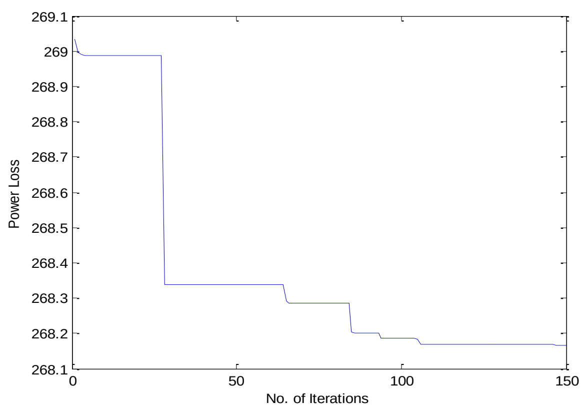

Fig 8: convergence curve of power loss in 94 – bus system using ABC algorithm

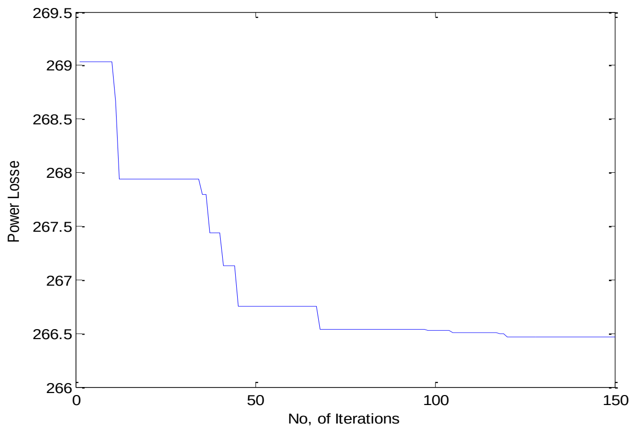

Fig 9: convergence curve of power loss in 94 – bus system using CS algorithm

7. CONCLUSION

The comparative analysis between Artificial Bee Colony (ABC) algorithm and the Cuckoo Search (CS) algorithm have 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 result shows that improvement in active and reactive power loss reductions, bus voltage profile enhancements while maximizing the annual net savings. Cuckoo Search (CS) algorithm exhibits the effective results of the algorithms. The main reason of the performance difference is basically in CS where cuckoo search its food within a vast area rather than limited. On the contrary, in ABC a bee only finds its place is limited not wide while searching for bees. So, that means cuckoo works on a wide range of area and it needs more dimension than ABC. On the other side, ABC needs fixed area to search its best. 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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