Planning of Distributed Generation and Capacitor in an Unbalanced Radial Distribution System using Cuckoo Search Algorithm

Padarbinda Samal [1], Sanjeeb Mohanty [1] and Sanjib Ganguly [2]
[1] Department of Electrical Engineering, National Institute of Technology, Rourkela, India
[2] Department of Electronics and Electrical Engineering, IIT, Guwahati, India

Abstract-- **This paper proposes a planning approach for distributed generation (DG) and capacitor in an unbalanced distribution system. The objective function of this planning includes power loss. A cuckoo search algorithm based optimization technique is utilized to obtain the optimal location and ratings of DG and capacitor. A forward-backward sweep based three-phase load flow algorithm is used to get the load flow solutions. The effectiveness of the proposed methodology is verified on 19-bus unbalanced radial distribution networks. The results indicate the power loss and voltage profile has improved significantly by simultaneous optimizing the capacitor and DG location.**

Index Terms-- **Unbalanced radial distribution systems, capacitor, distributed generation, power loss.**

I. INTRODUCTION

Most of the losses occur in the distribution networks due to their low operating voltages. Also, the conventional thermal power plants suffer from air pollution and global warming issues. Hence, distributed generations (DG) such as photovoltaic, and wind turbines are utilized to alleviate these issues. The DGs are beneficial in improving the feeder loading capacity and in the deferral of network expansion planning.

Various researchers have shown that DG can minimize the network power loss and improve the voltage profile [1-11] of the distribution systems. Classifying the solution strategies for DG planning problem as: genetic algorithm [1], location of the DG was determined by using multi-objective voltage index analysis and size of DG was obtained using fast approach [2], Load Flow Analysis [3], Firefly algorithm [4], global harmony search algorithm, improved particle swarm optimization (improved PSO), and loss sensitivity factors simulated annealing [5], accelerated PSO, principal component analysis method [7], PSO [8], real power flow sensitivity and real power loss sensitivity [9], modified artificial bee colony algorithm [10], and genetic algorithm (GA) [11].

The capacitor [12-25] also plays a significant role in reducing the power loss, and improvement in voltage profile of the network. The capacitor planning problem are classified in view of solution methodologies as: hybrid honey bee colony algorithm [12], binary PSO [13], two loss sensitivity indices (LSIs) was employed to select the most candidate capacitors locations and the ant colony optimization algorithm was utilized to find the optimal locations and sizes of capacitors [14], Bacterial Foraging Optimization Algorithm [15], Plant Growth Simulation Algorithm [16], A LSI technique was employed to select the candidate locations for the capacitor placement and size of the capacitor was determined simultaneously by optimizing the loss saving equation with respect to the capacitor currents [17], GA [18], Loss Sensitivity Factors and alpha Coefficients [19], differential evolution (DE) algorithm [20], artificial bee colony algorithm [21], Opposition Based DE Algorithm [22], and Cuckoo search algorithm (CSA) [23-25].

Most of the works are dealt with only DG allocation [1-11] or only capacitor allocation [12-25] in distribution systems. It has been observed from these literature studies that, the power loss has reduced significantly and also the voltage profile of the distribution systems has improved considerably by separately optimizing the DG location and ratings and capacitor location and ratings. Motived by the positive effect DG and capacitor separately in balanced/unbalanced distribution systems, an attempt has been taken in this work to study the impact of simultaneous DG and capacitor allocation on network power loss and voltage profile in unbalanced radial distribution systems.

In this paper, a CSA [26] based metaheuristic algorithm is employed to minimize the total system real power loss by obtaining the optimal DG and capacitor location and sizes respectively, in an unbalanced distribution system. A three-phase load flow algorithm [28] for unbalanced distribution systems is utilized as a subprogram to compute the power flow solutions. A 19-bus is considered as the test system for validation of the proposed algorithm.

The paper is organized as follows: In Section II, the problem statement is described. The proposed solution strategy is presented in Section III. Test results are given in Section IV. Section V concludes the paper.

II. PROBLEM STATEMENT

The objective of this planning problem is to minimize the total real power loss (PL) [1, 30] of a network subjected to some technical constraints as follows:

i. Voltage constraint: Voltage at each bus must remain within the permissible range.

$$V_s^{min} \le V_s^{abc} \le V_s^{\max} \tag{1}$$

ii. Thermal constraint: The current flowing through each branch must be within the permissible range.

$$I_j^{abc} \le I_j^{\max} \tag{2}$$

iii. DG active generation limits: The DG output power should remain within their operational limits.

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{3}$$

iii. Capacitor reactive power output limits: The capacitor output power should remain within their operational limits.

$$Q_i^{\min} \le Q_i \le Q_i^{\max} \tag{4}$$

III. Solution Strategy

A brief overview of CSA and its implementation is described in this subsection. In this paper, we have used a metaheuristic algorithm called cuckoo search algorithm (CSA) [26] for solving the planning problem.

A. *Overview of cuckoo search algorithm*

Cuckoo search algorithm (CSA) was developed by Xin-She Yang and Suash Deb by observing the intelligent egg laying strategy of cuckoos. They lay their eggs in a randomly chosen host nest for their survival. If the host nest identifies cuckoo eggs, it will either throw away their eggs or build a new nest somewhere else. The nest in the CSA algorithm is same as the population, which is used in particle swarm optimization. Each egg in the nest represents the possible solution or decision variable for the optimization problem. The CSA follows three rules [27] as:

- Each cuckoo lays one egg at a time, and abandons in a random nest;
- The better quality eggs (good solutions) moves to next generations;
- A host bird can discover an alien egg with a probability, p_a = [0, 1] and builds a new nest at a new location or completely abandons its own nest or throw away the eggs.

CSA generates random host nest using levy flight for new solution x_i^{t+1} as:

$$x_i^{t+1} = x_i^t + \alpha \times \text{Levy}(\lambda) \tag{5}$$

Where α>0, denotes the step size,

$$Levy(\lambda) = \left| \frac{\Gamma(1+\lambda) \times \sin(\frac{\pi \times \lambda}{2})}{\Gamma(\frac{1+\lambda}{2}) \times \lambda \times 2^{\frac{\lambda - 1}{2}}} \right|^{\frac{1}{\lambda}} \tag{6}$$

B. *Implementation of CSA*

In this section, the implementation of CSA for the planning problem is described. In this planning problem, the nest representing the decision variable vector L is given as:

$$L\text{= [D, PDG, C, QC]} \tag{7}$$

$$\text{D= }[D_1, D_2,.., D_{\text{M}}] \tag{8}$$

$$\text{PDG= }[PDG_1, PDG_2, \ldots, PDG_{\text{N}}] \tag{9}$$

$$\text{C= }[C_1, C_2,.., C_{\text{M}}] \tag{10}$$

$$\text{QC= }[QC_1, QC_2, \ldots, QC_{\text{N}}] \tag{11}$$

Where D denotes the vector of DG locations; PDG vector represents the active power generated by DGs; C denotes the vector of capacitor locations; QC represents the vector of reactive power provided by capacitors; M represents the location of DGs and capacitors, and N denotes the number of DGs and Capacitors.

To incorporate the DG and capacitor model in the three–phase unbalanced load flow algorithm [28], the active and reactive power demand at the bus at which a DG and a Capacitor unit is placed, say, at bus i, is modified by:

$$\begin{aligned} P_{D_{ip}}^{DG} &= P_{D_{ip}}^{base} - PDG_{ip} \\ Q_{D_{ip}}^{C} &= Q_{D_{ip}}^{base} - QC_{ip} \end{aligned} \tag{12}$$

Where, $P_{D_{ip}}^{DG}$ and $Q_{D_{ip}}^{C}$ are the active and reactive power demand for p^{th} phase of i^{th} bus with a DG unit and a capacitor unit are the active and reactive power demand for p^{th} phase of i^{th} bus of the base-case network; PDG_{ip} and QC_{ip} are the active power and the reactive power generated by the DG and the capacitor unit placed at p^{th} phase of i^{th} bus.

The flow chart of the planning approach is provided in Fig. 1.

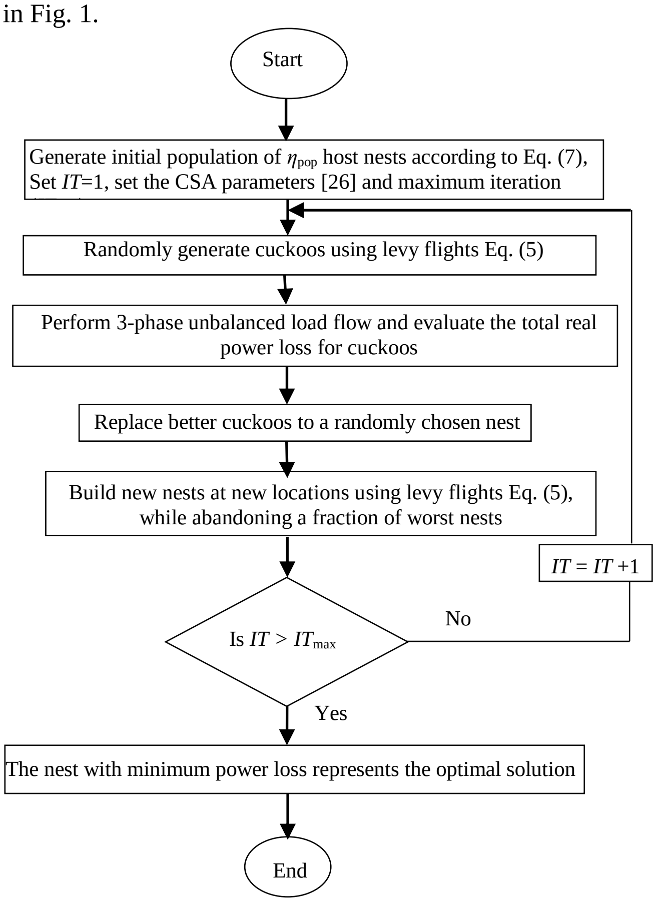

Fig. 1. Flow chart of the proposed planning approach

IV. Results and Discussion

The proposed solution methodology is implemented in a 19-bus [29] unbalanced distribution systems. The base kV and MVA of the system are considered as 11 and 1 respectively [29]. The total real and reactive power demand of this system are 1219.8 kW and 590.9 kVAR respectively. The base case power loss of the system is 50.1 kW. The base case minimum bus voltage magnitude (p.u.) for phase a, b, and c is 0.9460, 0.9439, and 0.9447 respectively. The optimal parameters such as the number of nests, the number of generation, and the λ (constant) value [26] are taken as 100, 300, and 1 respectively. The number of DGs and capacitors (N) are taken as 3, and the candidate locations for their placement (M) is considered as 18. Three different cases studies are considered as:

- *Case A*: only capacitor allocation
- *Case B*: only DG allocation
- *Case C*: Simultaneous DG and capacitor allocation.

The comparison results for different cases for a sample run are shown in Table I. It is observed from this table, that power loss is reduced by nearly 75% and the minimum bus voltage (p.u.) is found to be improved by 3% for Case C planning in comparison to base case values. The voltage profile for different planning cases is shown in Figs. (2)-(4). It can be seen from these figures that the voltage magnitude (p.u.) at all buses has improved for Case C optimization in comparison to base case values. Figs. (5)-(7) show the power loss in kW at each branch of the 19-bus system for different planning studies. As viewed from these figures, the power loss has been reduced for Case C planning in comparison to base case power loss.

TABLE I
COMPARISON OF RESULTS FOR A SAMPLE RUN FOR DIFFERENT CASES USING CSA

Objective	*Case*								
	A			*B*			*C*		
PL(kW)	42.9352			19.0289			12.5989		
DG location	-			12			11		
Capacitor location	12			-			12		
DG rating (kW)	-	-	-	159.8	163.7	164.4	165.3	147.6	174.9
Capacitor rating (kVAR)	71.3	74.9	73.8	-	-	-	90.8	68.7	60.5
Minimum bus voltage (p.u.)	0.9508	0.9491	0.9501	0.9713	0.9706	0.9713	0.9765	0.9710	0.9741

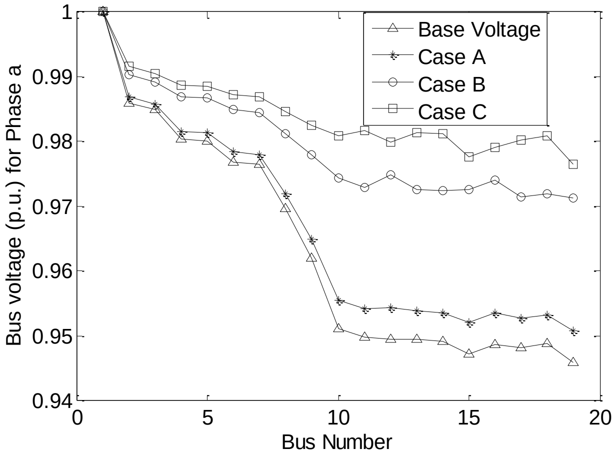

Fig. 2. Voltage profile for phase a for the 19-bus system for different planning cases

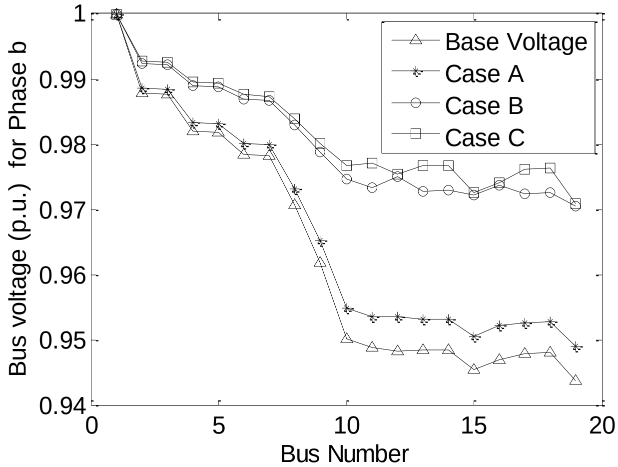

Fig. 3. Voltage profile for phase b for the 19-bus system for different planning cases

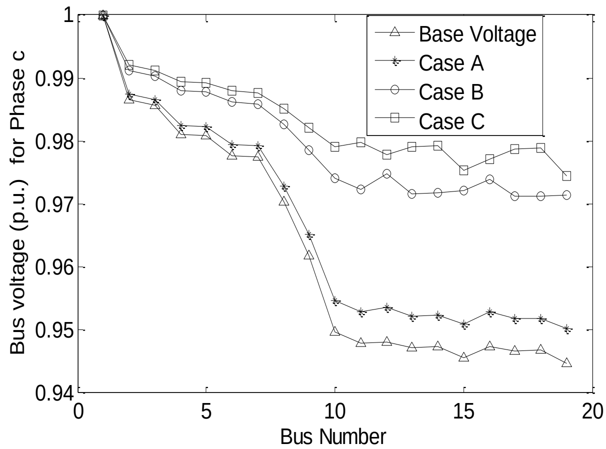

Fig. 4. Voltage profile for phase c for the 19-bus system for different planning cases

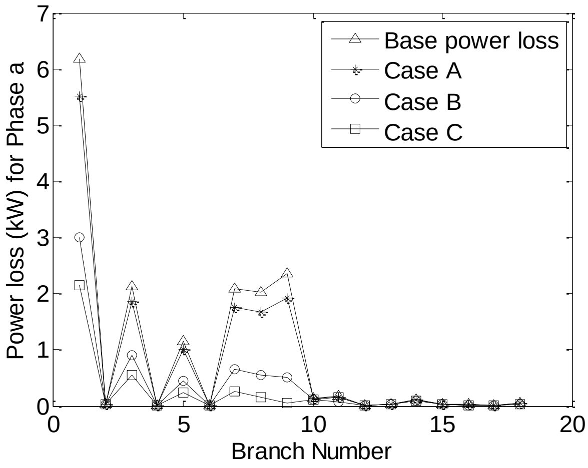

Fig. 5. Power loss in kW at each branch number for phase a for the 19-bus system for different planning cases

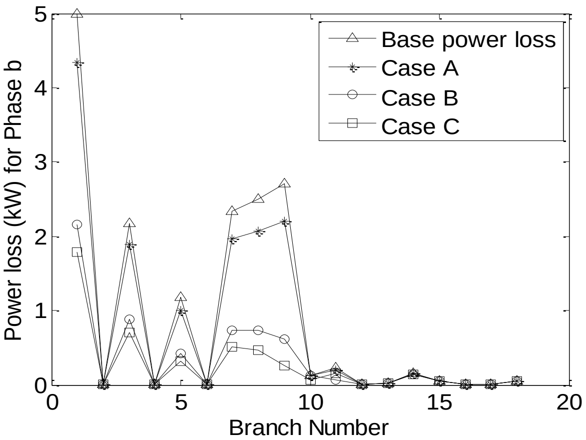

Fig. 6. Power loss in kW at each branch number for phase b for the 19-bus system for different planning cases

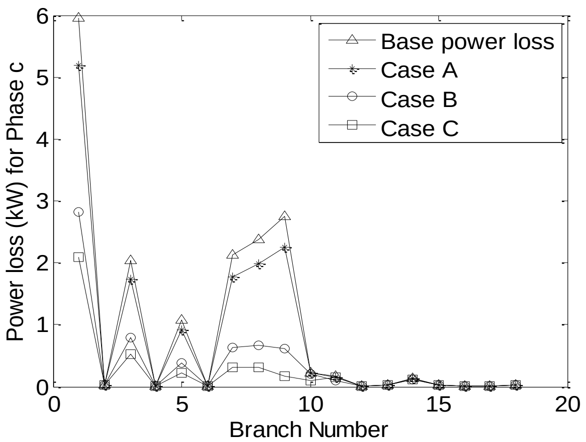

Fig. 7. Power loss in kW at each branch number for phase c for the 19-bus system for different planning cases

V. CONCLUSIONS

In this paper, a planning approach with CSA has been proposed for the simultaneous optimization of the DG and capacitor location and sizes. The real power loss minimization has been considered as the objective function for this planning problem. A three-phase unbalanced load flow algorithm has been used as a subprogram for the computation of the power flow solutions. The simulation results clearly indicate that the total real power loss of the 19-bus unbalanced radial distribution systems has been reduced by 75%. Moreover, the voltage profile of these systems have improved considerably in comparison to the base case results, for the simultaneous optimization of DG and capacitor location and rating.

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