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Optimal Capacitor Placement in Radial Distribution System Using Artificial Bee Colony Algorithm for Voltage Profile Improvement and Loss Reduction

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Abstract: ***High distribution system losses are mainly due to inadequate investments in R&D for system improvement and improper planning during installation, which has resulted in unplanned extensions of the distribution lines, overloading of the system elements like transformers and OH lines/conductors and lack of adequate reactive power support leading to voltage drop in a system. Capacitors affect the line power flow and voltage conditions on the system equipment by injecting reactive power. These impacts of capacitor may be improve system efficiency or reduce it depending on the distribution system operating conditions and allocation Capacitor. The improper allocation of capacitor units in few circumstances can lower efficiency level. For this purpose, the optimal allocation of shunt capacitors for a given radial distribution system can be useful for the system outlining and improve efficiency. In this paper a new method is used for optimal allocation of shunt capacitor units in radial distribution network to curtail distribution system losses and improve voltage profile. The advantage of Artificial Bee Colony algorithm is that its calculation time is less as it does not need exterior specifications such as cross over rate and mutation rate as in case of genetic algorithm and differential evolution. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on IEEE 33 bus system and practical 116 bus system, the simulation results are presented and discussed.***

Keywords: Voltage Deviation Index (VDI), Artificial Bee Colony (ABC), Optimal Capacitor Placement, Loss Reduction, Voltage Profile

1. Introduction

The inclination with respect to distribution automation depends upon the utmost efficient operating scenario for economic feasibility variations. Hence in distribution systems loss minimization and voltage profile improvement have been given greater importance. As the generation cost is increasing day by day and depleting resources it is necessary to have an efficient system, any efforts made towards loss reduction is appreciable. In electric power systems, 70% of total losses correspond to power losses in distribution systems. Many programs have been organized to minimize these huge technical losses. The most efficient loss reduction techniques in distribution systems are feeder reconfiguration, distributed generation (DG), VAR compensation. For VAR compensation, shunt capacitor banks are installed on distribution primary feeders to provide adequate reactive power support for voltage profile enhancement, reduce system losses and increase available capacity of feeders. To achieve maximum benefits of VAR compensation, it is important to find optimal location where capacitor bank need to be connected and of optimal capacity, for voltage profile enhancement and loss reduction. Many different optimization algorithms have been proposed in the past for optimal allocation of capacitor.

Ahmed R. Abul'Wafa, et al. [1] have presented an efficient approach for capacitor allocation in radial distribution systems that determine the optimal locations and sizes of capacitors with an objective of reduction of power loss and improving the voltage profile. A two stage technique is proposed: a reconfiguration of the feeder in the first stage followed by optimal capacitor allocation as a second stage. Mohamed B. Jannat, et al. [2] have proposed a new method for optimal allocation of shunt capacitors in distribution network with renewable distributed generation units such as wind turbines and/or solar power plants. Avadhanam Kartikeya Sarma, et al. [3] presented a new method which applies an artificial bee colony algorithm(ABC) for capacitor placement in distribution systems with an objective of improving the voltage profile and reduction of power loss using loss sensitivity factor for finding location and ABC algorithm for sizing of capacitor. H. Ng et al. [4] (2000) have presented capacitor placement problem by using fuzzy approximate reasoning. Sundharajan and Pahwa [5] (1994) proposed the genetic algorithm approach to determine the optimal placement of capacitors based on the mechanism of natural selection. Ji-Pyng Chiou et al (2006)[6] proposed the variable scale hybrid differential evolution algorithm for the capacitor placement in distribution system. In this paper an ABC algorithm is used to find simultaneously the optimal location and capacity of shunt capacitor to enhance voltage profile and reduce losses. The artificial bee colony algorithm is a new metaheuristic approach, proposed by Karaboga [7]-[9]. It is exalted by the clever exploring act of honey bees. The proposed method is tested on IEEE 33 bus system and practical 116 bus system; the simulation results are presented and discussed.

2. Objective

The objective of capacitor placement in the distribution system is to enhance system voltage profile and to minimize system losses. 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:

$$\textbf{Minimize F} = \textbf{Min}(P_L + \textbf{VDI}) \qquad (1)$$

Where,
P_L= Real power losses in system.
VDI = Voltage deviation index described as:

$$VDI = \sum_{i=0}^{N} \frac{|V_{rated} - V_i|^2}{V_{rated}} \qquad (2)$$

Where,
V_{rated} = 1.0pu.;$V_i$is the voltage at i^{th} bus.
N = Number of buses.

The voltage magnitude must satisfy its constraints and is expressed as:$|V_{min}| \leq V_i \leq |V_{max}|$i:e, ±5% of rated voltage. $V_{min}$and V_{max} are the minimum and maximum voltage limits, respectively.

3. Formulation

In distribution system load flow analysis is carried out by the backward-forward sweep method. The effective branch powers are calculated in backward propagation and in forward propagation voltage magnitudes at each node are calculated and updated.

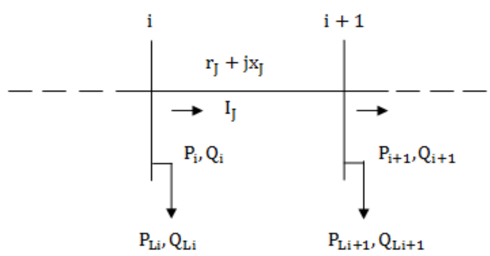

Figure 1: Representation of two nodes in a distribution line

The effective real and reactive powers that are flowing through branch j from node i to node i+1 can be calculated backwards from the last node and is given as,

$$P_i = P'_{i+1} + r_j \frac{P_{i+1}^2 + Q_{i+1}^2}{V_{i+1}^2} \qquad (3)$$

$$Q_i = Q'_{i+1} + x_j \frac{P_{i+1}^2 + Q_{i+1}^2}{V_{i+1}^2} \qquad (4)$$

Where, $P'_{i+1} = P_{i+1} + P_{Li+1}$ and $Q'_{i+1} = Q_{i+1} + Q_{Li+1}$
$P_{Li+1}$and$Q_{Li+1}$are loads that are connected at node ‘i+1’
$P_{i+1}$and$Q_{i+1}$are the effective real and reactive power flows from node ‘i+1’

The voltage magnitude and angle at each node are calculated in forward direction. Consider a voltage $V_i \angle \delta_i$at node ’i’ and $V_{i+1} \angle \delta_{i+1}$at node ‘i+1’ then the current flowing through the branch ‘j’ having impedance,$z_j = r_j + jx_j$Connected between ‘i’ and ‘i + 1’ is given as:

$$I_j = \frac{V_i \angle \delta_i - V_{i+1} \angle \delta_{i+1}}{r_j + jx_j} \qquad (5)$$

$$I_j = \frac{(P_i - jQ_i)}{V_i \angle - \delta_i} \qquad (6)$$

The voltage magnitude can be calculated by using equation described as:

$$V_{i+1} = \left[V_i^2 - 2(P_i r_j + Q_i x_j) + (r_j^2 + x_j^2) \frac{(P_i^2 + Q_i^2)}{V_i^2} \right]^{\frac{1}{2}} \qquad (7)$$

The total real and reactive power loss of radial distribution system can be calculated as,

$$TPL = \sum_{j=1}^{nb} \left[r_j \frac{(P_i^2 + Q_i^2)}{V_i^2} \right] \qquad (8)$$

$$TQL = \sum_{j=1}^{nb} \left[x_j \frac{(P_i^2 + Q_i^2)}{V_i^2} \right] \qquad (9)$$

Initially, a flat voltage profile is assumed at all nodes i.e., 1.0 p.u. The branch powers are computed iteratively with the updated voltages at each node. In the proposed load flow method, powers summation is done in the backward sweep and voltages are calculated in the forward sweep [12].

After obtaining the voltage values at all nodes voltage deviation index (VDI) is calculated by equation (10), assuming rated voltage as 1.0pu:

$$VDI = \sum_{i=0}^{N} \frac{|V_{rated} - V_i|^2}{V_{rated}} \qquad (10)$$

The main objectives are to enhance voltage profile and reduce system losses, with help of equation (8) & equation (10) an algorithm is developed to achieve the above objectives by optimally allocating capacitor units in distribution system.

4. Artificial Bee Colony Algorithm (ABC)

Artificial Bee Colony (ABC) algorithm, developed by Karaboga for optimization of numerical problems in [10], replicates the clever foraging act of swarm of honey bees. In ABC algorithm, the community of artificial bees is classified into three groups of bees and they are employed bees, onlookers and scouts. An assumption is made such that there is only one artificial employed bee for each food source. The role of Employed bees is to go to their food source around hive and come back to hive and perform a waggle dance on the dance area. The employed bee whose food source has been abandoned / discarded becomes a scout bee and it again starts finding a new food source. The role of onlookers is to watch the waggle dances performed by employed bees and select a food sources based on dances. Initially food sources are offered for all employed bees i.e. number of employed bees is equal to number of food sources. Each onlooker analyse the dance performed by employed bees and selects one of their food sources based on the dances and then goes to that source. After choosing a neighbour food source around that, onlookers estimates its nectar amount. Abandoned food sources are obtained and are replaced by new food sources discovered by scout bees. The best food source obtained so far is displayed. Flowchart of the proposed method depicted in Figure 2.

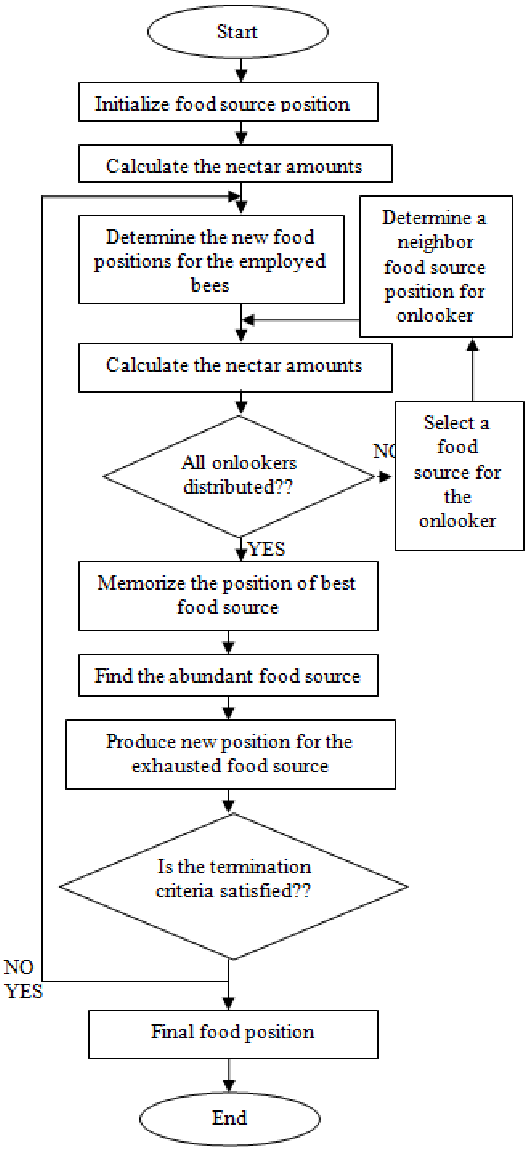

Figure 2: Flowchart of ABC algorithm

5. Test Results

To study the proposed method, IEEE 33 bus system and practical 116 bus system are simulated in MATLAB. The base values of the system are taken as 11kV and 100MVA. First the load flow analysis is carried out without connecting any capacitor units, system losses and voltage magnitude at all nodes are obtained. Losses of both IEEE 33 bus system and practical 116 bus system are tabulated in Table 1.

Table 1: Base case system losses

Losses	IEEE 33 Bus System	Practical 116 Bus System
Active power loss	210.0756KW	915.5021KW
Reactive power loss	142.5337KVAr	707.3342KVAr

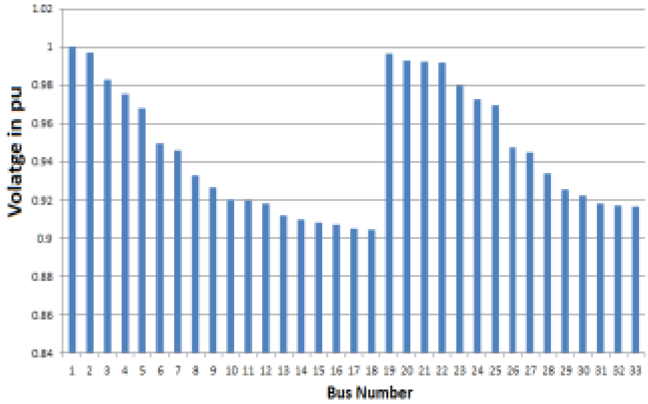

Figure 3: Voltage profile of IEEE 33 bus system

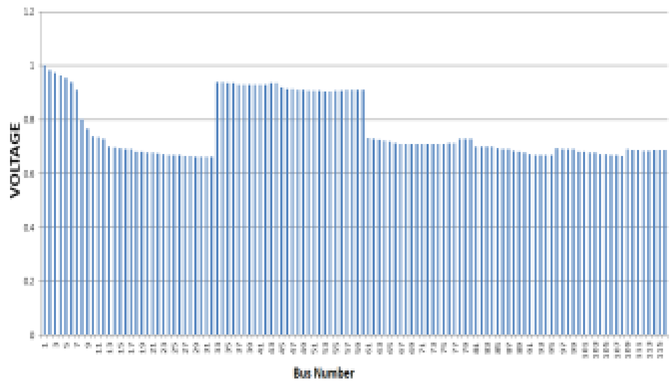

Figure 4: Voltage profile of Practical 116 bus system

Figure 3 and Figure 4 represents the voltage profile of IEEE 33 bus system and practical 116 bus system respectively, it can be seen that many buses have voltage values below the lower voltage limit and minimum voltages in both the systems are tabulated in Table 2.

Table 2: Minimum voltage in the system

-	IEEE 33 Bus System	Practical 116 Bus System
Bus No.	18	32
Voltage(PU)	0.9042	0.6614

Thus to improve the system voltage profile and to reduce losses Artificial Bee Colony algorithm is developed for optimally allocating capacitor units. Table 3 shows the optimal size and optimal location of capacitor units for IEEE 33 bus system.

Table 3: Optimal allocation of Capacitor units

	Capacitor Location	Capacitor Size
IEEE 33 Bus System	30	1750KVAr
	14	500 KVAr
Practical 116 Bus System	14	1810 KVAr
	48	360 KVAr

The obtained values of capacitor units are installed in respective systems (In IEEE 33 bus system capacitors of capacities 1750KVAr and 500KVAr are placed at buses 30 and 14 respectively, in practical 116 bus system capacitors of capacities 1810KVAr and 360KVAr are placed at buses 14 and 48 respectively). To check the performance of system load flow analysis is once again carried out after installing capacitor units optimally referring Table 3. The results are tabulated below.

Table 4: System losses with optimally allocated capacitor units

Losses	IEEE 33 Bus System	Practical 116 Bus System
Active power loss	154.0708KW	391.0954KW
Reactive power loss	106.4203KVAr	302.1676KVAr

From Table 4 it is evident that losses in system are effectively reduced by 26.7% in IEEE 33 bus system and in practical 116 bus losses are reduced by 57.28 %.

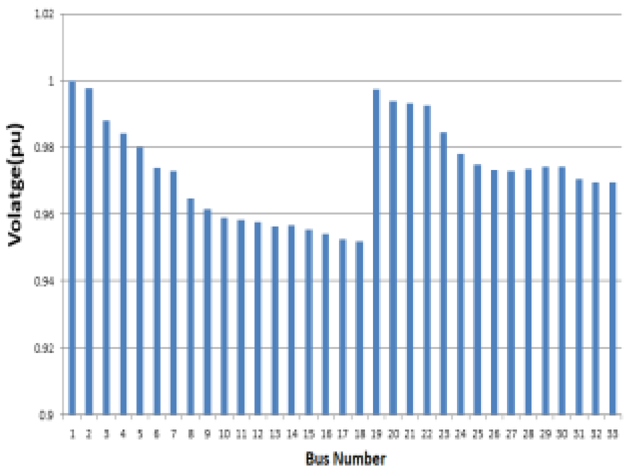

Figure 5: Voltage profile of IEEE 33 bus system with Capacitor units

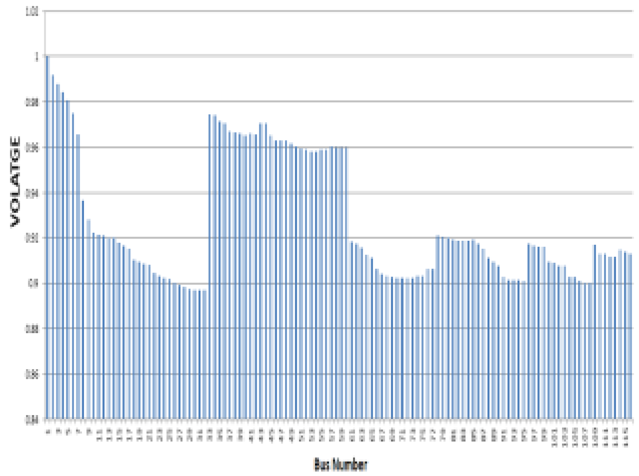

Figure 6: Voltage profile of practical 116 bus system with Capacitor units

Figure 5 and Figure 6 represent the voltage profile of IEEE 33 bus system and practical 116 bus system respectively. The minimum voltages in system are tabulated in Table 5.

Table 5: Minimum voltage in the system after Capacitor units placement

-	IEEE 33 Bus System	Practical 116 Bus System
Bus No.	18	32
Voltage(PU)	0.9519	0.8969

Thus on optimal allocation of capacitor units the voltage profile of the system is considerably improved and maintained within the limits. Figure 7(a & b) shows the comparison of voltage profile of both systems with and without capacitor units.

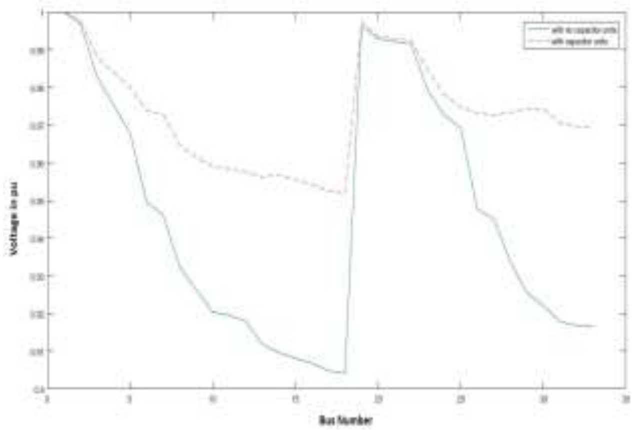

Figure 7(a): Voltage profile of IEEE 33 bus system without & with Capacitor units

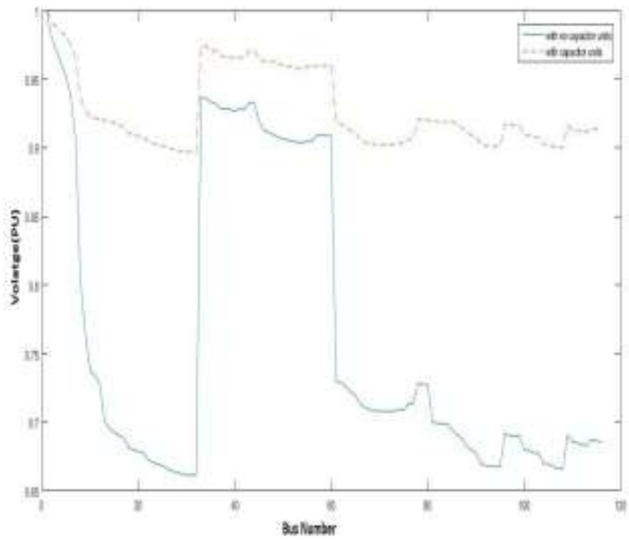

Figure 7(b): Voltage profile of Practical 116 bus system without & with Capacitor units

The solid line represents voltage profile of system without capacitor units and the dash line represents voltage profile of the system with optimally allocated capacitor units.

6. Conclusion

Capacitor has the potential to play a major role in line power flow and voltage conditions on the radial distribution system. The operating conditions of a power system after connecting capacitor unit can change significantly as compared to the base case. Therefore the planning of shunt capacitors installations should be optimal in terms of placement and capacity for maximum system benefits.

In the present paper, a new population based artificial bee colony algorithm (ABC) is used to solve optimal capacitor allocation problem to enhance voltage profile and minimize the losses in distribution system. Simulations are carried on IEEE 33 bus system and practical 116 bus distribution system. The simulation results show that the inclusion of capacitor, effectively improve voltage profile and considerably reduce the losses in a distribution system.

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