Voltage Profile Enhancement of Distribution Networks using PSO approach

[1]Divesh Kumar, [2]Satish Kansal
[1]Research Scholar, [2]Associate Professor
[1]Electrical Engineering Department
[1]IKGPTU, Kapurthala, India

Abstract : **This paper proposes the particle swarm optimization (PSO) technique to find the optimal placement of multiple capacitors in the radial distribution networks for enhancement in voltage profile of the distribution networks. The capacitors have been widely used in power system to reduce the power losses, improve the voltage sag, and increase the distribution feeder capacity. Capacitors provide reactive power required to low power factor loads, thereby decreasing the line current that reduces the active power loss of the line. The optimal size and location of capacitors are determined using the exact loss formula to minimize the distribution loss. The proposed technique is tested on standard 33-bus, 69-bus test systems.**

Keywords: Capacitor, optimal size, optimal location, power loss, PSO

I. Introduction

OBJECTIVE of power system operation is to meet the demand at all the locations within power network as economically and reliably as possible. The traditional electric power generation systems utilize the conventional energy resources, such as fossil fuels, hydro, nuclear etc. for electricity generation. The operation of such traditional generation systems is based on centralized control utility generators, delivering power through an extensive transmission and distribution system, to meet the given demands of widely dispersed users. Nowadays, the justification for the large central-station plants is weakening due to depleting conventional resources, increased transmission and distribution costs, deregulation trends, heightened environmental concerns, and technological advancements. Distributed Generations (DGs), a term commonly used for small-scale generations, offer solution to many of these new challenges [1]. The capacitor placement problem could naturally be formulated as a mixed integer optimization problem. Various algorithms are used to solve the problem. For example, heuristic constructive algorithm has been presented in [2], in which the integer variables are represented by sigmoid function. Another heuristic method has been adopted to obtain a near optimal solution for realistic sized systems, with an objective of minimizing harmonic levels, losses and capacitor costs [3]. This method has been extended to take unbalanced load into consideration in [4]. Ant colony search algorithm has been used in [5] to study the optimal placement of capacitor as well as the optimal feeder reconfiguration problem in the distribution system. Various objectives have been proposed for the optimal placement of capacitor. The objective function of minimizing the economic cost subject to voltage limits, sizes of installed capacitors at each bus, and power quality limits of harmonics has been considered in [6]. The impacts of capacitor placement on distribution system reliability have been considered in [7] by defining two objective functions. The first one is the sum of reliability cost and investment cost, and the second one is the sum of reliability cost, cost of losses and investment cost. Mixed integer non-linear programming has been suggested by D. O. Leonardo et al. [8] for capacitor placement as well as for reconfiguration in order to achieve the objective of minimum energy loss operation of a radial distribution network. M.A.S. Masoum et al. [9] applied GA to minimize the cost of power loss and capacitor bank. The solution has been achieved considering various constraints like voltage limit, number and size of capacitors. Baran and Wu [10] presented a method using mixed integer programming for the optimal placement of capacitor. Various other artificial intelligence techniques such as fuzzy logic, PSO and ant colony optimizations have also been used as tools for solving optimal capacitor allocation [11, 12and 163] to minimize the system loss, improvement in voltage profiles and other economic benefits. Recently, S.P. Singh et al. [12] employed the optimal placement of capacitors both switched and variable in the distribution system to minimize the real power loss and maximize the saving using PSO technique.

Most of the approaches presented so far model the optimal placement of single or multiple capacitors to minimize the losses only. However optimal placement of multiple capacitors being integrated into distribution systems to enhance the voltage profile of distribution networks by the application of PSO based technique.

The paper is organized as follows: Section II presents brief summary of location and sizing issue for reduction of line losses and improvement of voltage profile. Proposed PSO technique for optimal sizing of Capacitors at optimal locations is introduced in section III. Section IV presents the numerical results of the proposed approach, interesting observations along with discussions. Finally, the major contribution and conclusions are summarized in section V.

II. Proposed Methodology

The total power losses will be formulated as based on real power loss in the system is given by (1).This formula is popularly referred as “Exact Loss” formula [13].

$$Min\ P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j + P_iQ_j\right)\right] \quad \text{... (1)}$$

Where,

$$\alpha_{ij} = \frac{R_{ij}}{V_iV_j}Cos\left(\delta_i - \delta_j\right) \qquad \beta_{ij} = \frac{R_{ij}}{V_iV_j}Sin\left(\delta_i - \delta_j\right)$$

and

$Z_{ij} = r_{ij} + jx_{ij}$ are the ij^{th} element of [Z*bus*] matrix

$$P_i = P_{Gi} - P_{Di} \quad \text{and} \quad Q_i = Q_{Gi} - Q_{Di}$$

P_{Gi} & Q_{Gi} are power injection of generators to bus
P_{Di} & Q_{Di} are the loads.
P_i & Q_i are active and reactive power of the buses.

B. Objective Function

The objective is to determine the optimum size and location of capacitor to improve the voltage profiles and minimization of line losses of the networks using (1) while meeting the following constraints.

- The network power flow equation must be satisfied.
- The American National Standards Institute (ANSI) standard C84.1-1989 has stipulated that voltage variations in a distribution system should be controlled within the range of -13% to 7% [14],

$$V_{\min} \le V_i \le V_{\max}$$
$$\forall_i \in \{\ buses\ of\ the\ networks\ \} \quad \text{... (2)}$$

.

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population-based optimization technique which provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called pbest), and according to the experience of a neighboring particle (This value is called gbest), made use of the best position encountered by itself and its neighbor [15].

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand \times \left(pbest_{id} - s_{id}^{k}\right) + c_2 rand \times \left(gbest_{id} - s_{id}^{k}\right) \quad \text{... (3)}$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$S_{id}^{k+1} = S_{id}^{k} + v_{id}^{k+1}, \quad i = 1,2,3,....n,\ and\ d = 1,2,3,.....m. \quad \text{... (4)}$$

The following weight function is used:

$$\omega_i = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{k_{\max}}.k \quad \text{... (5)}$$

Where,

ωmin and ωmax are the minimum and maximum weights respectively. k and kmax are the current and maximum iteration. Appropriate value ranges for C1 and C2 are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for ωmin and ωmax are 0.4 and 0.9 [16] respectively.

The position and velocity of the ith particle has been considered as Xi and Vi respectively, these values are initialized according to (4) and (3), i.e., randomly generates an initial population (array) of particles with random positions and velocities on dimensions

(Locations of Capacitors, Sizes of Capacitors) in the solution space. For single capacitor placement, the dimensions of search space of the particle will be 2, i.e. [1x2]. The first column represents the location and second column represents the size of capacitor. For two Capacitor placements, the dimension of search space of the particle will be 4, i.e. [1x4]. The first two column will represents the Capacitor locations and third and fourth column represents the Capacitor sizes respectively and so on. In this work, the numbers of particle are taken 10 and number of iteration is taken as 500 in the present work. Evaluate the minimum real power loss with specified number of Capacitors and find the fitness value. PSO is a metaheuristic as it makes few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. The PSO-based approach for solving the optimal placement of multiple capacitors for improvement in voltage profiles and to minimize the loss takes the following steps:

Step 1: Input line and bus data, and bus voltage limits.

Step 2: Calculate the loss using distribution load flow based on backward sweep-forward sweep method.

Step 3: Randomly generates an initial population (array) of particles with random positions and velocities on dimensions (Locations of capacitors & Sizes of capacitors) in the solution space. Set the iteration counter k = 0.

Step 4: For each particle, find voltage profile after placing the combination. If the bus voltage is within the limits as given, evaluate the total loss using (1). Otherwise, that particle is infeasible so set it to base case.

Step 5: For each particle, compare its objective value with the individual best. If the objective value is lower than Pbest, set this value as the current Pbest, and record the corresponding particle position.

Step 6: Choose the particle associated with the minimum individual best Pbest of all particles, and set the value of this Pbest as the current overall best Gbest.

Step 7: Update the weight, velocity and position of particle using (5), (3) and (4) respectively.

Step8: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index k = k + 1, and go back to Step 3.

Step 9: Print out the optimal solution to the target problem. The best position includes the optimal locations and sizes of multiple capacitors and the corresponding fitness value representing the minimum total real power loss.

IV. NUMERICAL RESULTS

A. Test systems

The proposed methodology as described in section II & III is tested on two different test systems. The first system used in this paper is a 33-bus radial distribution system with total load of 3.72 MW and 2.3 MVAr [17] and the second one is 69-bus radial distribution system with a total load of 3.80 MW and 2.69 MVAr [18]. The proposed PSO technique has been developed in MATLAB environment to run load flow, calculate losses and optimal sizes of multiple capacitors. The maximum number of capacitor units installed is assumed to be three and the total capacity of the capacitor units is equal to the total load plus line losses.

B. Simulation Results

(i) 33-Bus test system:

Table I shows the total active power losses are 211 kW for 33-bus test distribution systems for base case i.e without Capacitor. When optimum size of 1.23MVAr capacitor is placed at bus number 30, then the power losses are reduced to 151.41kW and the improvement in voltage profile of the system is shown in Fig. 1. The reduction in line losses with the placement of two and three capacitor are 32.73% and 34.42% respectively. The enhancements in voltage profile of the system with two and three capacitor placement are shown in Fig.2 and Fig.3 respectively.

Table 1 Multiple capacitor placement by PSO approach of 33-bus system

Case	Installed Capacitor Schedule (MVAr)				Ploss (kW)	Loss Reduction (%)
No Cap					**211**	**0.00**
One Cap.	Bus	30				
	Size	1.23			151.41	28.24
Two Cap.	Bus	12	30			
	Size	0.43	1.04		141.94	32.73
Three Cap.	Bus	13	24	30		
	Size	0.36	0.51	1.02	138.37	34.42

It is observed that as the number and total installed capacity of capacitor units increases, the improvement in voltage profiles and reduction in line losses of the test system also increases.

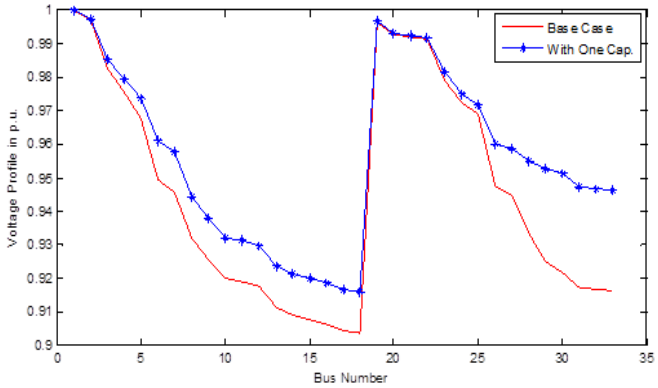

Fig.1 Voltage Profile with Single Capacitor.

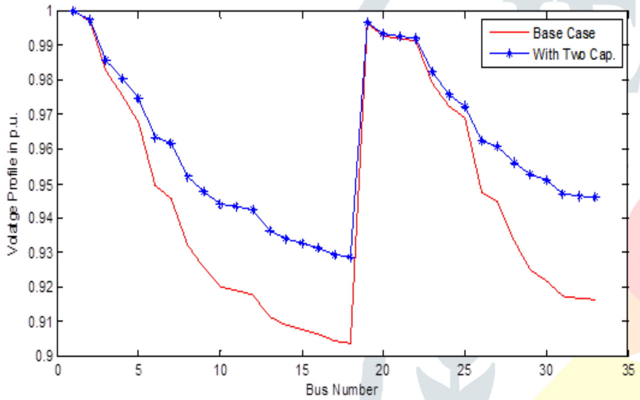

Fig.2 Voltage Profile with Two Capacitor

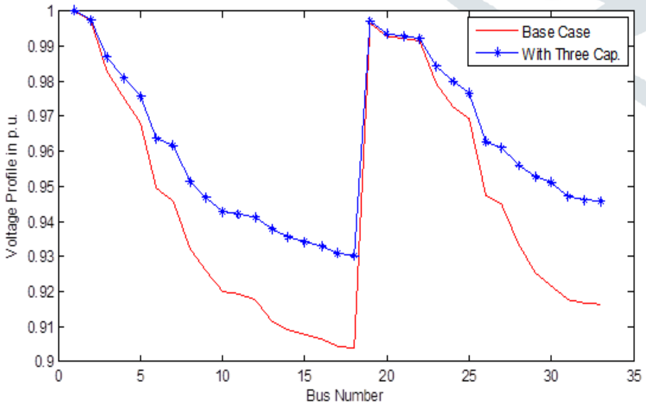

Fig.3 Voltage Profile with Three Capacitor

(ii) 69-Bus test system:

The optimal placement of capacitors ranging from one to three and the reduction in line losses are given in Table-II. The line losses are 225kW without the placement of capacitor. The enhancement in voltage profiles of 69-bus distribution system by the placement of one, two and three capacitors of optimal sizes at optimal locations are shown in Fig.4 to Fig.6 respectively.

Table 2 Multiple capacitor placement by PSO approach

Case	Installed Capacitor Schedule (MVAr)				Ploss (kW)	Loss Reduction (%)
No Cap					**225**	**0.00**
One Cap.	Bus	61				
	Size	1.29			152.1	32.40
Two Cap.	Bus	18	61			
	Size	0.35	1.24		146.5	34.88
Three Cap.	Bus	11	18	61		
	Size	0.33	0.25	1.19	145.2	35.45

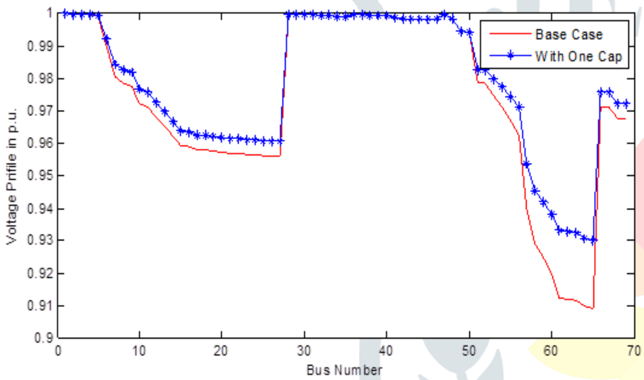

Fig.4 Voltage Profile with Single Capacitor

It is observed that as the installation of number of capacitors in the system, the voltage profile of the system improves more significantly.

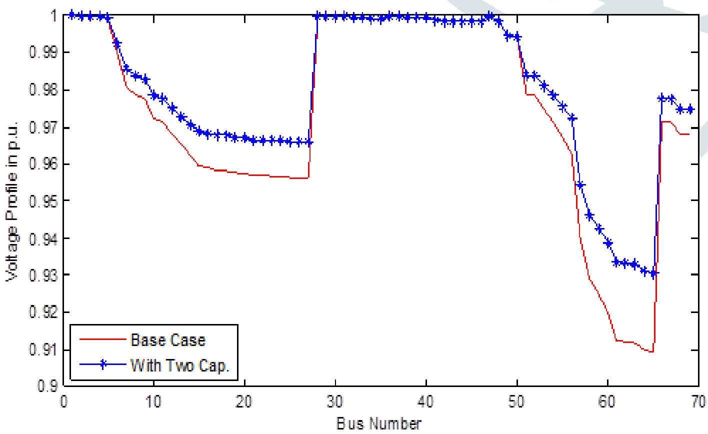

Fig.5 Voltage Profile with Two Capacitor

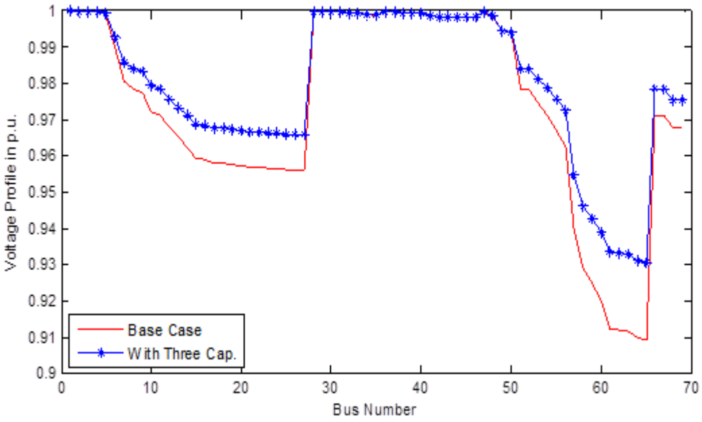

Fig.6 Voltage Profile with Three Capacitor

V. CONCLUSION

This paper has presented the allocation of optimal placement of multiple capacitors in the radial distribution networks for enhancement in voltage profile of the distribution networks. The optimal size and location of capacitors are determined by the application of PSO based technique. The proposed PSO approach for optimal placement of multiple capacitors not only improves the voltage profile of the systems but also minimize real power losses with satisfaction of the permissible voltage limits. In the age of integrated grid, the placement and analysis of multiple capacitors give guidance for optimal operation of power system.

REFERENCES

[1] S. Kumar, Ph.D. Dissertation, Optimal Placement of Distributed Generation in Distribution networks, IIT Roorkee, EED, 2014.
[2] C. da Silva, S. Carneiro, E. J. de Oliveira, J. de Souza Costa, J. L. Rezende Pereira, and P. A. N. Garcia, “A Heuristic Constructive Algorithm for Capacitor Placement on Distribution Systems,” IEEE Trans. Power Syst., vol. 23, no.4, pp. 1619-1626, November 2008.
[3] B. Gou and A. Abur, “Optimal capacitor placement for improving power quality,” Proceedings of IEEE/PES Summer Meeting, vol.1, pp. 488-492, July 1999.
[4] G. Carpinelli, P. Varilone, V. Di Vito, and A. Abur, “Capacitor placement in three-phase distribution systems with nonlinear and unbalanced loads,” IEE Proc. Gener. Transm. Distrib., vol. 152, pp. 47-52, 2005.
[5] C. Chung-Fu, “Reconfiguration and Capacitor Placement for Loss Reduction of Distribution Systems by Ant Colony Search Algorithm,” IEEE Trans. Power Syst., vol. 23, pp. 1747-1755, 2008.
[6] M. Ladjavardi and M.A.S. Masoum, “Genetically Optimized Fuzzy Placement and Sizing of Capacitor Banks in Distorted Distribution Networks,” IEEE Trans. Power Del., vol. 23, pp. 449-456, 2008.
[7] A.H. Etemadi and M. Fotuhi-Firuzabad, “Distribution system reliability enhancement using optimal capacitor placement,” IET Gener. Transm. Distrib., vol. 2, pp. 621-631, 2008.
[8] D. O. Leonardo W, C. Sandoval Jr, D. O. Edimar J, Pereira JLR, Silva Jr Ivo C, and C. Jeferson, “Optimal reconfiguration and capacitor allocation in radial distribution systems for energy losses minimization,” Elect. Power and Energy Syst., vol. 32, no.8, pp. 840–848, 2010.
[9] M.A.S. Masoum, M. Ladjevardi, A. Jafarian, and E.F. Fuchs, “Optimal placement, replacement and sizing of capacitor banks in distorted distribution networks by genetic algorithms,” IEEE Trans. Power Del., vol.19, no.4, pp. 1794-1801, October 2004.
[10] M. E. Baran and F. F. Wu, “Optimal capacitor placement on radial distribution systems,” IEEE Trans. Power Del., vol. 4, no.1, pp. 725-734, January 1989.
[11] S.M. Kannan, A.R.G. Monica, and S.M.R. Slochanal, “Fuzzy Logic Based Optimal Capacitor Placement on Radial Distribution Feeders,” IEEE Trans. Power Syst., vol.3, no. 2, October 2008.
[12] S.P. Singh and A.R. Rao, “Optimal allocation of capacitors in distribution systems using particle swarm optimization,” Elect. Power Syst. Res., vol. 43, pp.1267–1275, 2012.
[13] Elgerd IO, Electric energy system theory: an introduction, McGraw-Hill; 1971.
[14] H.L.Wills, Power Distribution Planning Reference Book. New York: Marcel Deckker, 2004.
[15] Kennedy J., Eberhart R., “Particle Swarm Optimizer,” IEEE International Conference on Neural Networks , Perth(Australia), IEEE Service Centre Piscataway, NJ, IV, pp1942-1948, 1995.
[16] Eberhart R.C.and Shi Y., “Comparing inertial weights and constriction factor in particle swarm optimization,” proceedings of the 2000 International congress on Evaluating computation, San Diego,Calfornia, IEEE service center, Piscataway, NJ, pp 84-88, 2000.
[17] M.A. Kashem, V. Ganapathy, G.B. Jasmon, M.I. Buhari, “A novel method for loss minimization in distribution networks”, Int. Conference on Electric Ulitity Deregulation and Restructuring and Power Technology, London, April 2000.
[18] M. Baran, F.F. Wu, Optimal capacitor placement on radial distribution systems, IEEE Trans. Power Deliv.4 (1),pp.725-734.1989