Optimal Allocation of Capacitor in Radial Distribution System

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Abstract: **Shunt Capacitors in power systems are generally used for reactive power compensation. The optimal location of capacitors plays a vital role for reducing real power losses in distribution system. This paper considers the problem of optimal allocation and sizing of capacitors in a radial distribution network. A power loss sensitivity technique is used to determine the optimal location and sizing of capacitors in distribution system. The objective function is formulated to reduce real power losses and to improve voltage profile of the system. The performance of the proposed method has been tested on IEEE 69-bus standard system. Test results are also compared with other optimization techniques and found that the proposed method is more effective and has higher capability in finding optimum solution.**

Keywords: **Shunt capacitor, radial distribution system, loss sensitivity, real power loss.**

1. INTRODUCTION

Distribution network in power system has losses as the major issue which causes electrical energy dropping as well as absorbs the capacity of transformers and transmission line. As load (burden) increases during peak times, the losses increases accordingly. There are various methods to minimize real power losses in distribution system like network restructuring, shunt capacitor placement, distributed generation etc.

The reactive power compensation by using capacitor placement method is commonly used method which minimize active and reactive power losses, improves the power factor, maintains required voltage profile. In addition to these benefits proper selection of capacitor, with appropriate size and location, is required in order to avoid abnormal conditions such as parallel resonance issues, unacceptable power factor etc. Optimal location and size of capacitor is the recent area of research. The researchers have been developed so many technique to solve the capacitor placement problem in radial distribution system. Carpinelli, G et. al proposed a technique for optimum location and size of shunt capacitor in three - phase distribution system with non linear and unbalanced load. Number of capacitor units and their size for placement is represented by the coded variables [1]. Biswas, S. et. al. [2] developed an algorithm in order to reduce losses and to solve power quality issues by considering voltage and power factor constraints. Hamid Reza Esmaeilian et al. [3] proposed Backward-forward power flow and GA for optimal placement of capacitor. Deepti Sharma et al. [4] developed an objective function in order to minimize net annual power loss and cost of shunt capacitor using genetic algorithm. However power quality issues and reliability indices are not addressed. Calderaro et al. [5] formulate an objective function to solve capacitor placement problem for Wind Farm Power Plant. Cost function includes energy cost and cost of capacitor. Neha Goyal et al. [6] originated a Genetic algorithm based population search method for optimal allocation of capacitors which is utilized to evaluate power loss in IEEE 33. Anwar S Siddiqui et al. [7] presented fuzzy logic based technique for capacitor placement which is used to reduce losses in 10 bus radial distribution system. Pravin Chopade et al. [8] presented optimal capacitor placement module for OCP simulation using genetic algorithm and ETAP software. A. A. Ahmed et al. [9] introduced a particle swarm optimization (PSO) as a tool for power loss reduction study. Khalil, T.M. et al. [10-11] proposed a simple modification into the binary PSO to search in selected space. The proposed technique is implemented on three feeder distribution system and Taiwan Power Distribution Company for reconfiguration and power loss minimization. A new selective particle swarm optimization (SPSO) is introduced to solve optimal capacitor placement problem. Saeid Jalilzadeh et al. [12] introduced a Shuffled frog leaping and PSO technique for optimal placement of capacitor in IEEE 45 bus radial system. Reza Sirjani et al., [13] proposed a heuristic optimization technique for optimal placement and selection of capacitor size in radial distribution network. The obtained results are compared with ant colony, fuzzy logic, genetic algorithm, harmony search, particle swarm optimization, tabu search, simulated annealing and hybrid methods. Meng Zhang. et.al. [14] proposed a technique in which loss sensitivity factor is used to determine the location for optimal capacitor placement. Mahdi Mozaff ari Legha et al. [15] discussed artificial Bee Colony (ABC) algorithm for capacitor placement to improve the network efficiency.

In this paper a power loss sensitivity technique has been proposed in. A objective function is formulated to minimize active power loss of the system. The optimal location of shunt capacitor unit is determined by loss sensitivity factor. The kVAr rating of capacitor is calculated by power loss sensitivity technique. The proposed technique is tested on IEEE 69 bus standard system. The obtained results are compared with various algorithms to confirm its credibility.

2. PROBLEM FORMULATION

The objective of optimal allocation of capacitor in radial distribution system is to minimize the real power losses subjected to certain operating constraints and load pattern.

Mathematically, the objective function of the problem is described as:

$$\min f = \min (P_{loss}) \quad (1)$$

Where, P_{loss} is the real power loss of the system.

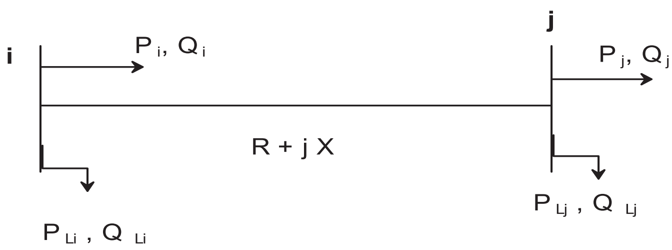

Figure 1. Power flow in a feeder

The power loss of the line section connecting buses i and j is computed as:

$$P_{Loss} = R.\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (2)$$

$$Q_{Loss} = X.\frac{(P_i^2+Q_i^2)}{|V_i|^2} \quad (3)$$

Where, Pi and Qi are the real and reactive powers flowing out of bus i, and P_{Li} and Q_{Li} are the real and reactive load powers at bus i. Pj and Qj are the real and reactive powers flowing out of bus j, and P_{Lj} and Q_{Lj} are the real and reactive load powers at bus j The resistance and reactance of the line section between buses i and j are denoted by R and X respectively.

The constraints are:

(i) The voltage must be kept within the specified limits at each bus:

$$V_{min} \leqslant V \leqslant V_{max}$$

Where V_{min}, V_{max} are the lower and upper limits of bus voltage respectively.

(ii) The apparent power flow through each branch must be less than the maximum apparent power admissible for the line and it may be expressed as follows:

$S_i \leqslant S_{imax}$ i=1,2,3……n

where n is the number of branches, Si is the apparent power flow of the ith branch and Simax is the maximum apparent power flow limit of the ith branch.

(iii) Capacitors are available in discrete sizes. So, shunt capacitors are to be dealt with multiple integers of the smallest capacitor size available and it may mathematically be expressed as:

$L\,Q_{ci} \leqslant LQS$ L= 1; 2; . . . nc

Where nc number of shunt capacitors, Qci is the kVAr rating of the capacitor installed at the i^{th} bus and QS smallest capacitor size available.

3. SOLUTION METHODOLOGY

Real power loss sensitivity factors are calculated for determining the candidate buses for placement of capacitor. Estimation of these sensitive nodes helps in reducing the search space. Installation of capacitor reduces the real power loss and reactive power losses. Therefore, combined loss sensitivity is calculated based on reactive power loss.

$$\frac{\partial P_{Loss}}{\partial Q} = \frac{2Q_i R}{|V_i|^2} \quad (4)$$

$$\frac{\partial Q_{Loss}}{\partial Q} = \frac{2Q_i X}{|V_i|^2} \quad (5)$$

Combined loss sensitivity with respect to reactive power is given by

$$\frac{\partial S_{Loss}}{\partial Q} = \frac{\partial P_{Loss}}{\partial Q} + j\frac{\partial Q_{Loss}}{\partial Q} \quad (6)$$

Loss sensitivity factors are calculated from load flow analysis and values are arranged in descending order for all the lines.

Computational procedure:

Step 1: Run load flow program for base case.

Step 2: Calculate loss sensitivity factor using Eq. (4) & (5) of each bus and rank the sensitivity in descending order and form priority list.

Step 3: Select the bus which has highest priority and place capacitor at that bus.

Step 4: Change the size of capacitor in "small" step and calculate real power loss for each size by running load flow program.

Step 5: Store the size of capacitor that gives the minimum real power loss.

Step 6: Repeat Step 3 to 5 to find more location of capacitor.

Step 7: Place the capacitor of obtained size at optimal location and once again perform load flow.

4. SIMULATION AND RESULTS

In this section case studies are presented to show the effectiveness of the proposed technique. The proposed technique is tested on IEEE 69 bus radial distribution system.

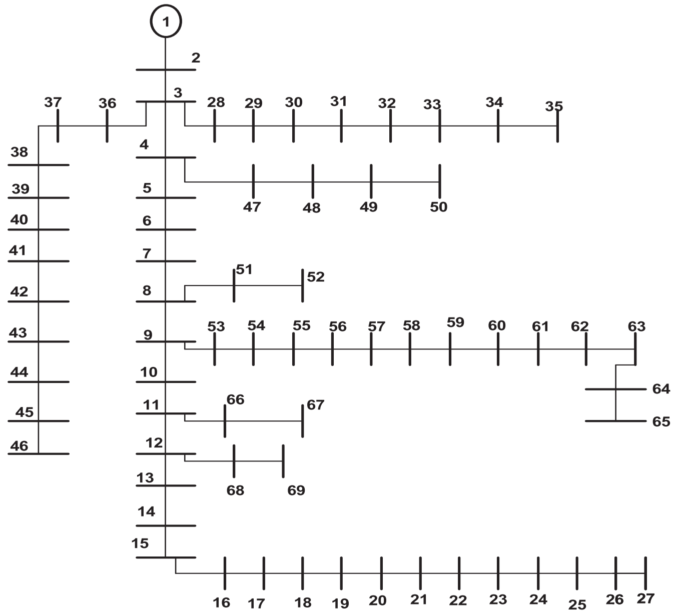

Fig. 2 IEEE 69 bus distribution system

The proposed method is implemented using MATLAB 10 software running on a computer with Intel_ Core_ i3 CPU @ 2.27 GHz and 4 GB of RAM.

Table 1 Comparison of simulation result of 69 bus system after Capacitor placement

Without DG	Power Loss (kW)	225
	Minimum bus Voltage (p.u.)	0.9092
With DG	Capacitor size (bus no.) in kVAr	270 (21) 750 (61) 490 (64)
	Total Capacitor size in kVAr	1510
	Power Loss (kW)	147.19
	Minimum bus Voltage (p.u.)	0.932
% loss reduction		34.60%

The total real and reactive power demands in IEEE 69-bus system are 3.8MW and 2.69 MVAr respectively [16]. The real power loss without capacitor placement is 225 kW. The simulation results of placement of multiple capacitor units are presented in table (I)

The losses without compensation are 225 kW and are decreased to 147.19 kW due to shunt capacitor units as shown in Table 1. Moreover, the minimum voltage has been also enhanced from 0.9092 p.u to 0.932 p.u. The comparison of system voltages before and after capacitor allocation is shown in Fig. 3 . The value of total installed capacity of capacitor bank is 1510 kVAr.

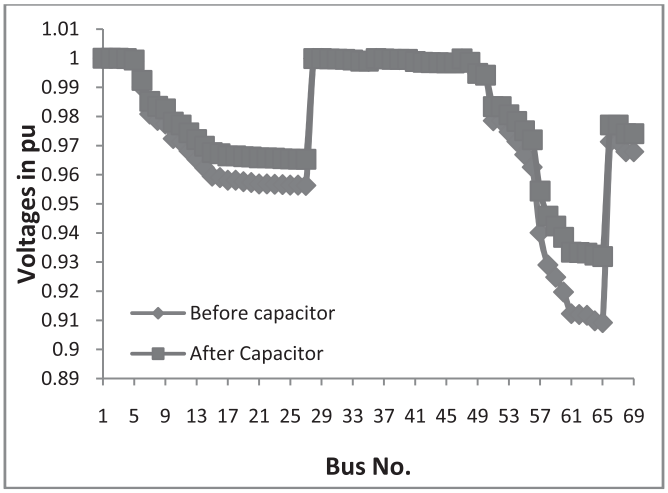

Fig. 3. Comparison of bus voltage before & after capacitor placement for 69 bus system

The results of the proposed method are compared with the results of fuzzy-GA method [17], differential evolutionary algorithm [18], Particle Swarm Optimization technique [19] and Heuristic based method [20] and is shown in Table 2. It is observed from table 2 that the proposed technique gives more loss reduction and better voltage profile than latest optimization techniques.

Table 2: Comparison of results of capacitor placement on 69 bus system

Technique	Total Capacitor size (kVAr)	Power Loss (kW)	% loss reduction	V_{min}. (pu)
Fuzzy GA [17]	1600	156.62	30.4	0.9369
DE [18]	1450	151.37	32.7	0.9311
PSO [19]	1621	152.48	32.23	0.931
Heuristic [20]	1800	148.48	34	0.9305
Proposed	1510	147.19	34.6	0.932

5. CONCLUSION

A new and efficient power loss sensitivity technique has been presented to solve capacitor placement problem. The loss sensitivity factors are used to determine the location of candidate bus. The proposed technique is used to determine the optimal locations and size of shunt capacitor to enhance the voltage profile and to reduce the real power losses. The methodology is tested on IEEE 69 bus system. By installing capacitor at all potential locations, the real power loss of the system has been reduced drastically and the voltage profile of the system is also enhanced. Comparative study in terms of capacitor size, real power loss and minimum bus voltage is carried out with latest optimization technique. Comparison of results is shown that the power loss sensitivity technique is capable of producing high-quality solutions.

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