Optimal Sizing & Siting of Capacitors in Radial Distribution System using Power Loss Sensitivity Technique

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Abstract: **The power distribution system has more real power losses than transmission system. Allocation of shunt capacitors in RDN acting a crucial role for reducing real & reactive power loss and also for enhancing bus voltages. This paper presents a power loss sensitivity technique to find out optimal size and location of shunt capacitors. The objective function is formulated to maximize net annual saving. The performance of the projected technique is experienced on 33 bus test distribution system. Obtain results are also compared with the results of other latest approaches and found that the proposed approach has superior ability in finding best solution.**

Keywords— **Radial distribution network (RDN), shunt capacitor, loss sensitivity technique.**

1. INTRODUCTION

Distribution systems has feeder and distributors. It connects high voltage transmission line and the low voltage consumers. Distribution systems are operated in radial structure. Various power loads like industrial, commercial, domestic, etc. are included in Radial Distribution Network (RDN). At remote end, the voltage level of RDN is very low and it has also very poor voltage regulation. Due to this, the quality of power supply and system stability has adverse effect. Because of huge inductive loads, the reactive power demand is high and hence this will cause poor voltage profile and increase power losses. Shunt Capacitors are coupled with distribution systems to get better voltage profile and to decrease the I^2R loss. The optimal location of shunt capacitors will minimize the active & reactive power losses and also maximize the net annual saving. Many researchers have been consistently worked on objective function of controlling voltage and reactive power and minimizing feeder losses.

In 1981, authors [1-2] proposed a unique method to maximize the gross savings along with curtailing the I^2R losses by inserting capacitors in RDN. In [3-5] authors solve the capacitor allocation problem as an optimization problem. Capacitor sizing problem was framed by the authors of [6] a non-linear programming problem. The author proposed a novel computational technique called Dist-Flow method to solve capacitor allocation problem [7]. Huang & Yang in 1996 utilized the Tabu Search (TS) method [8] to solve the issue regarding the size of capacitor and its optimum allocation for satisfying output. To minimize the losses radial distribution network, Goswami et al. [9] during September 1999 illustrated the maximization problem by implementing the heuristics technique. A genetic Algorithm (GA) based system approach was presented by Kalyuzhny et al. [10] to deduce a solution methodology for optimum capacitor allocation. Attia et-al [11] anticipated a integrated evolutionary algorithm for solving the capacitor allocation problem with cheap annual operating cost. Optimal allocation of capacitors problem has been solved by using Simulated Annealing (SA) and GA technique [12]. Priyanka Das, et-al.[13] presented Firefly algorithm (FA) to maximize net annual cost saving by installation of capacitor units. Raju et al. [14] used Direct Search Algorithm (DSA) for optimal sizing and siting of capacitor banks.

A power loss sensitivity technique has been proposed in this paper. The objective function is formulated to reduce annual energy cost of RDN. A loss sensitivity factor (LSF) is used to determine optimal position of shunt capacitor units. The rating of capacitor banks are calculated by power loss sensitivity technique. The proposed technique is experienced on 33 bus standard RDN. To assure its credibility, obtained results are compared with various algorithms.

2. PROBLEM FORMULATION

The objective function is to reduce the annual cost incurred due to energy losses and capacitor installation's cost, under certain operating constraints. It does not comprise with functional and repair costs of the capacitors.

Mathematical model of the problem can be expressed as [15]:

Min. f= Energy loss cost + Reactive power compensation cost

$$\text{Min. } f = K_1 * P_L * t + K_2 * C_n + K_3 * \sum_{i}^{Cn} Q_{ci} \quad (1)$$

The constraints are:

(i) The bus voltages of RDN must retain between limits

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

(ii) The total reactive power generated should not exceed the reactive power load of the system.

(iii) Capacitors are available in discrete sizes.

3. SOLUTION METHODOLOGY

In this paper, loss sensitivity factors (LSF) are calculated to locate the candidate bus. The bus which has highest value of LSF is used for capacitor placing. The algorithm of proposed method is used from [18].

4. SIMULATION AND RESULTS

The proposed approach has been applied to the 33 bus test distribution system as shown in figure 1. The total load of this test system is 3.715 MW and 2.3 MVAr respectively and base voltage is 12.66 kV [16]. The proposed method is implemented using MATLAB software.

The values of various constant used in equation (1) are: Cost of energy loss (K_1)= \$0.06/kwh, capacitor's installation cost for single unit (K_2)= \$1000, Cost of per kVAr capacitor bank (K_3)=\$3, C_n=Number of capacitors, P_L= real power loss after compensation, Q_{ci}= Rating of each capacitors, t=8760 hrs.

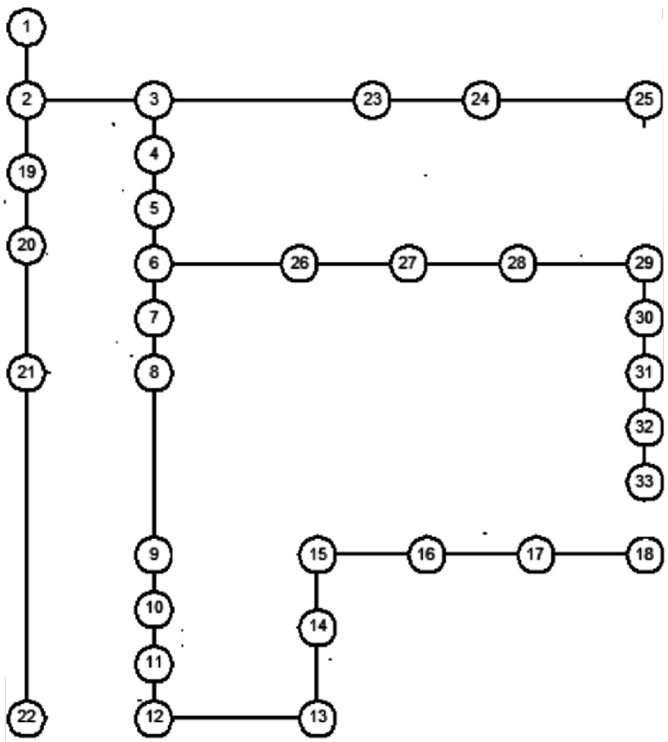

Figure 1: Single line diagram of IEEE 33 bus distribution system

The real power loss without capacitor placement is 202.7 kW. The simulation results of placement of multiple capacitor units are presented in table (1). By proposed method first 3 candidate buses are chosen for capacitor installation. The losses without compensation are 202.7 kW and are reduced to 138.77 kW as shown in table 1

Table 1: Comparison of annual loss saving for various techniques at nominal load for 33 bus system

Item	**Without Capacitor**	**SA [17] -2015**	**IP [17] -2015**	**Proposed**
Total Loss	202.7	151.7	171.8	138.77
% Loss Reduction		25.12	15.24	31.50%
Min. Voltage	0.9131	0.959	0.95	0.944
Optimal Size (Location) in kVAr		450 (10)	450 (9)	550 (14)
		900 (14)	800 (29)	480 (30)
		350 (30)	900 (30)	330 (32)
Total kVAr	-	1700	2150	1060
Annual Cost (\$/year)	106540	87860	99738	79991
Net Saving (\$/year)	-	**18680**	**6802**	**26550**
% Saving	-	17.53%	6.30%	25%

The minimum voltage is also increased from 0.9131 p.u. to 0.944 p.u. The improvement in system voltage profile due to installed capacitors is shown in fig. 2. The kVAR value of installed capacitor bank is 1060 kVAr which is very less as compared to other optimization methods. The annual cost saving (\$/year) is also maximum in proposed method as shown in figure 3. The % net annual saving in cost is 25 % which is maximum compared to other algorithms i.e. Simulated Annealing (SA) [17] and interior point algorithm (IP) [17].

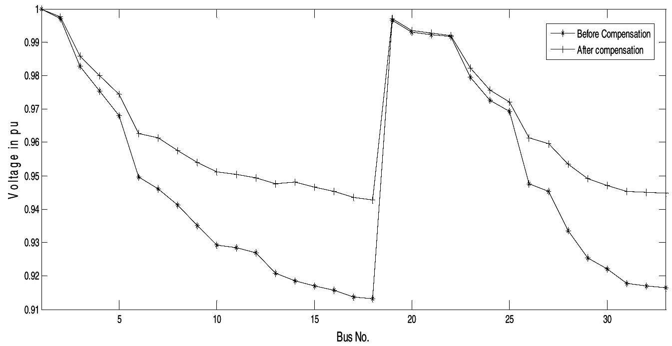

Fig. 2. Comparison of bus voltage before & after capacitor placement for 33 bus system

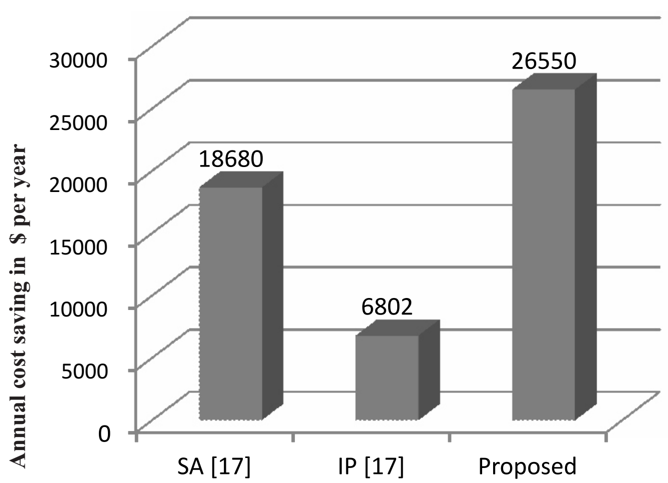

Figure 3: Comparison of annual cost saving (\$/year) of various approaches

5. CONCLUSION

In this paper, power loss sensitivity approach has been presented to solve sizing and siting problem of shunt capacitor in RDN with the objective of minimizing the cost due to energy loss and reactive power compensation. The effectiveness of proposed technique has been implemented on 33 bus test distribution system.

Computational results shown that the performance of Power loss sensitivity technique is better than the latest methods compared. The annual installation cost of capacitor bank is $7080 whereas the annual cost saving due to energy loss and capacitor banks is $ 26550. Therefore, the cost of shunt capacitor bank will be recovered in first 4 months of installation.

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