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Optimal Capacitor Placement for Loss Reduction in Radial Distribution Feeder

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Abstract *: A distribution system is an interface between the bulk power transmission system and the consumer. Among these systems, radial distribution system is popular because of low cost and simple design. In radial distribution feeders, the voltage at buses reduces and loss increases as moved away from the substation due to insufficient amount of reactive power. The reactive power requirement is provided by the shunt capacitor banks. The most important benefit of capacitor placement is loss reduction, voltage profile improvement, increment of power factor and freeing up the power system capacity. Optimal capacitor placement in distribution systems has been studied for a long time. It is an optimization problem which has an objective to define the optimal sizes and allocations of capacitors to be installed. This paper presents an approach for optimal capacitor banks placement in radial distribution feeders for loss reducction.*

Keywords ***-*** *capacitor banks, distribution system, optimal capacitor placement, radial distribution feeder, reactive power, loss reduction.*

I. INTRODUCTION

The increase in power demand and high load density makes the operation of power system complicated. To provide more capacity margin for the substation to meet load demand, system loss minimization and voltage profile improvement techniques are employed [1]. An important method of controlling bus voltage is by placement of shunt capacitor banks at the buses at both transmission and distribution levels, along lines or at substations and loads. Essentially capacitors are a means of supplying VARs at the point of installation [2]. HT shunt capacitor banks provide the fixed reactive compensation in the network [3]. The purpose of capacitors is to minimize the power and energy losses and to maintain better voltage regulation for load buses and to improve system security. The amount of compensation provided with the capacitors that are placed in the distribution network depends upon the location, size and type of capacitors placed in the system [4].

The problem of optimal reactive power dispatch is directly concerned not only with service quality and reliability of supply, but also with economy and security of the power system. Therefore, the power system reactive power optimization problem result directly influences the power system stability and power quality [5]. A large variety of research work has been done on capacitor placement problem in the past. Om Prakash Mahela *et al.* [6] presented different techniques of capacitor placement in transmission and distribution system to reduce line losses and voltage stability enhancement. References [7]-[9] have considered optimal capacitor placement in networks using fuzzy logic, [10]-[11] have considered Genetic Algorithm, [12] has considered successive quadratic programming method, [13] has considered the tabu search, [14] has considered the Game Theory, [15]-[16] have considered Ant Colony Optimization and [17] has considered Body Immune Algorithm for optimal Placement of Capacitors.

In this paper, a method is proposed to search for optimal HT shunt capacitor placement in radial distribution feeder. The objective function is to reduce the power loss in the feeder. The constraint is voltage limits. The proposed method is tested on the 9-bus IEEE system using MATLAB for optimum capacitor places and sizes. The simulation results show a considerable reduction in active power losses in the radial distribution feeder under study on the placement of capacitors. The active power losses are calculated for different arrangement and sizing of capacitors.

II. OPTIMAL CAPACITOR PLACEMENT AND SIZING PROBLEM FORMULATION

The power flow evaluation includes the calculation of bus voltages and line flows of a network. Associated with each bus, there are four quantities to be determined: the real power, the reactive power, and the voltage magnitude and phase angle. Fig. 1 shows the single line diagram of 9-bus IEEE system.

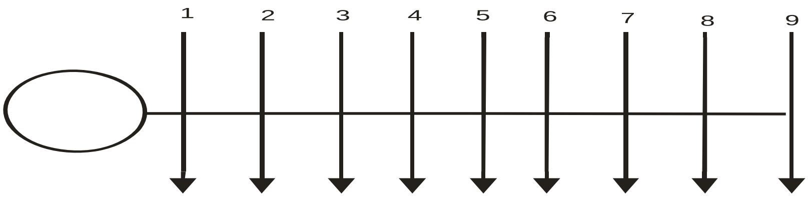

Fig. 1. IEEE 9-bus system

The complex power at the i^th bus is given by the relation

$$P_i - jQ_i = V_i^* I_i \quad (1)$$

Where

P_i : Load active power
Q_i : Load reactive power
V_i : Voltage at i^{th} bus
I_i : Load current at i^{th} bus

The bus voltage and line losses can be calculated by the Gauss-Seidel iterative method employing the following formula [18]:

$$V_i^{(k+1)} = \frac{1}{Y_{ii}}\left(\frac{P_i - jQ_i}{V_i^{*(k)}} - \sum_{\substack{n=1 \\ n\neq i}}^{m} Y_{in} V_n\right) \quad (2)$$

Where

$V_i^{(k)}$: Voltage of bus i at the k^{th} iteration
P_i , Q_i : Bus active and reactive power of bus i
$Y_{im} = y_{i,m}$ for $i \neq m$
and $Y_{ii} = y_{i,m-1} + y_{i,m+1} + y_{ci}$ for i = m

The power loss in the line section between buses i and i+1, at power frequency can be computed by:

$$P_{loss\,(i,i+1)} = R_{i,i+1}\left[|V_{i+1} - V_i|.\left|y_{i,i+1}\right|\right]^2 \quad (3)$$

Where

$y_{i,i+1} = \frac{1}{(R_{i,i+1}+X_{i,i+1})}$: Admittance of the line section between buses i and i+1.
$R_{i,i+1}$: Resistance of the line connecting bus i and i+1.
$X_{i,i+1}$: Reactance of the line connecting bus i and i+1.

The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} < |V_i| < V_{max} \quad (4)$$

Where $|V_i|$ is voltage magnitude of i^{th} bus. V_{min} is bus minimum voltage limit. V_{max} is bus maximum voltage limit. The maximum and minimum voltages limits in the suggested model used are the voltage limits specified by the Indian Electricity Grid Code as given in table-1.

TABLE 1
MAXIMUM AND MINIMUM VOLTAGE LEVEL AS PER IEGC*

Voltage-(KV rms)		
Nominal	**Maximum**	**Minimum**
765	800	728
400	420	380
220	245	198
132	145	122
110	121	99
66	72	60
33	36	30

*Source L-1/18/2010-CERC [19].

The purpose of placing compensating capacitors is to obtain the lower total power loss and bring the bus voltages within their specified values. The total power loss is given by the relation:

$$P_{loss} = \sum_{i=0}^{mn} P_{loss\,(i,i+1)} \qquad (5)$$

III. Objective Function Formulation

The three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is minimizing the loss and voltage deviation. This function is:

$$F = W_1 \times P_{loss} + W_2 \sum_{i=1}^{m} \{max(0, V_{min} - V_i)^2 + max(0, V_i - V_{max})^2\} \qquad (6)$$

Where

W_1 : Objective function coefficient for power loss

W_2 : Objective function coefficient for voltage deviation.

P_{loss} : Total loss in transmission system.

V_{min} : Minimum permissible bus voltage.

V_{max} : Maximum permissible bus voltage

IV. Proposed Computational Algorithm

The capacitor placement and sizing is provided by calculation of objective function. The simulation has been done on IEEE 9-bus system shown in Fig. 1. In the first case, power flow is calculated without capacitor placement. In the other cases, the power flow is calculated with capacitor placed at different locations. The objective function is calculated in each case, if this function has the tendency of convergence then capacitors are again placed and process is repeated and if there is no tendency of convergence then location and size of capacitors is suggested. The algorithm used for the capacitor placement in this paper is shown in Fig. 2.

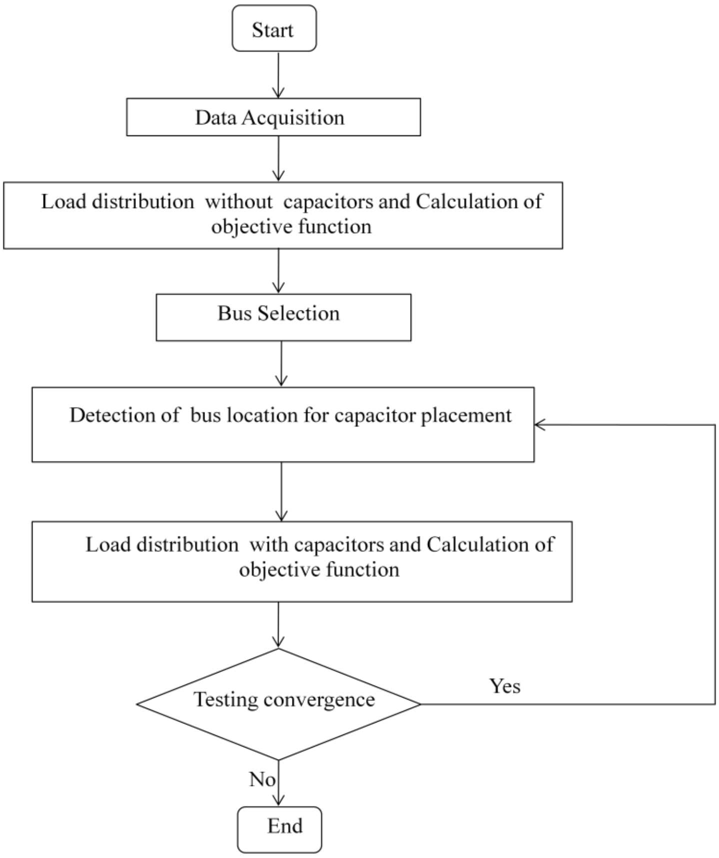

Fig. 2. Flow Chart of Proposed Algorithm for Capacitor placement in Radial Distribution System

V. SIMULATION RESULTS AND DISCUSSION

The optimal location and sizing is provided by the objective function. The simulation using MATLAB is carried out on IEEE 9-bus system shown in Fig. 1. The steps of algorithm shown in Fig. 2 are used. The line data set and network buses data set for the 9-bus IEEE system as shown in Table-2, and Table-3 respectively are used [20].

TABLE 2
THE 9-BUS IEEE NETWORK LINE DATA SET

Sending End Bus	Receiving End Bus	R (ohm)	X (ohm)
0	1	0.1233	0.4127
1	2	0.0140	0.6050
2	3	0.7463	1.2050
3	4	0.6984	0.6084
4	5	1.9831	1.7276
5	6	0.9053	0.7886
6	7	2.0552	1.1640
7	8	4.7953	2.7160
8	9	5.3434	3.0264

TABLE 3
THE 9-BUS IEEE NETWORK BUSES DATA SET

Bus No.	Active Power (P) in KW	Reactive Power (Q) in KVAR
1	1840	460
2	980	340
3	1790	446
4	1598	1840
5	1610	600
6	780	110
7	1150	60
8	980	130
9	1640	200

For simulation purposes different cases have been considered. In first case, power flow calculations have been conducted on the network without capacitors. In second and subsequent cases, power flow calculations have been conducted on the network with capacitors of different ratings installed on the different buses. The five different cases with capacitors of different ratings placed at different buses of the radial feeder are studied. The active power losses in the feeder without capacitor placement for first case and with capacitor placement for subsequent cases are shown in Table. 4. The percentage power losses in the feeder in different cases of study are also shown in the Table. 4.

TABLE 4
POWER FLOW RESULTS OF STUDY WITH AND WITHOUT CAPACITORS

Proposed Cases	Active Power Losses (KW)	Active Power Losses (%)
1	1821.75	14.73
2	939.41	07.59
3	807.72	06.53
4	654.60	05.26
5	550.62	04.45
6	397.06	03.21

The size of capacitors at different bus locations in different cases of study are shown in Table. 5. In first case capacitors are not installed at any bus. The sixth case is the result of optimal capacitor placement at different bus locations in the proposed study with optimal capacitor sizing in the IEEE 9-bus radial distribution feeder.

TABLE 5
CAPACITOR SIZES AT DIFFERENT BUS LOCATIONS IN DIFFERENT CASES OF STUDY

Bus No.	Case-1 (Without Capacitors)	Case-2 (Capacitors in KVAR)	Case-3 (Capacitor in KVAR)	Case-4 (Capacitors in KVAR)	Case-5 (Capacitors in KVAR)	Case-6 (Optimal Capacitor in KVAR)
1	0	100	40	60	80	80
2	0	100	50	50	20	30
3	0	100	50	50	30	30
4	0	500	1600	1450	1400	1350
5	0	100	100	100	80	90
6	0	100	50	50	40	50
7	0	50	0	20	0	0
8	0	100	50	60	10	0
9	0	100	100	120	50	40

We conclude from the table (4) that the amounts of active power losses have been reduced when we place some capacitors at appropriate buses in the network. The voltage profile also improves with the placement of capacitors. The optimal sizes of capacitors for minimum active power losses and the minimum voltage deviation from the systems values are obtained in case-6. The suggested optimal sizing of capacitor placement in the network at different bus locations is shown in Table. 5 as case-6 with optimal capacitors..

VI. CONCLUSION

The presented results in this paper have shown that the power loss in radial distribution feeder reduces significantly on the placement of capacitors of proper size at appropriate places. The power losses in the feeder were 14.73% without any capacitors in the network. The losses have reduced to 3.21% after optimal placement of capacitors. The optimal placement of capacitors in the radial distribution feeder under study has resulted in saving of 11.52% power.

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BIOGRAPHIES

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