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Optimal Capacitor Placement to Maximize Voltage Profile in Radial Distribution System

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ABSTRACT

This paper undertakes the problem of loss reduction in a radial distribution System. The objective is to determine the suitable size and location of the capacitors to be placed on a radial distribution system. The objective function is to increase of saving due to reduction of energy losses thereby taking into consideration cost of capacitor. In this part, load flow solution for the radial feeder is obtained and followed by a loss sensitivity analysis to select the candidate capacitor installation in load areas. It obtains the optimal value of capacitors to be installed. The solution algorithms have been developed into and tested on a 34-bus radial distribution system. In the capacitor placement issues, those day to day capacitor operating constraints, load profiles, feeder capacities and allowable voltage limits at light load and peak load levels are all considered while the investment cost and energy loss are minimized. In the proposed method, objective functions and obstacles are represented as antigens. In this part, load flow solution for the radial feeder is gathered and followed by a loss sensitivity analytical statistics to select the candidate capacitor installation in light and high load areas.

Keywords: Radial Distribution System (RDS), Capacitor placement, Loss reduction, Loss sensitivity factor (LSF),

1. INTRODUCTION

The statically data's of the customer failure of most utilities shows that the distribution system makes the greatest contribution to the unavailability of supply to a customer or load. Therefore, the distribution system plays a vital area of activity. It is known that losses in a distribution system are very high due to various factors. The reason for decrease of losses in power systems is considered one of the important issues in the economy of all countries in the world. Because of the growing effort to reduce system losses, many ideas have been implemented in recent years referring to optimal distribution planning. The loss reduction in distribution systems has assumed greater importance recently since the trend towards distribution automation will need the most effective operating scenario for economic variations. In [1] an Immune Algorithm (IA) based optimization approach for solving the capacitor placement problem is proposed. In [2] objective function is to have maximization of saving due to reduction of energy losses thereby considering cost of capacitor. In [3] Voltage instability in power systems is analyzed by a monotonic voltage drop, which is slow at first and becomes abrupt after some period and occurs when the system is unable to meet the increasing power demand. In [4] a new and efficient approach for capacitor placement in radial distribution systems that determine the optimal locations and size of capacitor with an objective of maximize the voltage profile and reduction of power loss. In [5] a novel method to find the best locations for capacitor placement in unbalanced radial distribution networks and simple GA is used to calculate the optimal sizing of the capacitor bank.

In [6] a new method using fuzzy and Real Coded Genetic Algorithm for the placement of capacitors on the primary feeders of the radial distribution systems to decrease the power losses and to maximize the voltage profile. In this connection, Capacitor banks are placed on Radial Distribution system for Power Factor Correction, Loss Reduction and Voltage profile improvement.

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2. IN EMENTED RED ONE OF THE MOST REPORTED WORKS

In [1] an Immune Algorithm (IA) based optimization approach for solving the capacitor placement problem is proposed. In the capacitor placement issue, those practical capacitor operating constraints, load profiles, feeder capacities and allowable voltage limits at various load levels are all considered while the investment cost and energy loss are minimized. Through the genetic evolution, an antibody that most fits the antigen becomes the solution. In this IA computation, a calculation process is also embedded to guarantee the diversity. The process stagnation can be thus better prevented. In [2] objective function is to have maximization of saving due to reduction of energy losses thereby considering cost of capacitor. The methodology used divides the problem into two sections. In first section, load flow solution for the radial feeder is calculated and followed by a loss sensitivity analysis to select the candidate capacitor installation locations. In second section, Genetic algorithm is used as an optimization tool, which obtains the optimal value of capacitors to be installed.

The solution ideas have been implemented into and tested on a 33-bus radial distribution system. In [3] Voltage instability in power systems is analyzed by a monotonic voltage drop, which is slow at first and becomes abrupt after some period and occurs when the system is unable to meet the increasing power demand. The operating conditions of the present day distribution systems are near to the voltage stability boundaries due to the ever increasing load demand. Capacitors are placed in distribution systems to minimize line losses and maximize the voltage profile. In [4] a new and efficient approach for capacitor placement in radial distribution systems that determine the optimal locations and size of capacitor with an objective of maximize the voltage profile and reduction of power loss. The solution methodology has two sections: in first section the loss sensitivity factors are used to select the candidate locations for the capacitor placement and in second section a new algorithm that employs Plant growth Simulation Algorithm is used to determine the optimal size of capacitors at the optimal buses determined in part one.

In [5] a novel method to find the best locations for capacitor placement in unbalanced radial distribution networks and simple GA is used to calculate the optimal sizing of the capacitor bank. These function formulated includes the energy cost, capacitor installation cost and purchase cost, so that the fitness function is to be maximized for the net saving. In [6] a new methodology using fuzzy and Real Coded Genetic Algorithm for the placement of capacitors on the primary feeders of the radial distribution systems to decrease the power losses and to maximize the voltage profile. A two-stage methodology is used for the optimal capacitor location problem. In the first stage, fuzzy approach is used to determine the suitable capacitor locations and in the second stage, Real Coded Genetic Algorithm is used to locate the sizes of the capacitors.

3. DESCRIPTION OF 34-BUS SYSTEM

The various sizes of the capacitors corresponding to maximum annual savings are determined In [7] a novel approach that determines the optimal location and ratings of capacitors on radial distribution systems to increase voltage profile and decrease the active power loss. Capacitor placement & sizing are done by Loss Sensitivity Factors and Particle Swarm Optimization respectively. The subject of Loss sensitivity Factors and can be considered as the new approach in the area of distribution systems. Loss Sensitivity Factors offer the vital information about the various nodes for capacitor placement. These factors are calculated using single base case load flow study.

In [1] the energy losses and the voltage profiles with & without capacitor placement are listed. Note that in Table I & Table III, the results were obtained through the ten-year planning horizon. For each scenario, the simulations were performed ten times. Then, the results were obtained by calculating their averaged values.

In [2] the compensated and uncompensated test system i.e. 33 bus system Considered. It has been found that by keeping the capacitor at highly sensitive points (i.e. buses 7, 12, 16, 27) huge benefit can be obtained. Comparison of results of the compensated and uncompensated RDS is formatted as shown in table 3.

In [3] the low value of reactive power compensation required to enhance voltage stability for different loading conditions for 33 node system are given in Table 4. The system minimum and maximum reactive power demands are 1150 kVAR and 2530 kVAR respectively. The suitable rating and type of capacitor banks required for 33 node system based on the variation of reactive power demands are given in Table 3. It compares, and the system losses before and after capacitor placement for different loading conditions.

Table 1
Power losses and voltage profiles

Test System Conditions		*Without Capacitor*	*With Capacitor*
Real	Light load	713.47	458.29
Power	Medium load	1848.35	1222.62
Losses (kW)	Peak load	3495.83	2295.04
Voltage	V_{min}	0.9101	0.9567
(p.u.)	V_{max}	1.0	1.0

Table 2
Real power losses and voltage profiles

Test System Conditions		*Without Capacitor*	*With Capacitor*
Real	Light load	713.47	449.15
Power	Medium load	1848.35	1214.53
Losses (kW)	Peak load	3495.83	2286.79
Voltage	V_{min}	0.9101	0.9592
(p.u.)	V_{max}	1.0	1.0

Table 3
Comparison between compensation and uncompensation parameter

parameters	*Uncompensated*	*Compensated*	
Minimum SystemVoltage (p.u.)	0.9041	0.9304	
Power Loss (kW)	177KW	104KW	
Loss reduction (%)	–	41.24%(73kW	
Buses and Capacitor size (kVAr)	–	7	250
		12	350
		16	250
		27	200
TotalCompensation	–	1050 kVAr	

Table 4
Performance of the PA for 33-node system

LoadLevel	*Before Capacitor Placement*			*After Capacitor Placement*		
	low L	*low V*	*Loss (kW)*	*L*	*low V*	*Loss (kW)*
Light	0.828	0.954	48.78	0.897	0.973	36.25
Medium	0.730	0.924	130.71	0.797	0.945	89.14
Full	0.667	0.904	210.97	0.781	0.940	146.25
Over	0.636	0.893	259.64	0.777	0.939	178.53

Checking the performance of this table clearly presents that the optimal capacitor placement enhances voltage stability, maximizes voltage profile and reduces the system losses.

In [4] the method is a 34-bus radial distribution system. This system has a main feeder and four laterals. The buses are placed according to their sensitivity value as {19, 22, 20, 21, 23, 24, 25, 26, and 27} indicated by the values. Top three buses are considered as optimal locations and the value of kVAr injected are 1200, 639, and 200 kVAr respectively. The power loss before and after capacitor placement are 221.67 and 161.07 kW. The low and high value of voltages before capacitor placements is 0.9417 p.u (bus 27) and 0.9941 p.u (bus 2) are maximized to 09731 p.u and 1.000 p.u after capacitor placement respectively at the buses 27 and 2. The *Nmax* value is tried from 2 to 80 bus shown in table 4.

In [5] the proposed algorithm is tested on IEEE 37 bus test system shown in table 6. The load data has modified with some changes and regulator is not included in the system. The line and load data are given in reference. The capacitor bank considered here is delta connected. The voltage profile with & without compensation of 37 bus URDS.

In [6] the proposed method is also tested on 37 bus test system and compared with the heuristic method [16] and Fuzzy Expert Systems (FES) approach [20], results obtained are more promising.

4. RESULTS OF 34 BUS SYSTEMS

4.1. Bus number and capacitor size

In [7] the proposed method is also tested on 34 bus test system and compared with the heuristic method [16] and Fuzzy Expert Systems (FES) approach [20], results obtained are more promising.

Table 5
Simulation Results of 34-Bus System

Items	*Un Compensated*	*Compensated*				
		Heuristicbased [19]		*PSO [21]*	*Proposed*	
Total losses (kW)	221.67	168.47		168.8	161.07	
Loss reduction (%)	–	23.999		23.850	27.337	
Optimallocations andSize in kVAR	–	26	1400	19	19	1200
		11	750	781	22	639
		17	300	22	20	200
		4	250	803	–	–
				20		
				479		
Total kVAr	–	2700		2063	2039	

Table 6
Voltage profile of 37 bus URDS

Description	*25 Node system*	
	Without compensation with	*compensation*
Total QC required (kVAR)	800	1400
Total reactive power release (kVAR)	–	48.13
Total reactive power Demand (kVAR)	2560.30	2512.17
Min. voltage (p.u)	0.9311	0.9566
Improvement of voltage regulation (%)	–	2.77
Total losses (kW)	150.1225	106.3117

In practice the capacitor size should be in discrete in value. With this in mind, for a 34 bus system, when buses 19, 22 and 20 are compensated by 800kvar, 800kvar and 450kvar instead of 781kvar, 803kvar and 479kvar respectively as shown in Table 8. The following values are based between bus number and values of reactors based on light and peak loads in order to reduce the losses and maximize the total kvar values.

4.2. Power loss with effect of line number and buses

The following values are based between the sending bus and receiving bus by choosing the appropriate line number thereby the percentage of power losses are taken into the considerations with the reference of suitable placement of capacitor values.

The above graph shows that the percentage of power loss by considering the line number and minimum losses in the 34 bus system for maximizing the voltage profile.

Table 7
Results for 34 bus system

Bus No	*Capacitor size inkVAr*
20	683
21	145
22	144
23	143
24	143
25	143228
Total kVAr	1629
Total power loss inkW (before)	221.7235
Total power loss inkW (after)	168.9548

Table 8
Results for 34 Bus Radial Distribution Systems

Heuristic based [16]		*FES based[20]*		*Proposed PSO based*	
Bus No	*kvar*	*Bus No*	*kvar*	*Bus No*	*kvar*
26	1400	24	1500	19	781
11	750	17	750	22	803
17	300	7	450	20	479
4	250	–	–	–	–
Total kvar 2700		Total kvar 2700		Total kvar 2063	
Power loss(kw) 168.47		Power loss(kw) 168.98		Power loss(kw) 168.8	

Table 9
Percentage in Power loss

Line Number	*Sending Bus*	*Receiving Bus*	*(%) Power Losses*
1	10	11	9.44
2	2	19	14.9
3	4	5	19.67
4	14	15	25.68
5	5	6	38.8
6	17	18	66.55

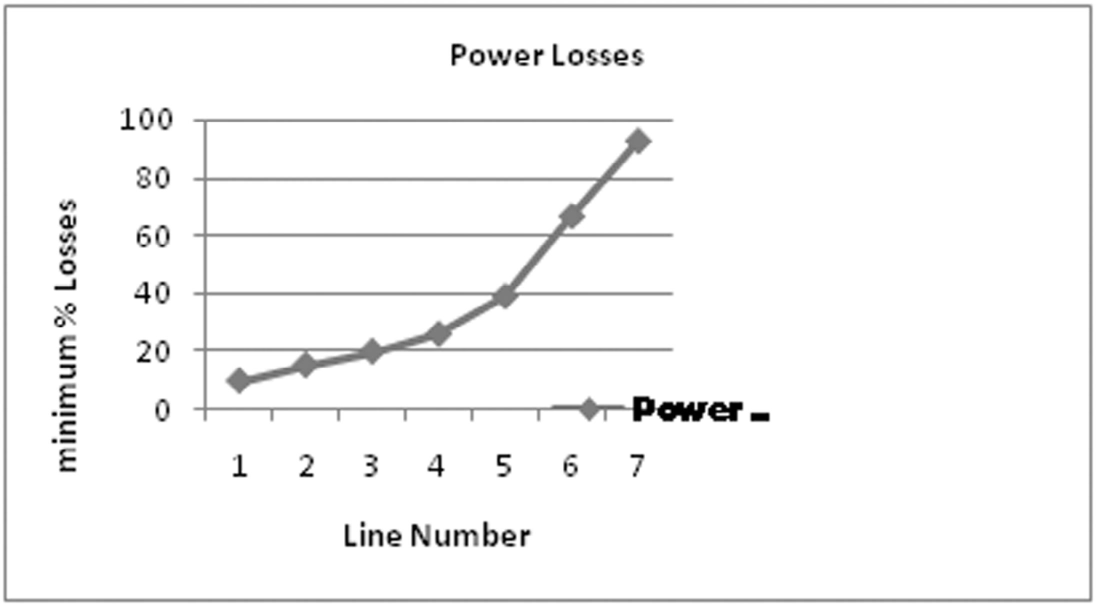

Figure 1: Percentage of power losses with respective distribution line number

Table 10
Percentage in maximum load variations

Line Number	*Sending Bus*	*Receiving Bus*	*(%) Power Losses*
1	2	3	44.82
2	3	4	62.62
3	6	7	84.16
4	16	17	61.03
5	13	14	92.67
6	30	31	99.8

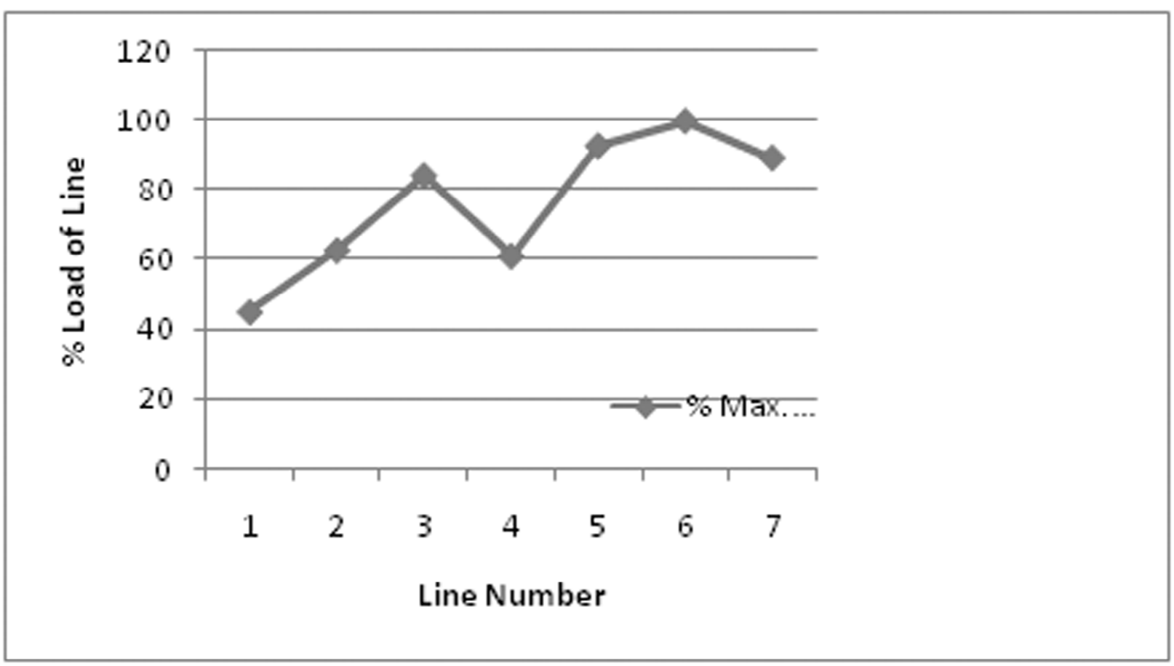

Figure 2: Percentage load of line

The Figure shows percentage load of line, which reflects the variation between power loss.

4.3. Power loss based with and without capacitor

Case (i) Without Capacitor

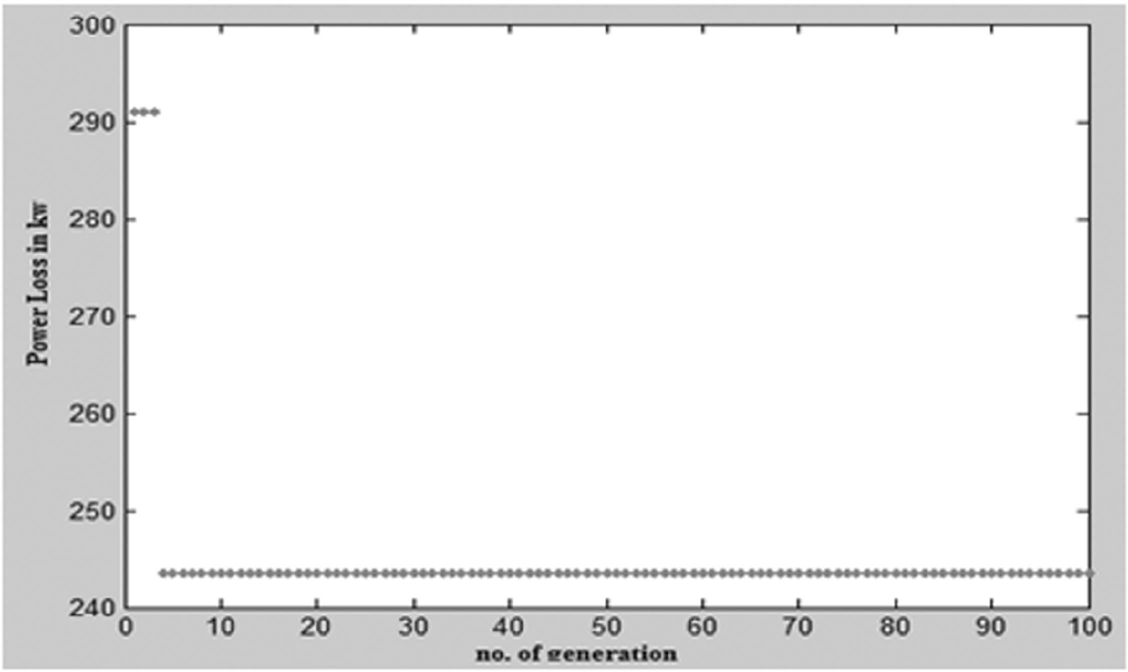

Figure 3: Power loss with respective no. of generation

Different optimal switching operations in the power loss with respect to generations of optimization algorithm.

Case (ii) With Capacitor

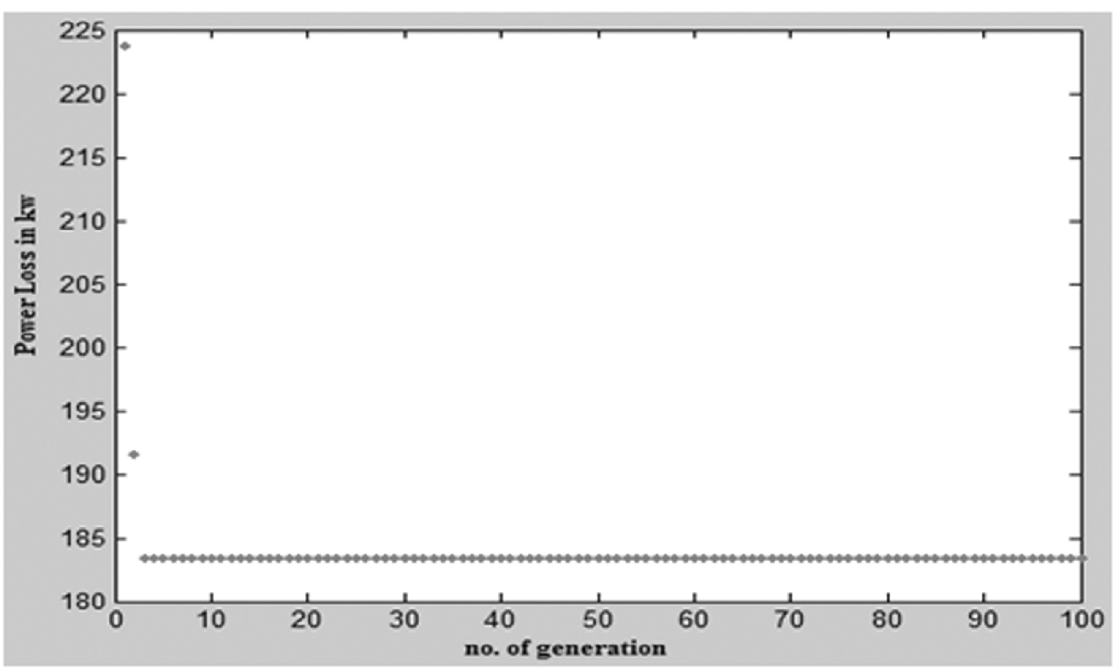

Figure 4: Power loss v/s no. of generation

The following figure reveals that the power loss in the generation unit by providing the capacitor in order to improve the voltage profile. Different optimum switching operation in power loss with respect to generation of optimization algorithm.

5. CONCLUSION

A test case of 34 bus system has been used and results demonstrate the improvement in voltage profile and reduction of the losses thereby improving net annual savings. This method places the capacitors at less number of places with optimum size and provides much net annual savings. It has been found that huge benefit can be obtained by placing the capacitors at highly sensitive nodes. The capacitor banks in order to improve voltage stability of radial distribution system have been developed. This method increases the voltage profile by appropriate placement of capacitor in the line number with respect to sending and receiving buses thereby enhancing voltage stability. By installing capacitors at all the potential areas, the total real power loss of the system has been reduced and bus voltages are improved. The main advantage of this proposed method is that it systematically finds the locations and size of capacitors to realize the maximum sizable reduction in active power loss and significant improvement in voltage profile.

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