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Capacitor Placement on Radial Distribution System Using Particle Swarm Optimization

Mrs.M.Bhavani.ME.
Assistant professor,
Anna Universsity
Regional Centre,
Madurai.

K.A.Murugan ,ME power
Management (PT),
Anna University
Regional Centre, Madurai.

***Abstract*: A distribution system is an interface between the bulk power system and the consumers. Among these systems, radial distribution systems are popular because of low cost and simple design. In distribution systems, the voltages at buses reduce when moved away from the substation and also the losses incurred are high. The reason for decrease in voltage and high losses is the insufficient amount of reactive power, which can be provided by the shunt capacitors. Minimization of active power loss is very essential and necessary to increase the overall efficiency of power system. Generally capacitors are used to supply reactive power to increase the voltage profile and reduce losses in the power system. The proper placement of capacitors is also important to provide that system capacitor costs and total power losses can be reduced. The aim of this paper is to identify the optimal location of capacitor using Particle Swarm Optimization (PSO) and compare results with Loss Sensitivity Factor (LSF).The ability of the proposed method has been tested on 33 bus IEEE standard radial distribution system.**

Keywords: Capacitor Placement, Loss Sensitivity Factor, Particle Swarm Optimization

I.INTRODUCTION

The electrical energy delivers from bulk substation to many services or loads are the networks called distribution system. Distribution systems are becoming huge and stretched too far leading to higher system losses and poor voltage regulation. In the radial distribution system, capacitors are installed at suitable locations for the improvement of voltage profile and to decrease the energy loss. It is estimated that as much as 13% of total power generation is dissipated as I2R losses in the distribution networks. Reactive currents flowing in the network constitute for a portion of these losses. By the installation of shunt capacitors, the losses produced by reactive currents can be reduced. This is also vital for power flow control, improving system stability, power factor correction, voltage profile management, and the reduction in active energy losses. Hence it is essential to find the optimal location and size of capacitors required to maintain a nominal voltage profile and to reduce the feeder losses. Hence there is a need to reduce the system losses. By minimizing the losses, the system may acquire longer life span and has greater reliability.

The general formulation of the volt/var design problem which involves the optimal real-time control of the ON/OFF switched capacitors and voltage regulators is given. The formulation is simplified through physically justifiable approximations. It is shown that the resultant formulation (decouples the volt and var problems. The two decoupled problems are expressed as two independent optimization problems. [1]The two decoupled problems are expressed as two independent optimization problems. The solution of the problems is given here (Analytical) [2]. P. K. Dash, S. Saha, and P. K. Nanda also introduced combinatorial algorithms as a means of solving the Capacitor Placement Problem and neural network technique and were investigated [6]. The main advantage of the PSO are summarized as follows easy implementation robustness to control parameters, simple concept and better computation efficiency when compared with other heuristic algorithms[12].In distribution system, heuristic search techniques are used to determine the optimum capacitor placement. In the heuristic approach proposed a small number of named sensitive nodes, critical nodes are selected for installing capacitors that optimize the net savings while achieving a large overall loss reduction

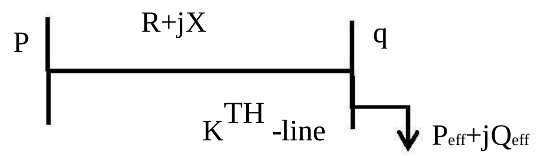
Shunt capacitors and voltage regulators are used to keep the voltage profile within the desired limit in the distribution system. The most economical mode of operation for the distribution system is ensured all the time, without violating any of the system voltages constraints [17].
Reduction of 1^2R loss is very essential to improve the overall efficiency of power delivery in distribution system. The 1^2R loss can be detached into two parts based on the active and reactive components of branch currents. Placing shunt capacitors are used to minimizing the loss associated with the reactive component of branch currents. This method first determines a sequence of nodes to be compensated by capacitors. The size of the optimal capacitor at the compensated nodes is then determined by optimizing the loss saving equation with respect to the capacitor currents [18]. The majority of the energy losses happen in the distribution and transmission systems. The losses in the power system are produced by reactive power current in the transmission lines. The reactive power is manufactured in the power generation sections and is engrossed transmission line by transferring. This problem can be rise up with production of power in vicinity of the consumers. Power capacitors are the main equipment that can produce reactive power needed by

consumers. Now, we do not need to transfer reactive power and which leads to term of distribution system improvement.

This paper presents a method for the placement of capacitors on radial distribution system to reduce the power loss and to improve voltage profile using PSO and compare their results with LSF.

II. SENSITIVITY ANALYSIS AND LOSS SENSITIVITY FACTORS

Consider a distribution line with an impedance R+jX and a load of Peff + jQeff connected between p and q buses as given below.



Active power loss in the kth line is given by, $I_K^2 * R[k]$ which can be expressed as,

$$P_{lineloss}[q] = \frac{(P_{eff}^2[q] + Q_{eff}^2[q]).R[k]}{(V[q])^2}$$

similarly the reactive power loss in the kth line is given by

$$Q_{lineloss}[q] = \frac{(P_{eff}^2[q] + Q_{eff}^2[q]).X[k]}{(V[q])^2}$$

Where, $P_{eff}[q]$ = Total effective active power supplied beyond the node 'q'

$Q_{eff}[q]$= Total effective reactive power supplied beyond the node 'q'

Now, both the Loss Sensitivity Factors can be obtained as shown below:

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * R[k])}{(V[q])^2}$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[q] * X[k])}{(V[q])^2}$$

A. *Candidate node selection using Loss Sensitivity Factors:*

From the base case load flows the Loss Sensitivity Factors (∂Plineloss / ∂Qeff) are calculated and the values are arranged in descending order for all the lines of the given system. (∂Plineloss / ∂Qeff) values arranged in descending order with respective buses are stored in vector bus position bpos[i]. The buses are to be considered for compensation is decided by descending order of elements of bpos[i]. The proposed Loss Sensitive Factors become very powerful and effective in capacitor allotment or placement and the sequence is purely governed by (∂Plineloss / ∂Qeff). The base case voltage magnitudes given by (norm[i] =v[i]/0.95) are considered to calculate the normalized voltage magnitude of bus bpos[i]. Capacitor placement at required candidate bus are

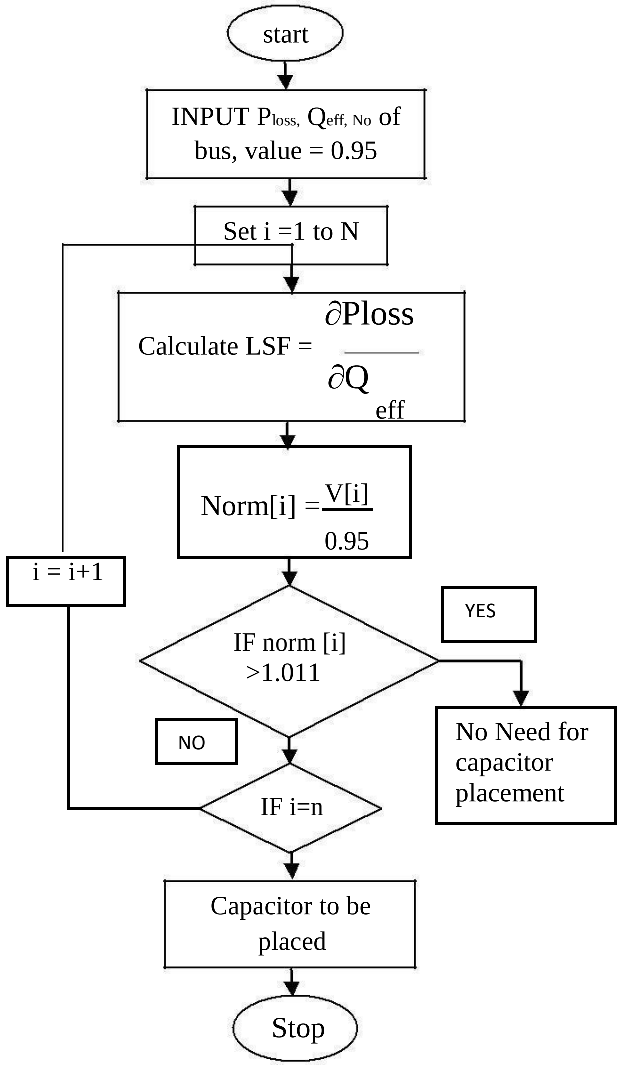


Fig.1. Flow chart for LSF

consider, whose bus norm[i] value is less than 1.01. norm[i] decide whether the bus needs Q compensation or not and Loss sensitivity Factors decide the sequence in which buses are to be considered for compensation placement. The rank bus vector offers the information about the possible potential or candidate buses for capacitor placement. Flow chart for LSF is shown in fig.1.

II. PARTICLE SWARM OPTIMIZATION

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Particle Swarm Optimization (PSO) is a technique used for optimization of continues non linear problems. The method was sighted through simulation of an interpreted social model. PSO has roots in two main methodologies maybe more obvious are ties to artificial life in general, and to bird flocking, fish schooling and swarming theory in particular. It is also related, however to evolutionary computation and has ties to both genetic algorithms and evolutionary programming. It requires only basic mathematical operators, and is computationally economical in terms of both memory requirements and speed. It conducts searches using a population of particles, corresponding to individuals. Each particle represents a Candidate solution to the capacitor sizing problem. In a PSO system, particles change their positions by flying around a multi dimensional search space until a relatively unchanged position has been observed, or until computational limits are exceeded. In social science context, a PSO system combines a social and cognition models.

Particle X(t): It is a k-dimensional real valued vector which represents the candidate solution. For an ith particle at a time t, the particle is described as $X_i(t)=\{X_{i,1}(t), X_{i,2}(t), \ldots X_{i,k}(t)\}$.

Population: It is a set of 'n' number of particles at a time t described as $\{X_1(t), X_2(t) \ldots X_n(t)\}$.

Swarm: It is an apparently shuffled population of moving particles that tend to cluster together while each particle seems to be moving in random direction.

Particle Velocity V(t): It is the velocity of the moving particle represented by a k-dimensional real valued vector $V_i(t)= \{v_{i,1}(t), v_{i,2}(t) \ldots\ldots v_{i,k}(t)\}$.

Inertia weight W(t): It is a control parameter that is used to control the impact of the previous velocity on the current velocity.

Particle Best (pbest): Conceptually pbest is similar to autobiographical memory, as each particle remembers its own experience. When a particle moves through the search space, it compares its fitness value at the current position to the best value it has ever reached at any time up to the current time. The best position that is associated with the best fitness arrived so far is termed as individual best or Particle best. For each Particle in the swarm its pbest can be resolved and updated during the search.

Global Best (gbest): It is the best position among all the individual pbest of the particle achieved so far.

Velocity Updation: Using the global best and individual best, the ith particle velocity in kth dimension is updated according to the following equation.

$$V[i][j] = K * (w * v[i][j] + C_1 * rand_1 * (pbestX[i][j] - X[i][j] + C_2 rand_2 * gbestX[j] - X[i][j]))$$

Where,
K - constriction factor
c_1, c_2 - weight factors
w - Inertia weight parameter
i-particle number
j -control variable
rand1, rand2 random numbers between 0 and 1

Stopping criteria: This is the condition to terminate the search process. It can be achieved either of the two following methods:

The number of the iterations since the last change of the best solution is greater than a pre-specified number. The numbers of iterations reach a pre specified maximum value.

IV. ALGORITHM FOR CAPACITOR PLACEMENT USING LOSS SENSITIVITY FACTOR AND PARTICLE SWARM OPTIMIZATION

Step1: Run the base case Distribution load flow and determine the active power loss.

Step2: Identify the Candidate buses for placement of capacitors using Loss Sensitivity Factors.

Step3: Generate randomly 'n' number of particles, where each particle is represented as particle[i]={Qc 1,Qc 2,….,Qc j}Where 'j' represents number of candidate buses.

Step4: Generate the particle velocities (v[i]) between –vmax and vmax.

Where, vmax = (capmax-capmin)/N
Cap max= maximum capacitor rating in kvar
Cap min= minimum capacitor rating in kvar
N= number of steps to move the particle from one position to the other.

Step5: Set the Iteration count, iter=1.

Step6: Run the load flows by placing a particle 'i' at the candidate bus for reactive power compensation and store the active power loss (pl).

Step7: Evaluate the fitness value (base power loss-pl) of the particle 'i' and compare with previous particle best(pbest) value. If the current fitness value is greater than itspbest value, then assign the pbest value to the current value.

Step8: Determine the current global best(gbest) maximum value among the particles individual best (pbest)values.

Step9: Compare the global position with the previous global position. If the current global position is greater than the previous, then set the global position to the current global position.

Step10: Update the velocities by using

$$V[i][j] = K * (w) * v[i][j] + C_1 * rand_1 * (Pbestparticle[i][j] - particle[i][j] + C_2 * rand)(gbestparticle[j] - particle[i][j])$$

Where,
particle[i] position of individual 'i
pbest particle[i] best position of individual 'i' gbest particle best position among the swarm v[i] velocity if individual 'i'

Step11: If the velocity v[i][j] violates its limits (-vmax,vmax), set it at its proper limits

Step12: Update the position of the particle by adding the velocity (v[i][j]) to it.

Step13: Now run the load flow and determine the active power loss (pl) with the updated particle.

Step14: Repeat step 7 to step 9

Step15: Repeat the same procedure for each particle from steps from 6 to 13.

Step16: Repeat steps from 6 to 13 until the termination criteria are achieved.

Data taken to run PSO

23 Number of buses identified from LSF for capacitor placement.

Cap $_{max}$=1200: cap $_{mini}$=200 : V $_{max}$=(cap$_{max}$-c$_{min}$)/N
Weight w=1.2: C1 =2.05 : C2=2.05
K - Constriction factor as

0.7259 c_1, c_2-weight factors
w- Inertia weight parameter I- particle number
j- Control variable

V.TEST RESULTS

The proposed method for loss reduction by capacitor placement is rested on IEEE 33 bus system. The figure is shown in fig.2. Particle Swarm Optimization is used to find the optimal location for the voltage improvement and the results were compared to Loss Sensitivity Factor.

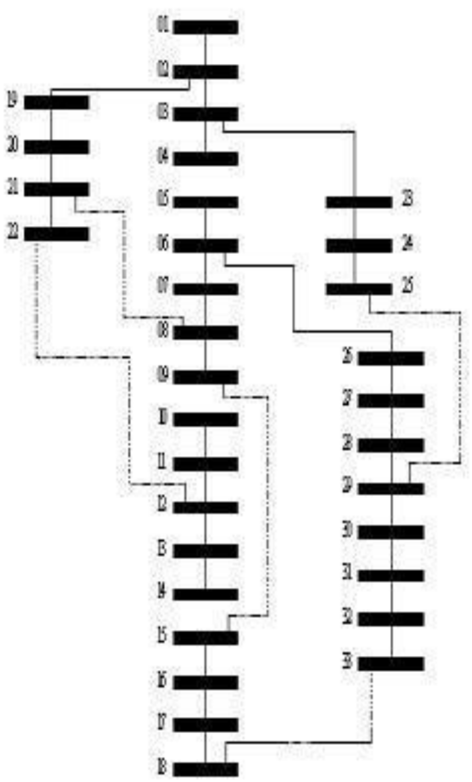

Fig.2 33 Bus Radial Distribution System

TABLE.I CAPACITOR PLACEMENT BASED ON THE LOSS SENSITIVITY CO EFFICIENT FACTOR IN DESCENDING ORDER OF A 33 BUS RADIAL DISTRIBUTION SYSTEM

LSF=dploss/ dQ$_{eff}$	**Bus No**	**Norm[i] V[i]/0.95**	**Base Voltage**	**Need of Capacitor Placement based on LSF**
0.0001	2	1.0484	0.9960	0
0.0001	19	1.0477	0.9953	0
0.0001	26	0.9781	0.9292	1.0000
0.0001	27	0.9744	0.9257	1.0000
0.0001	11	0.9503	0.9028	1.0000
0.0001	15	0.9342	0.8874	1.0000
0.0002	5	1.0071	0.9568	1.0000
0.0003	21	1.0417	0.9896	0
0.0003	3	1.0284	0.9770	0
0.0003	6	0.9808	0.9318	1.0000
0.0003	12	0.9482	0.9008	1.0000
0.0003	33	0.9334	0.8867	1.0000
0.0003	16	0.9322	0.8856	1.0000
0.0004	23	1.0233	0.9722	0
0.0004	7	0.9759	0.9271	1.0000
0.0004	9	0.9599	0.9119	1.0000
0.0004	28	0.9580	0.9101	1.0000
0.0004	10	0.9516	0.9040	1.0000
0.0005	22	1.0408	0.9888	0
0.0005	4	1.0177	0.9668	0
0.0005	17	0.9293	0.8828	1.0000
0.0006	18	0.9284	0.8820	1.0000
0.0007	32	0.9338	0.8871	1.0000
0.0009	14	0.9362	0.8894	1.0000
0.0010	20	1.0427	0.9906	0
0.0011	13	0.9394	0.8924	1.0000
0.0012	29	0.9463	0.8989	1.0000
0.0014	8	0.9689	0.9205	1.0000
0.0014	31	0.9352	0.8884	1.0000
0.0032	24	1.0139	0.9632	0
0.0032	25	1.0093	0.9588	1.0000
0.0063	30	0.9412	0.8941	1.0000
				Cp =23node No cp =9node

Loss sensitivity factors are arranged in the descending order for 33 radial distribution system in table I. Based on the results it is concluded that capacitor has to be placed where the nominal voltage less than unity. It is observed that the node, some node having the nominal voltage level well within the limit of 1.01 and many of the nodes are having lower than the limit specified. Those places having the lower limit have to be provided with capacitor to compensate the reactive power. Best position bus number selected as initial and then successive buses are placed one by one based on the based voltage at that bus which is proposal to the real power loss with respective to the effective reactive power at that node point. The no of node where capacitor has to be placed in conventional method based on the LSF found as 23. These 23 buses are introduced and subjected to Particle Swarm

TABLE.II CAPACITOR PLACEMENT USING PARTICLE SWARM OPTIMIZATION AND CONVENTIONAL METHOD

No of time PSO run	Bus which was searched repeated time.	CONVENTIONAL	PSO			
			Best case NO cap.pl Sl no.		Rare case CP(sl.no)	
1	2,15,17	**CAPACITOR PLACEMENT**	**1,2,3, 4,15,16,17**		**5,6,7,8, 9,10,11,12, 13,14,18,19, 20,21,22,23**	
2	1,15,16					
3	1,15,17					
4	1,4,15,16,17					
5	1,3,16					
6	2,4,15,16					
7	15,17					
8	1,3,4,15,16					
9	1,2,15,16					
10	1,2,15,16					
11	1,2,3,15					
12	1,15	**13**	1	13	5	**9**
13	4,15,16	**17**	2	17	6	**31**
14	1,2,15	**28**	3	28	7	**25**
15	1,2,15	**10**	4	10	8	**6**
16	1,3,15,17	**9**	15	30	9	**29**
17	1,2,3,15	**31**	16	5	10	**16**
18	1,15	**25**	17	12	11	**18**
19	4,15,16	**6**			12	**8**
20	1,2,15	**29**			13	**15**
21	1,2,15	**16**			14	**14**
22	1,2,4,15,16	**18**			18	**33**
23	1,15,16	**8**			19	**32**
24	1,3,15,16	**15**			20	**27**
25	1,2,15	**14**			21	**26**
26	1,15,16	**30**			22	**11**
27	1,3,15,16	**5**			23	**7**
28	1,3,15,17	**12**				
29	1,3,15	**33**				
30	1,3,15,17	**32**				
		27				
		26				
		11				
		7				
TOTAL		**23**		7		**16**

Optimization. The result obtained as "No capacitor will be placed in 7 nodes selected as Best place and remaining 16 nodes are selected as rare place which needs placement of capacitor and hence considerably reduced the size of the system compared to the conventional method. The comparison between the conventional method and PSO is shown in table

II. PSO gives the better optimal location to place a capacitors in a radial distribution system

CONCLUSION

In this paper, the optimal location of capacitor that are need to placed on potential buses of IEEE 33 radial distribution system has been successfully determines with the help of PSO and the results obtained in terms of power loss is better than the conventional method. The main advantage of this proposed method is that it systematically decides to reduce the locations of capacitors to be placed and significant improvement in voltage profile.

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