A PARTICLE SWARM OPTIMIZATION TO OPTIMAL SHUNT-CAPACITOR PLACEMENT IN RADIAL DISTRIBUTION SYSTEMS

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Abstract: Shunt-capacitor placement plays an important role in operation and distribution system planning. Optimal Shunt-capacitor placement can result in system loss reduction, voltage profile improvement, power factor correction and feeder capacity release. To reach these benefits to extent under various distribution engineers, operating constraints are required to determine the optimal locations and sizes of capacitors to be placed and control settings of switched capacitors at different load levels.

A Particle Swarm Optimization (PSO) based approach is used to achieve optimal shunt-capacitor placement in radial distribution systems. Different load levels and Discrete nature of capacitors are all taken into consideration in the problem formulation. Mathematically, the shunt-capacitor placement problem is a non-differentiable and non-linear mixed integer optimization problem with a set of inequality and equality operating constraints. The proposed solution method employs to search for optimal locations and sizes of capacitors to be placed and optimal numbers of switched capacitor banks at different load levels. The proposed method is tested on 15, 33, 69 for balanced loads and 19, 52 for unbalanced loads in radial distribution systems by using MATLAB software.

I.INTRODUCTION

 Distribution systems are the networks that transport the electrical energy from bulk substation to many services or loads. Distribution systems are becoming large and stretched too far leading to higher system losses and poor voltage regulation. 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.

Due to high concentration of inductive loads in distribution system, power and energy losses are more. Shunt capacitors are widely used in distribution system consuming negative VAR, which counteracts some of the lagging components of inductive VAR at the point of installation. Thus, it modifies the characteristics of inductive load. Shunt capacitor results in to a number of benefits like improvement of power factor, reduction of power loss, improvement of voltage profile, improvement of voltage stability and system-released capacity. To achieve these benefits to the utmost extent under various operating constraints, distribution engineers are required to determine the optimal locations, types and sizes of capacitors to be placed and control settings of switched capacitors at different load levels.

A variety of solution techniques have been employed to solve the capacitor placement problem. These techniques are classified into four categories. They are analytical methods, numerical programming methods, heuristic search methods and artificial intelligence (AI) based methods. When a realistic problem formulation with all considerations is to be solved, however, most analytical, numerical programming heuristic are unable to work well. In recent years, AI- based methods

such as genetic algorithms (GA) have been applied to the capacitor placement problem with promising results. Mean while, some new AI-based methods are introduced and developed. Although these AI- based methods do not always guarantee the globally optimal solution, they will provide sub optimal (near globally optimal) solutions in a short CPU time.

A modern AI-based method, particle swarm optimization is used to solve the capacitor placement with all the realistic problem formulation considerations. This optimization technique can be used to solve many of the same kinds of problems as GA, and does not suffer from some of GA's difficulties. PSO has been found to be robust in solving problems featuring non-linearity, non-differentiability and high dimensionality.

II. MATHEMATICAL FORMULATION

In any radial distribution system, the electrical equivalent of a branch-1, which is connected between node 1 and 2 having a resistance $r_{(1)}$ and inductive reactance $x_{(1)}$ is shown in figure 1

Fig 1.Single line diagram for a system
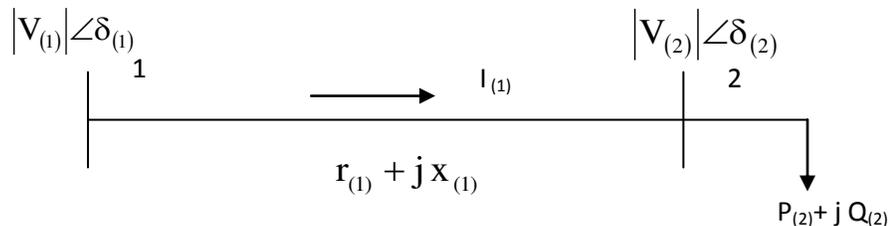
Current flowing branch-1is given by

$$I_{(1)} = |V_{(1)}|\angle\delta_{(1)} - |V_{(2)}|\angle\delta_{(2)} /(r_{(1)} + jx_{(1)}) \tag{1}$$

And
$$I_{(1)} = (P_{(2)} - jQ_{(2)})/ V_{(2)} * \angle\delta_{(2)} \tag{2}$$

Where, $| V_{(1)}|\angle\delta_{(1)}, | V_{(2)}|\angle\delta_{(2)}$ are the voltage magnitudes and corresponding phase angles at sending end node 1 and receiving end node 2 respectively. In general

$$|V_{(i+1)}| = \{\{(r_{(j)}P_{(i+1)} + x_{(j)}Q_{(i+1)} - 0.5|V_{(i)}|^2)^2 - (r_{(j)}^2 + x_{(j)}^2)(P_{(i+1)}^2 + Q_{(i+1)}^2) \}^{1/2}$$
$$- (r_{(j)}P_{(i+1)} + x_{(j)}Q_{(i+1)} - 0.5|V_{(i)}|^2) \} \tag{3}$$

Where, node no.,   i=1,2,…,nd
branch no., j=1,2…,nd-1
nd=total no. of nodes

The active and reactive power losses in branch 'j' are given by, $\text{Ploss[j]} = \dfrac{r_{(j)}\left\{P^2_{(i+1)} + Q^2_{(i+1)}\right\}}{\left|V_{(i+1)}\right|^2}$

(4)

$$\text{Qloss[j]} = \dfrac{x_{(j)}\left\{P^2_{(i+1)} + Q^2_{(i+1)}\right\}}{\left|V_{(i+1)}\right|^2}$$

(5)

The total active and reactive power losses of the system are

$$\text{TPL} = \sum_{j=1}^{nd-1} Ploss[j]$$

(6)

$$\text{TQL} = \sum_{j=1}^{nd-1} Qloss[j]$$

(7)

Where
    Ploss[j], Qloss[j] =Active and reactive power losses of branch 'j'
    TPL, TQL = Total active and reactive power losses of the system

    Usually the substation voltage $V_{(i)}$ is known and is taken as $|V_{(1)}|$ =1.0 p.u. Initially, Ploss [j] and Qloss [j] are set to zero for all j. Then the initial estimate of $P_{(2)}$ and $Q_{(2)}$ will be the sum of the load of all the nodes beyond node 2 plus the local load of node 2. For all the branches j=1,2…nd-1, compute $P_{(i+1)}$ and $Q_{(i+1)}$ using the algorithm. Compute $|V_{(i+1)}|$, $\text{Ploss}_{(j)}$ and $\text{Qloss}_{(j)}$ using equations (2),(4) and (5). This will complete   iteration. Update the loads $P_{(i+1)}$ and $Q_{(i+1)}$ (including losses) and repeat the same procedure until the voltage magnitudes are computed to a tolerance of 0.0001 p.u. in successive iteration.

III. ALGORITHM FOR NODE IDENTIFICATION

   Following algorithm explains the methodology to identify the candidate nodes, which are more suitable for capacitor placement.

- Read radial distribution system data.

- Run the load flows and calculate the base case active power loss.

- By compensating the reactive power injections (Qc) at each node and run the load flows, to calculate the active power losses in each case.

- Calculate the power loss reduction and power loss index(PLI).

- Select the candidate node whose PLI>Tolerance.

- Stop.

The proposed algorithm is tested on 15-node radial distribution system, 33-node radial distribution system and 69-node radial distribution system

The capacitor sizes at the nodes are obtained from Particle Swarm Optimization. These capacitors are kept at candidate nodes and the load flow solution is performed to observe the improvement in voltage profile and net savings in three systems.

IV .PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a meta heuristic parallel search technique used for optimization of continues non linear problems. The method was discovered through simulation of a simplified social model. PSO has roots in two main component methodologies perhaps 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 primitive mathematical operators, and is computationally inexpensive 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 encountered, or until computational limits are exceeded. In social science context, a PSO system combines a social and cognition models.

The general elements of the PSO are briefly explained as follows:

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 $X_i(t)=\{X_{i,1}(t), X_{i,2}(t),\dots X_{i,k}(t)\}$.

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

Swarm: It is an apparently disorganized 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 $V_i(t)= \{v_{i,1}(t), v_{i,2}(t)\dots v_{i,k}(t)\}$.

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 resembles 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 attained 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 determined and updated during the search.

Global Best (gbest): It is the best position among all the individual pbest of the particles 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]+c1*rand1*(pbestX[i][j]-X[i][j])+c2*rand2*(gbestX[j]-X[i][j])).

where, K constriction factor c1, c2 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:

  i. The number of the iterations since the last change of the best solution is greater than a pre-specified number.

  ii. The number of iterations reaches a prespecified maximum value

IV. ALGORITHM FOR CAPACITOR PLACEMENT AND SIZING USING PLI & PSO

step1: Run the base case Distribution load flow and determine the active power loss.

Step2: Identify the Candidate buses for placement of capacitors using power loss indices.

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

Capmax= maximum capacitor rating in kvar

Capmin= 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 its pbest 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]+c1*rand1*(pbestparticle[i]

Where, particle[i] position of individual 'I

gbestparticle 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.

V.RESULTS AND ANALYSIS

Balanced Radial Distribution Systems

Example 1: The proposed algorithm is tested on 15-node radial distribution system whose single line diagram is shown in fig 1. The test results are given in Table1. The voltage profile before and after compensation are shown in Fig 2. From the results, to observe that active power losses reduce from 60.34821 kW to 29.77601kW i.e., 50.6596 % loss reduction and minimum voltage improved from 0.942389 p.u to 0.967561 p.u. thus voltage regulation improved from 5.7611% to 3.2439%, i.e., 43.6930 % improved.

Table 1 Test results of 15-node system before and after compensation for load level of 1 p.u

| Node No	Total kVAR compensated	Before Compensation		After Compensation	
		Total losses (kW)	Min Voltage (p.u)	Total losses (kW)	Min Voltage (p.u)
4,8,9,11,15	1200	60.34821	0.942389	29.77601	0.967561
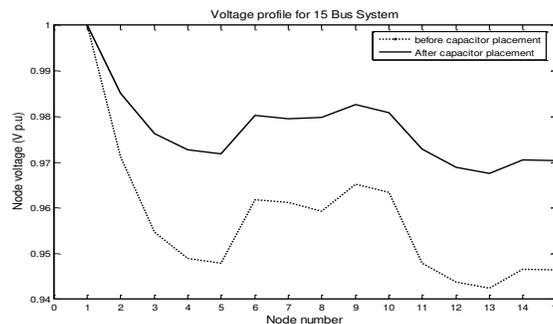
Fig 1: Voltage profile for 15-node system before and after compensation for full load

 Example 2: The test results of 33-node radial distribution system are given in Table2.The voltage profile before and after compensation are shown in fig 3. From the results, to observe that active powerlosses reduce from 202.7069 kW to 143.7255 kW i.e., 29.096866% loss reduction and minimum voltage improved from 0.913041 p.u to 0.925082 p.u. thus voltage regulation improved from 8.6959% to 7.4918% i.e., 13.8468 % improved.

Table2 Test results of 33-node system before and after copensation.

| Node No	Total kVAR compensated	Before Compensation		After Compensation	
		Total losses (kW)	Min Voltage (p.u)	Total losses (kW)	Min Voltage (p.u)
30	1200	202.7069	0.913041	143.7255	0.925082
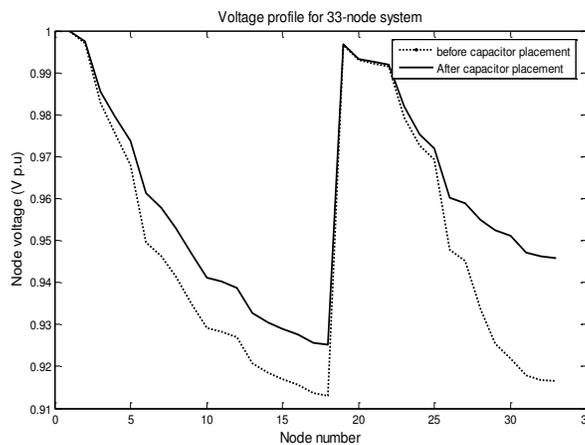
Fig 2: voltage profile for 33-node system before and after compensation unbalanced radial distribution systems

Example 3: The test results of 69-node radial distribution system are given in Table3.The voltage profile before and after compensation are shown in fig 3

Node No	Total kVAR compensated	Before Compensation		After Compensation	
		Total losses (kW)	Min Voltage (p.u)	Total losses (kW)	Min Voltage (p.u)
61	1200	225.4388	0.908308	52.8311	0.928465

Table3 Test results of 69-node system before and after compensation
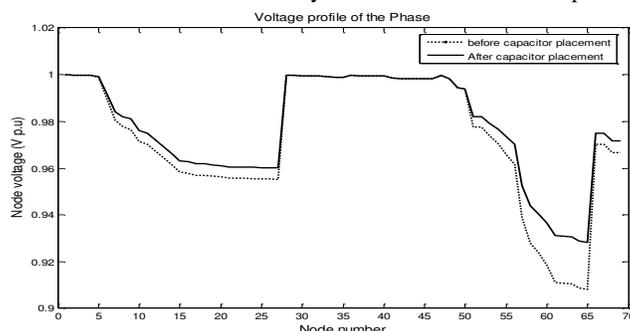
Fig 3 :Voltage profile for 69-node system before and after compensation

UNBALANCED RADIAL DISTRIBUTION SYSTEMS
Example 1   The proposed algorithm for unbalanced radial distribution system is also tested on unbalanced 19-node radial distribution system. The test results of 19-node radial distribution system are given in Table 4. From the results, it is observed that total active power losses reduce from 13.471 kW to 11.013 kW i.e., 18.27 % loss reduction and minimum voltage of phase A, phase B and phase C improved from 0.951592, 0.949758, 0.950466 p.u to 0.958514, 0.95719, 0.957709 p.u. respectively.

Table 4 Test results of unbalanced 19-node radial distribution system before and after compensation

Total kVAR compensated	Before Compensation				After Compensation			
	Total losses (kW)	Min Voltage(p.u)			Total losses (kW)	Min Voltage(p.u)		
		Phase A	Phase B	Phase C		Phase A	Phase B	Phase C
105	13.471	0.9515	0.9497	0.9504	11.013	0.9588	0.9571	0.9577

Example2: The proposed algorithm for radial distribution system is tested on unbalanced 52-node radial distribution system. The test results of unbalanced 52-node radial distribution system are given in Table 5. From the results, it is observed that active power losses reduce from 159.0603 kW to 131.083 kW i.e., 17.58 % loss reduction and minimum voltage of phase A, phase B and phase C improved from 0.92777, 0.95127, 0.91318 p.u to 0.93783, 0.96002, 0.92386 p.u.

Table5: Test results of unbalanced 52-node radial distribution system before and after compensation for load level of '1' p.u

Total kVAR compensated	Before Compensation				After Compensation			
	Total losses (kW)	Min Voltage(p.u)			Total losses (kW)	Min Voltage(p.u)		
		Phase A	Phase B	Phase C		Phase A	Phase B	Phase C
720	159.0604	0.92777	0.95127	0.91318	131.083	0.93781	0.96002	0.92386

VI. CONCLUSION

A new approach based on PSO algorithm for solving the shunt-capacitor placement problem in radial distribution systems has been proposed in the project. With full considerations of different load levels, and practical aspects of fixed or switched capacitor banks, the target problem is reformulated by a comprehensive objective function and a set of equality and inequality constraints. The proposed solution method employs PSO to search for optimal locations and sizes of capacitors to be placed and optimal numbers of switched capacitor banks at different load levels.

An effective approach for optimum location of capacitor in radial distribution system has been proposed. From the results, several important observations can be concluded as follows.

- The power losses of radial distribution system can be efficiently reduced by proper placement of shunt-capacitor.

- In addition of power factor improvement, power loss reduction, the voltage profile can be improved as well by the proposed method.

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