Optimal Location of Capacitors For Voltage Control In Radial Distribution Network By Using PSO Algorithm

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Abstract- This paper proposes a Particle Swarm Optimization method for optimal placement of capacitors in radial distribution system. Because of simple design and low cost radial distribution systems are more popular. But in distribution system, when buses moved away from the substation, the voltage drop increases and losses are also high. Lack of reactive power is the reason for voltage drops and high losses. It is necessary to solve this voltage problem for supply of good quality of power. In this paper series capacitors are used as reactive power compensators. By optimal location and sizing of capacitors voltage can be maintained in permissible limits and also losses can be reduced. In this work, a case study of 6-bus system is considered and comparison of PSO method is made with conventional calculations.

Key Words- Distribution system, Particle Swarm Optimization, Voltage Control, Series Capacitors.

I. Introduction

Now-a-days there is vast increase in the loads which are more sensitive to poor quality of power supply. Hence it is necessary to provide good power quality by power utilities. Power system can be divided into 3 subsystems, namely generation, transmission and distribution systems. Among these distribution is the system which acts as barrier between bulk power generating systems and consumers. Hence distribution system must be maintained problem less.

Distribution system is mainly of two types, radial type and mesh /interconnected type. Radial distribution system is the simplest and the lower cost, hence these types of feeders are more preferable. But the voltage will decrease out towards the end of the feeder, because it is tapped by laterals and sub-laterals. As the voltage reduces, the current drawn by the feeders will increase and hence losses also increase, since losses are proportional to square of current. To avoid the voltage problem and maintain the voltage in permissible limits, voltage must be controlled, means increase the node voltage when it is low and to reduce it when it is too high. Voltage control can be done by controlling the reactive power. To maintain the voltage and to control the reactive power many voltage controlling devices can be installed in distribution system. Some of the devices are voltage regulators, tap changing transformers, capacitors [1].

In early 1910's, capacitors are used to improve quality of electric power. Still today they are used to correct power factor in order to lower feeder losses, to raise power transfer capabilities, and to improve a feeder's voltage profile [2]. In the proposed work series capacitors are applied to distribution feeders to maintain the voltage profile almost constant. Series capacitors provide negative reactance (capacitive) in series with the circuit's positive reactance (inductive), which compensates the part of it or all. To enhance the advantages, location and size of series capacitors must be determined. Above mentioned parameters can be determined by dynamic programming and fuzzy set theory [8].

In the proposed work PSO method has been applied for determining the location and size of series capacitors. Recently PSO got many applications in different areas of power system, such as solving economic dispatch problems considering generator constraints and non smooth cost function,[6,9] reactive power and voltage control considering voltage security assessment,[4]. A modification of PSO also has been introduced for distribution state estimation [5].

II. Effect of Series Capacitor

Primarily the voltage drop caused by the inductive reactance is suppressed or minimized by series capacitor. As capacitor is connected in series, voltage drop across the capacitor is proportional to the current through it and power factor. Hence the voltage control is automatic and instantaneous as the load grows. From above discussion capacitor can also be considered as voltage boosters. A series capacitor produced more net voltage rise than a shunt capacitor at lower power factor. Low power factor means, more inductive reactance and thus when series capacitors connected they provide reactive power to compensate inductive reactance.

Distribution line can be represented as R (resistance) and X (reactance). Voltage drop through feeder can be expressed as

$$V.D = I.R\ COS\Phi + I.X_L\ SIN\Phi$$

After adding capacitance reduction in voltage drop can be expressed as

$$V.D = I.R\ COS\Phi + I\ (X_L - X_c)\ SIN\Phi$$

By adding capacitor power factor can also be increased and thereby power losses can be reduced since losses are inversely proportional to power factor.

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III. Formulation for Finding the Voltages and Power Losses at Each Node

The presented method involves only the evaluation of simple algebraic expression of receiving end voltages [3].

A constant voltage has been assumed at each node initially and load currents are calculated by:

$$IL(j)=S(j)/V(j);\ \ j=1,2,3,\ldots.N$$

Expression for finding branch currents is:

$$I(i)=\sum_{j=j+1}^{N(i)} IL(j)$$

Actual voltages at each node are calculated from:

$$V(j+1)=V(j)-I(i)Z(i)$$

Where, j=node number; i= Branch number

I(i)=branch current; Z(i)=branch impedance

Real and reactive power losses of branch i are given by

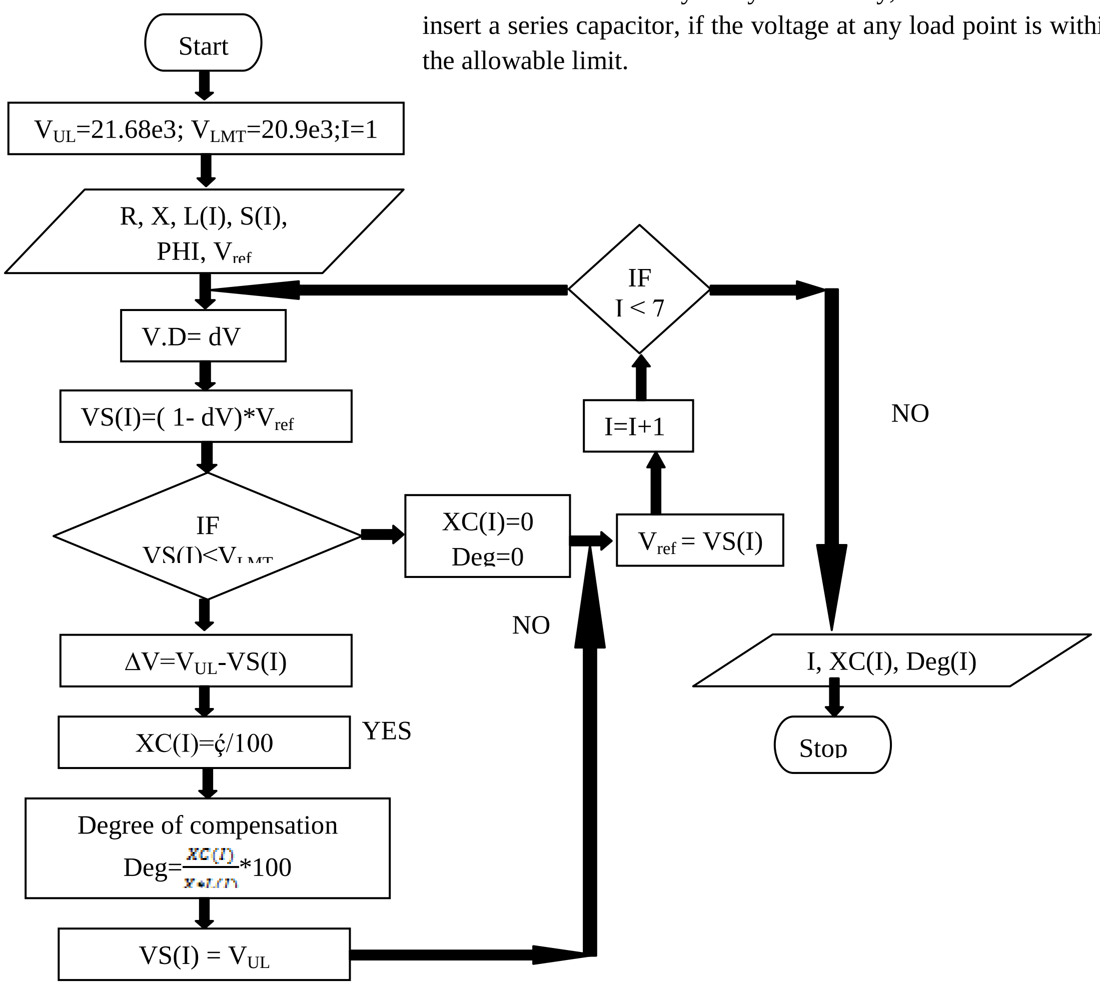
$$P(i)=I(i)^2R$$

$$Q(i)=I(i)^2X$$

IV. Conventional Calculations For Placement of Capacitors

Many researches were made on optimal site selection for placement of compensating devices in power system by considering different criteria. In deregulated electricity market, best location, and appropriate sizing of compensating devices is important. Investment of these devices includes high cost on the other hand location and setting of these devices have discriminatory and direct impact on the consumers and utilities. Therefore the location and setting of these devices require critical consideration.

The setting of series capacitor at appropriate location is to maintain voltage at nominal value or to be not less than allowable limit [11]. The calculated voltage at the previous load point is, considered as the sending voltage of the next section on the main feeder. By the flow chart illustrated below in Fig.1, size of series capacitor and corresponding voltage at each load point can be determined analytically. Obviously, there is no need to insert a series capacitor, if the voltage at any load point is within the allowable limit.



$$dV=\frac{S(I)*L(I)*R*COS(PHI)+S(I)*L(I)*X*SIN(PHI)}{(V_{ref})^2}*100$$

$$ç = \frac{((S(I)*L(I)*R*COS(PHI)+S(I)*L(I)*X*SIN(PHI))*X)-(\Delta V* V_{ref}*2)}{S(I)*L(I)*X*SIN(PHI)}$$

Fig(1) Flow chart for finding the size of capacitors by using analytical method

V. Overview of PSO method

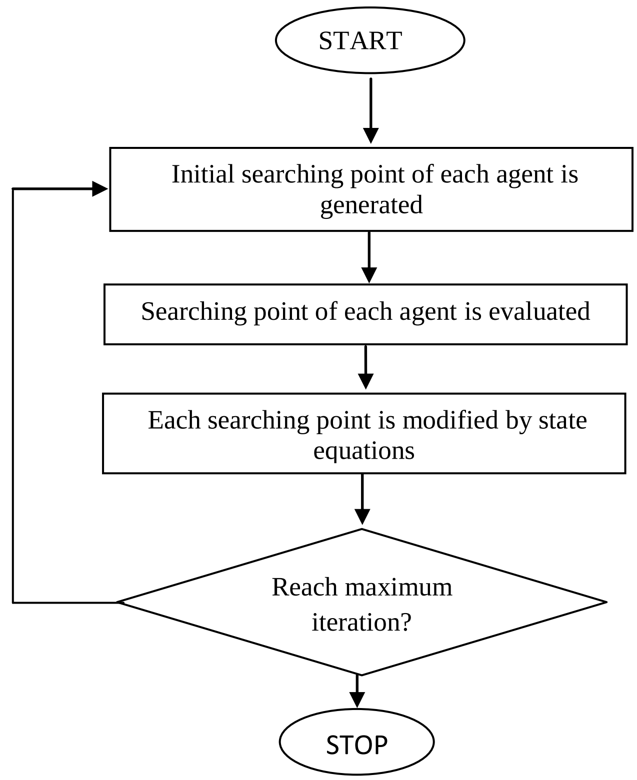
PSO method is first introduced by Kennedy and Eberhart in 1995.PSO is similar to the fish schooling and bird flocking. The behavior of such organisms in finding their resting places, food sources or other habitat can be, considered as optimization procedure [10]. During flight each particle adjusts its position according to its own experience, and the experience of neighboring particles, making use of the best position encountered by itself and its neighbors. The swarm direction of a particle is defined by the set of particles neighboring the particle and its history experience [6].

Each member is called as particle. Each particle is treated as volume less particle in d-dimensional search space. Each particle knows its best value so far known as Particle best(Pbest) and also knows the best value in the group among the Pbest which is called as global best (Gbest) [7]. According to PSO concept, velocity of particle changes towards its Pbest and Gbest locations. Acceleration is weighted by random term, and separate random numbers are generated for acceleration towards Pbest and Gbest locations. The flow chart for PSO method is given in fig(2).

For example consider,

- i^{th} particle is represented by d-dimensional vector and described as $\mathbf{X_i = [x_{i1}, x_{i2},……,x_{id}]}$.
- Population is the set of n particle in the swarm and given as **pop =** $\mathbf{[X_1, X_2… X_n]}$.
- Particle best of each particle is the best previous position of particle and represented in D-dimension as
  $\mathbf{PB_i= [\ pb_{i1}, pb_{i2} …,pb_{id}]}$.
- Global best is the best position among all of the particle best position achieved so far and described as ***GB=*** $\boldsymbol{[gb_1, gb_2, ….., g_{bd}]}$.
- The rate of change of position for each particle is called *particle velocity* and described as $\mathbf{V_i = [v_{i1}, v_{i2},…, v_{id}\ ]}$.
- The *velocity* for *d*-dimension of *i*-particle at iteration k is updated by equation
  $$\mathbf{V_{id}^{k+1} =wv^k_{id} +c_1r_1(pb_{id}^k-x_{id}^k) +c_2r_2\ (gb_d^k-x_{id}^k)}$$
  where w is the inertia weight, $\mathbf{c_1}$ **&** $\mathbf{c_2}$ are acceleration constants ans $\mathbf{r_1}$**&** $\mathbf{r_2}$ are two random values in range [0,1].
- The position of i-particle is updated by $\mathbf{x_{id}^{k+1}= x_{id}^k+ V_{id}^{k+1}}$

Flow chart for PSO method:



Fig(2) Flow chart for PSO method

PSO Technique for the problem considered to calculate the size of the capacitors is used as follows:

- Considering load points as n, the population of n particles is represented by **pop=** $\mathbf{[X_1, X_2,… ,X_i,….,X_n]}$**,**
  Where, X_i at any iteration is manipulated as the capacitor size
- All particles are represented in D-dimensional, where D represents the candidate buses
- The particle best, global best and the particle velocity are represented also in D-dimensions.
- The objective function is the power loss for each particle and the constraints are the voltage limit.

VI. Case Study

A real distribution system includes a radial line to transmit a power at 22KV. The power demand at load points and distances are shown in fig (3) The total length of the line is

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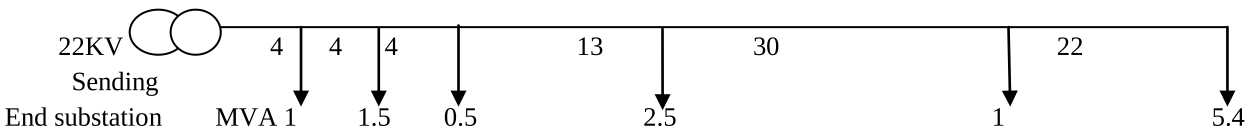
77Km (O.H.L.240/40 mm^2). The line resistance and reactance are 0.1329 and 0.32Ω/Km, respectively. The power factor of loads is assumed to be 0.8 lag.
In this case study the PSO will be used to calculate the optimal size of the series capacitors to be located at each node point. The simulation results using PSO are compared with the results obtained by using conventional calculation.
Initially, voltages at each node are calculated by formulation given in section –III and also power losses are also found.

Next to this, node voltages are calculated by analytical method, the voltages at nodes 2,4,5,6 are lower than the upper limit hence the suitable capacitors has placed by the flowchart mentioned in section-IV. Results by analytical method are shown in Table-1
In PSO method voltages resulted in section-III are considered as the node voltages. These voltage values are less than the best value hence capacitors are placed at all nodes by PSO method. Voltage and capacitor values are given in the Table-2. The comparison of voltages at each by each method are shown in the fig(4).



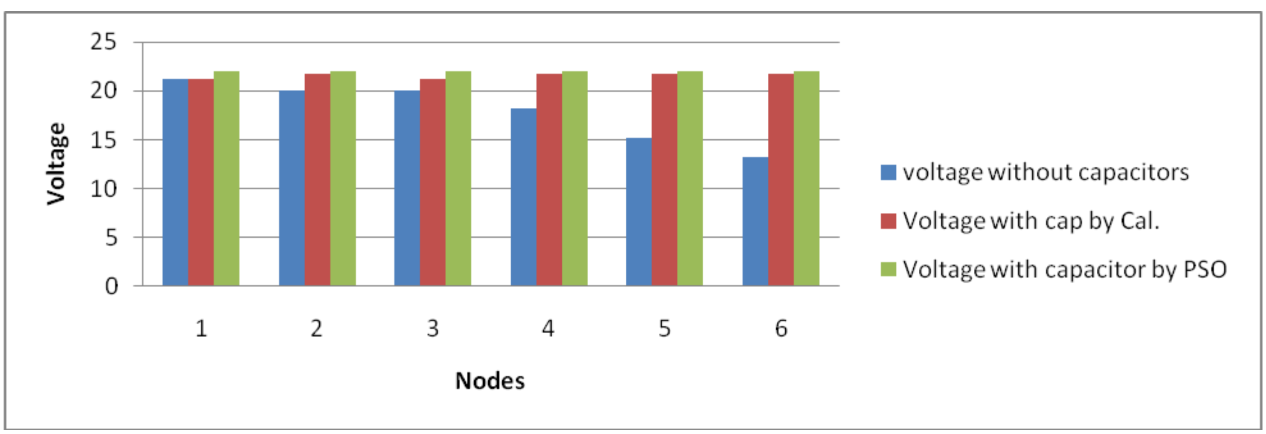
Fig(3) 6-node bus system

Node No.	Voltage Without Cap.s KV	Cap.s Size (Xc) Ω/Km	Voltage with Cap.s KV
1	21.25	0	21.25
2	20.623	3.886	21.680
3	21.179	0	21.179
4	17.658	8.7486	21.680
5	18.925	14.9914	21.680
6	10.911	10.8312	21.680

Table 1- Results with analytical method

Node No.	Voltage Without Cap.s KV	Cap.s Size (Xc) Ω/Km	Voltage with Cap KV
1	21.25	1.995	22.0
2	20.05	1.972	21.998
3	19.971	1.991	22.0
4	18.149	6.717	21.986
5	15.125	14.82	22.0
6	13.254	10.91	21.992

Table 2- Results with PSO method



Fig(4)- comparison of voltages by each method

Loss Reduction by each Method

The reduction in total power losses by different methods are given in the Table 3

Type of Method	Power loss in MVA
Without capacitors	3.0749
With capacitors by analytical calculations	2.388
With capacitors by PSO method	2.3184

Table 3- power losses by different methods

Also the total power loss with and without compensation are determined for each solution method. The power losses by each method are represented in the Table-3.

VII. Conclusions

A new algorithm has been proposed in the work for better management of voltages at the different nodes of lateral radial distribution feeder. It is based on particle Swarm Optimization technique using series capacitors. A real case-study on 6-bus system has been introduced. a comparison of PSO method with analytical calculations has been done. From the results obtained and comparisons made it is clearly observed that the solution using PSO has better power loss reduction and low degree of compensation than conventional calculations. This indicates the applicability of& effectiveness of PSO algorithm to manage the voltage in distribution networks in addition to reduction power loss.

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