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To Improve the Voltage Profile of Distribution System with the Optimal Placement of Capacitor

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Abstract

The demand of electricity is increasing very rapidly, with this increase in demand the burden on power system is increasing to meet this increasing demand, but it is very challenging because, the power system which we are using is aradial bus distribution system. The main problem while using redial system as a distribution network is the voltage drop which distorts the voltage profile of whole network. The primary cause of reduction of system voltage is, a huge amount of reactive power requirement of the load, because a large part of load is inductive. Around 13% of the generated power is wasted during transmission of power, so it is very necessary to improve voltage profile and to increase the efficiency of the network to prevent this loss of power. The PSO approach has been implemented to improve the voltage profile by optimizing the location of capacitor and to find its size. This test has been performed on the IEEE 33-bus and 66-bus radial distribution system which is designed with the use of MATLAB Software. The maximum number of capacitor units appropriate for the improvement for voltage profile is also checked in this work.

Keywords: Bibliography Review, Distribution System, Optimal Placement of Capacitor, Optimization Technique PSO, MATLAB

1. Introduction

The network of power system is spreading in all the developed and developing countries, because the demand of energy is increasing day by day. In the developing countries like India it is very challenging to meet the increasing demand of this energy. The electric power is supplied from the suppliers to the consumers, mainly in three parts i.e. generation, transmission and distribution, a large amount of energy is wasted in this process. About the 13% of generated power is wasted during the distribution process only. This loss in power causes the voltage drop in the system and hence reduces the distribution system voltage. So it is very necessary to improve the voltage profile of distribution system to prevent from the wastage of supply.

Distribution system provides a final linkage between the high voltage transmission system and the customers. The distribution system mostly used is the radial distribution system due to its low installation cost and simplicity, but the major drawback of radial distribution system is that all the consumers are connected to a single distributer so the is huge fluctuation of load which cause the variation in system voltage and distorts the voltage profile. The X/R ratio of distribution system is low as compared to the transmission system it causes the high power loss and drop in voltage magnitude[1–3]. In the distribution network the voltage at the nodes reduces if we moved away from the substation, this decrease in voltage is mainly due to insufficient amount of reactive power. The primary reason for the insufficient reactive power is that the load connected to the distribution network is mostly reactive in nature (inductive load) which consumes more reactive power. As we know the reactance of distribution system is low so when there are not enough reactive power (VAR) flowing locally to the loads, the generators must have to supply them, it causes the flow of unnecessarily large cur-

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rents in the distribution lines and resulting a drop in the voltage everywhere along the path.

The capacitor is a reactive device in which energy is not dissipated; the energy is stored in the form of electrostatic field. So there is no power loss in capacitor. As we know in distribution system the most of load is inductive, so there is a flow of reactive power in the distribution lines which cause the increase in power losses due to which the voltage drop in distribution system increases which cause the reduction in system voltage. As we know that capacitor has a property that the current leads the voltage by some angle. When the reactive load requirement of distribution system is cancelled by the capacitor placed at the reactive load centre, the entire power delivery system will be relieved of kVAR, supplied from the generator of power supplier. This removes the extra burden of reactive power and the generator's full capacity is available to serve real power loads[5]. It is very important to select the proper location and size of capacitor, if a capacitor connected to the distribution system is either too far ahead or too far beyond the system's inductive load centre, it still provides the reactive power to load, but the system will not gain the full advantages of voltage and loss improvement[8].

2. Distribution System

Distribution system basically is a part of power system which is required to distribute the electrical power to the local consumers. In other words we can say that distribution system is the final stage of power system it carries the power from transmission system to individual consumers. The main parts of distribution system are feeders, distributers and service mains.

2.1 Feeder

A feeder is a line or conductor which connects the generating station or a substation to the area where power has to be distributed. The current carrying capacity is the main consideration during designing of the feeder. No tapping are taken from the feeder to take the current constant. Feeder is shown in Figure 1.

2.2 Distributer

Distributers are conductors to which various consumers are connect. Tapping are taken from distributers to connect the various consumers. The main considerations while designing the distributer is voltage rating. Since the tappings are taken from distributers so the current through it is not constant. Distributers are shown in Figure 1. Generally the limit of voltage variation accepted is % on consumer's rated voltage.

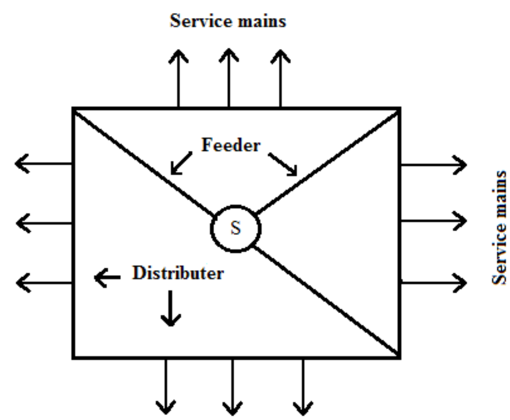

Figure 1. Distribution system (Whitaker J.C, 1999).

2.3 Service Mains

Service mains are conductors or small capacity cables which are at the end point of distribution system. Service mains connect the directly consumer to power supply. Service mains are shown in Figure 1.

3. Objective of Work

There should be a single or multiple objectives behind optimal siting and sizing of capacitor. Some of important objectives are:

- Improve the voltage profile of distribution system.
- Optimize the location and size of placement of capacitor.
- Find the maximum number of capacitor units can be installed economically.
- Design 33-bus and 69-bus radial distribution network in Matlab Software and run the power flow of distribution network.

3.1 Constraints

The constraints which are mostly considered in optimal DG placement are:

The above mentioned objective is achieved by following certain constraints. The constraints applied in this thesis are mentioned below:

- *Power Flow Equations of the network:* All the power flow equations of the network should be satisfied.
- *Voltage Constraint:* The main consideration of this work is to maintain the system voltage in specified limits, so the standard voltage is an important power quality aspect. The voltage in the network should be within the acceptable range i.e. % of the base Voltage.

$$V_{min} \leq V_i \leq V_{max} \tag{3.1}$$

The voltage at each bus should be within ±8% of the rated voltage i.e. the voltage should be 0.98 to 1.08.

4. Problem Formulation

In this section, problem is formulated for finding the optimal size and location of capacitors with the help of Particle Swarm Optimization (PSO). The objective of the placement of Capacitors is to improve the voltage profile of distribution system with satisfying the certain constraints explained in section 3.2. The power loss in the system is given by equation 4.1. This formula is popularly referred as “Exact Loss” formula[9].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \tag{4.1}$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right)$$

and

$$Z_{ij} = r_{ij} + jx_{ij}$$

Where,

Z_{ij} is impedance of line between bus *i* and *j*, is resistance and is reactance of line between bus *i* and *j*.

To improve voltage, the rate of change of real power losses with respect to injected reactive power becomes zero, which provides the size of capacitor at each bus for the loss to be minimized.

Therefore,

$$\frac{\partial P_L}{\partial Q_i} = 2\alpha_{ii}Q_i + 2\sum_{\substack{j=1 \\ j\neq i}}^{N}\left(\alpha_{ij}Q_j + \beta_{ij}P_j\right) = 0 \tag{4.2}$$

It follows that

$$Q_{DGi} = Q_{Di} - \frac{1}{\alpha_{ii}}\left[\sum_{\substack{j=1 \\ j\neq i}}^{N}\left(\alpha_{ij}Q_j + \beta_{ij}P_j\right)\right] \tag{4.3}$$

and

$$Q_i = Q_{DGi} - Q_{Di} \tag{4.4}$$

Where,

Q_{DGi} - Reactive power generated at bus *i*

Q_{Di} - Reactive power demand at bus *i*

5. Purposed Methodology PSO

In the literature, a number of authors have proposed various methods considering different fitness function including minimization of power losses, reduction in installation cost, and improvement of voltage profile, lessen the burden on existing lines, maximization of system stability etc. To obtain best Particle Swarm Optimization technique has been used.

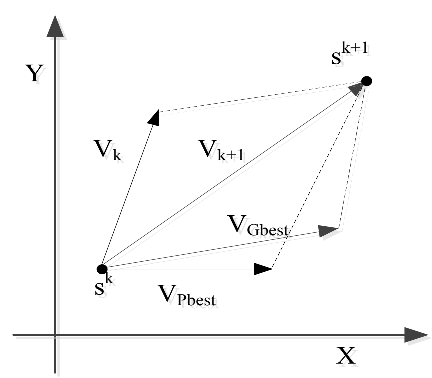

Figure 2. Concept of a searching point by PSO (Lee, 2004).

The optimization techniques are referred as both minimizing and maximizing tasks. The minimization of a function is same as maximizing additive inverse of the function, so the term minimization and optimization can be used interchangeably[10], because of this reason, optimization became very important in many fields. PSO is a famous population-based optimization method. The PSO was first introduced by Kennedy J. and Eberhart R. in 1995. They proposed a solution to the non-linear and complex optimization problem by observing behaviour of flock of birds or fish schooling[11]. PSO algorithm is inspired by the animal's activity in order to solve the optimization problems. In PSO as individuals called particles change their position (state) with the time. PSO works as an optimization tool which provides a population-based search procedure. PSO is a parallel search technique which utilizes multi-agents (a swarm of particles).

PSO represents the concept of optimizing the function using swarm of particles. It considers a function of n dimension which is defined by:

$$f(x) = f(x_1, x_2, x_3 \ldots x_n) \tag{5.1}$$

Where, x_i is the optimizing variable, which represents the set of variables for a given function *f(x).*

Here, the goal is to get an optimum value *x* so that the function *f(x)* can become either a maximum value or a minimum value. As we in PSO each particle change its position and set to a best position, suppose denotes the agent or particle 'i' position vector search space at time step k, then each agent position is updated in the search space by:

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1} \tag{5.2}$$

Where, $i = 1, 2, \ldots n$ and $d = 1, 2, \ldots m$

n is number of particles in a group

m is number of members in a particle

While updating particle's velocity, the velocity component plays a vital role. The velocity of each particle can be modified according to the following equation:

Where

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand\left(pbest_{id}^{k} - x_{id}^{k}\right) + c_2 rand\left(gbest_{id}^{k} - x_{id}^{k}\right)$$

$i = 1,2,\ldots,n$

$d = 1,2,\ldots,m$

v^k is current velocity

v^{k+1} is modified velocity of agent i

v_{pbest} is velocity based on pbest

v_{gbest} is velocity based on gbest

$pbest_i$ is pbest of agent i

$gbest_i$ is gbest of the group

ω_i is weight function for velocity of agent i

c_i is weight coefficients for each term

Each agent of the swarm represents a solution. All agents go through entire search space and update its position and velocity. In PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called pbest), and according to the experience of a neighbouring particle (This value is called gbest), obtain the best position encountered by itself and its neighbour (Figure 2). So, finally all the particles in the swarm try to move towards better positions until the swarm reaches an optimal solution.

An Inertia weight ω related with the speed of last time is a proportional agent. The impact of the last speed on the current speed can be controlled by inertia weights. The greater value of ω, the bigger is the searching ability of PSO for the whole, and the smaller value of ω, the bigger the PSO's searching ability for the partial.

The weight function used is:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}} . k \tag{5.2}$$

Where,

ω_{min} and ω_{max} are the minimum and maximum weights respectively and k and k_{max} are the current and maximum iteration.

Appropriate value for c_1 and c_2 ranges from 1 to 2, but 2 is the most appropriate in many cases and appropriate value for ω_{min} and ω_{max} are 0.4 and 0.9 respectively[13]. In this work the value of c_1 and c_2 is selected equal to 2 and the value for ω_{min} and ω_{max} is selected 0.4 and 0.9 respectively.

Steps for PSO algorithm

The PSO approach is based on the exact loss formula given by (4.1). The computational procedure to find the optimal size at optimal location for multiple capacitors is described below:

Step 1: Input line data, bus loading data, and the constraints.

Step 2: Enter the number of Capacitor units to be placed.

Step 3: Run the load flow for the base case and calculate the loss using (4.1).

Step 4: Initialize random values into particles which correspond to bus numbers or locations corresponding to optimal sizes of Capacitors of the given network. Set the iteration counter equal to zero.

Step 5: Take the first particle as the locations and sizes of Capacitors, there are number of possible locations as the number of particles.

Step 6: Find the fitness value for the every selected location for corresponding size of Capacitors.

Step 7: Update the position and velocity of each particle.

Step 8: if the iteration number reaches the maximum limit, go to step 9. Otherwise, set the iteration index it = it+1, and go back to step 4.

Step 9: Print out the optimal solution to the target problem. The best position includes the optimal location and size of Capacitors, which represents the voltage profile improvement of network.

6. Results and Discussions

The proposed methodology is tested on the two different test systems. The first system used is IEEE standard 33-bus radial distribution system with a total load of 3.72 MW and 2.3 MVAr[14] and the second one is IEEE standard 69-bus radial distribution system with a total load of 3.80 MW and 2.69 MVAr[15] with Beaver conductors.

6.1 33-Bus Test System

6.1.1 Single Capacitor Placement

Table 1 presents the simulation results of placing single capacitor by PSO technique. The results of the base case i.e. without using any capacitor and two cases in which single capacitor is placed by using PSO are described in table. The results include the optimal sizes and locations of capacitor proposed technique. In the base case power losses in the test system is 211kW. For single capacitor placement the loss reduction is 28.24% by PSO technique.

Table 1. Single capacitor placement for 33-bus system

Number of capacitors	Location Bus No.	Installed Capacity (MVAr)	Loss in (kW)	Loss Reduction (%)
Without Capacitor	-	-	225.00	0.00
Single	61	1.29	152.10	32.40

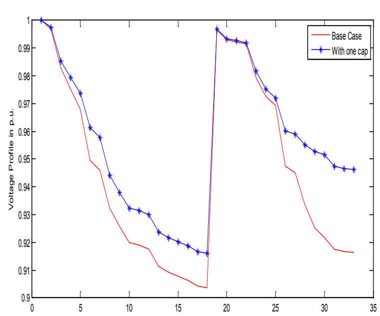

Figure 3. Voltage profile improvement with single capacitor 33-bus.

The voltage profile improvement of the 33-bus radial distribution system with the installation of single DG by using PSO is shown in Figure 3.

6.1.2 Multi Capacitor Placements

Simulation results of 33-bus test system with multi capacitor placement are shown in Table 2. The percentage reduction in losses by using multiple capacitors with PSO is also shown in Table 2. We can see that with the increase in number of capacitor system losses are reduced, but the number of installed capacitors limited to four by the decrease in voltage profile of system with further increases in number of capacitors.

Table 2. Multi capacitors placement for 33-bus system

Number of capacitors	Location Bus No.	Installed Capacity (MVAr)	Loss in (kW)	Loss Reduction (%)
Without Capacitor	-	-	211.00	0.00
Two	$C_1 = 12$ $C_2 = 30$	$C_1 = 0.43$ $C_2 = 1.04$	141.94	32.73
Three	$C_1 = 13$ $C_2 = 24$ $C_3 = 30$	$C_1 = 0.36$ $C_2 = 0.51$ $C_3 = 1.02$	138.37	34.42
Four	$C_1 = 7$ $C_2 = 14$ $C_3 = 24$ $C_4 = 30$	$C_1 = 0.34$ $C_2 = 0.28$ $C_3 = 0.49$ $C_4 = 0.91$	137.02	35.06
Five	$C_1 = 8$ $C_2 = 14$ $C_3 = 24$ $C_4 = 26$ $C_5 = 30$	$C_1 = 0.18$ $C_2 = 0.24$ $C_3 = 0.46$ $C_4 = 0.22$ $C_5 = 0.89$	136.76	35.18

6.2 69-Bus Test System

6.2.1 Single Capacitor Placement

Similar to 33-bus system, the Table 3 shows the optimal sizes and locations of single capacitor with percentage reduction in line losses of 69-bus test system. Table 3 presents the simulation results of placement of single capacitor by PSO. As given in Table 3 the optimal placement of single capacitor having a loss reduction of 32.40% compared to base case by using PSO. As the numbers of

DG and Capacitor units are increased, the loss reduction becomes more effective.

Figure 4 shows the voltage profile improvement of 69-bus radial distribution system with single capacitor placement by using PSO.

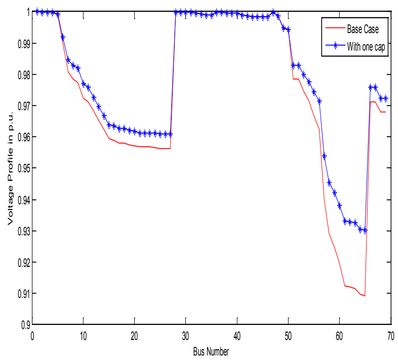

Figure 4. Voltage profile improvement with single capacitor 69-bus.

6.2.2 Multi Capacitor Placements

Simulation results of the 69-bus test system with multi capacitor placement are shown in Table 4. The percentage reduction in losses by using multiple capacitors with PSO is shown in Table 4.

Table 3. Single capacitor placement for 69-bus system

Number of capacitors	Location Bus No.	Installed Capacity (MVAr)	Loss in (kW)	Loss Reduction (%)
Without Capacitor	-	-	225.00	0.00
Two	$C_1 = 17$ $C_2 = 61$	$C_1 = 0.35$ $C_2 = 1.24$	146.50	34.88
Three	$C_1 = 11$ $C_2 = 20$ $C_3 = 61$	$C_1 = 0.35$ $C_2 = 0.25$ $C_3 = 1.19$	145.25	35.45
Five	$C_1 = 11$ $C_2 = 19$ $C_3 = 50$ $C_4 = 61$	$C_1 = 0.34$ $C_2 = 0.24$ $C_3 = 0.51$ $C_4 = 1.19$	144.50	35.78
Five	$C_1 = 12$ $C_2 = 18$ $C_3 = 50$ $C_4 = 56$ $C_5 = 61$	$C_1 = 0.28$ $C_2 = 0.22$ $C_3 = 0.51$ $C_4 = 0.67$ $C_5 = 1.18$	144.50	35.78

The voltage profile improvement of 33-bus system and 69-bus.

Table 4. Multi capacitors placement for 69-bus system

Number of capacitors	Location Bus No.	Installed Capacity (MVAr)	Loss in (kW)	Loss Reduction (%)
Without Capacitor	-	-	211.00	0.00
Single	61	1.29	151.41	28.24

system is described in Table 5. From the table it is clear that both the voltage profile and system power losses decreased by increasing the number of installed capacitors. While selecting the number of capacitors the main considerations are system voltage profile, system power loss and installation cost of capacitors, with the fulfilment of above considerations the number of capacitor suitable to install in 33-bus radial distribution system are four capacitors and in 69-bus radial distribution system are three capacitors.

Table 5. Voltage profile improvement of 33-bus and 69-bus system

Number of capacitors	Type of system	Power loss (MW)		
Base case (without cap)	33 bus	211.00	0.9038	1.0000
	69 bus	225.00	0.9092	1.0000
One	33 bus	151.41	0.9162	1.0000
	69 bus	152.10	0.9301	1.0000
Two	33 bus	141.94	0.9290	1.0000
	69 bus	146.50	0.9306	1.0000
Three	33 bus	138.37	0.9303	1.0000
	69 bus	145.25	0.9306	1.0000
Four	33 bus	137.02	0.9319	1.0000
	69 bus	144.50	0.9306	1.0000
Five	33 bus	136.76	0.9313	1.0000
	69 bus	144.50	0.9306	1.0000

7. Conclusion

In this research work the size and location of single and multi-capacitors have been optimized. The main consideration of this work is to improve the voltage profile of distribution system with the fulfilment of reactive power requirement of distribution system by installing the capacitors. To optimize the location and size of capacitors PSO algorithm is implemented with the help of MATLAB software. Purposed PSO algorithm is applied on the 33-bus and 69-bus radial distribution system. It is proved from the results that the voltage profile of distribution system is improved and the losses of system are also reduced with the placement of capacitor. The voltage profile further improves by increasing number of capacitors but upto a certain limit, after that the point of saturation comes; now the voltage profile remain unchanged by further increasing the number of capacitors. The numbers of capacitor banks suitable for 33-bus network are four, and for 69-bus network they are three.

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