

# Voltage Stability Analysis of Distribution System

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## Abstract

This paper presents a new methodology using Particle Swarm Optimization (PSO) technique to find the optimal size and optimum location for the placement of DG in the radial distribution system for improvement in the voltage profile of the distribution system. In the first segment, the optimal size of DG is calculated at each bus using PSO and in the second segment the optimal location of DG is found by using the loss sensitivity factor. The proposed method is tested on standard IEEE 33 bus test system.

Keywords: distributed generation, PSO, optimal size, optimal location, voltage profile

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## 1. Introduction

DGs are also referred to as ‘Embedded Generations’ or ‘Disperse Generations’. International Energy Agency (IEA) define distributed generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at Distribution level voltages. CIGRE define DG as the generation, which has the characteristics [1]: it is not centrally planned; it is not centrally dispatched at present; it is usually connected to the distribution networks; it is smaller then 50-100MW. Other organization like, Electric Power Research Institute define distributed generation as generation from few kilowatts up to 50MW. Ackermann *et al.* [2] have given the most recent definition of DG as:

“DG is an electric power generation source connected directly to the distribution network or on the customer side of the meter.” It may be understood in simple term as small-scale electricity generation. Distributed or dispersed generation (DG) or embedded generation (EG) is small-scale power generation that is usually connected to or embedded in the distribution system. Using DG can enhance the performance of a power system in many aspects. The objective of power system operation is to meet the demand at all the locations within power network as economically and reliably as possible. The traditional electric power generation systems utilize the conventional energy resources, such as fossil fuels, hydro, nuclear etc. for electricity generation. The operation of such traditional generation systems is based on centralized control utility generators, delivering power through an extensive transmission and distribution system, to meet the given demands of widely dispersed users. Nowadays, the justification for the large central-station plants is weakening due to depleting conventional resources, increased transmission and distribution costs, deregulation trends, heightened environmental concerns, and technological advancements. Distributed Generations (DGs), a term commonly used for small-scale generations, offer solution to many of these new challenges.

Supplying peaking power to reduce cost of electricity, reduce environmental emissions through clean and renewable technologies (Green Power), combined heat and power (CHP), high level of reliability and quality of supplied power and deferral of the transmission and distribution line investment through improved loadability are the major applications of the DG [3]. Other than these applications, the major application of DG in the deregulated environment lies in the form of ancillary services. These ancillary service include spinning and non-spinning reserves, reactive power supply and voltage control etc. [4]. DG also has several benefits like energy costs through combined heat and power generation, avoiding electricity transmission costs and less exposure to price volatility [5]. Though the DG is consider as a viable solution to most of the problems that the utility are facing, there are many problems (e.g. DG integration into grid, pricing, change in protection scheme, nuisance tripping etc.) that need to be addressed. Furthermore the type of DG technology adopted will have significant bearing on the solution approach.

The share of distributed generators (DGs) in power systems has been slowly increasing in the last few years and there is no sign that it would decrease in near future. Moreover, the policy initiatives to promote DG throughout the world also indicate that the number will grow rapidly. There are number of DG technologies available in the market today and few are still in research and development stage. Some currently available technologies are reciprocating engines, micro turbines, combustion gas turbines, fuel cells, photovoltaic, and wind turbines. Each one of these technologies has its own benefits and characteristics. Among all the DG, diesel or gas reciprocating engines and gas turbines make up most of the capacity installed so far. Simultaneously, new DG technology like micro turbine is being introduced and an older technology like reciprocating engines is being improved [6]. Fuel cells are technology of the future. However, there are some prototype demonstration projects. The costs of photovoltaic systems are expected to falling over the next decade.

The significant benefits to the sub transmission and distribution systems by Integrating DGs into power systems can be classified into the following Categories [7]:

## **2. Economical Benefits of DGs**

The economic benefits by DG utilization can be summarized as follows:

1. Installation of DG units near the load centers defers the necessity for:
  - Addition of new expensive feeders to distribute power among customer loads.
  - Construction of new substations or expansion of existing ones.
  - Extension of new transmission lines to energize new substations.
2. Integration of DGs improves the system efficiency by:
  - Enhancing the system voltage profile and minimizing the number of required voltage regulators and capacitors.
  - Reducing the feeder power loss and minimizing the costs of losses.
  - Decreasing the loading on existing electric equipments, minimizing their maintenance costs, and increasing their service lives.
3. The planning of DG is considered as a short-term investment approach from the point of view of capital investment due to:
  - Low capital cost,
  - Paying the revenue and benefits back in a short period of time,
  - Requiring less time for installation (varying between a day and few months depending on the technology and size of DG).
4. Implementing DGs for distribution system planning minimizing the investment risk due to reduced capital costs and less installation time.

### **2.1 Operational Benefits of DGs**

Various operational benefits of DG employment are as follows:

- DGs deliver safe, clean, reliable, and efficient electrical energy at low price with no or low emissions,
- DGs directly provide power in the vicinity of the loads and help in reducing the loadings on feeders,
- Introduction of DGs in the distribution system reduces the number of electric elements (substations, transformers, feeders, capacitors, regulators, protective devices, and control circuits) in the network, which in turn, leads to minimization of number of possibilities as well as randomness of faults and outage occurrences.
- DGs with their modern power electronic interface devices can be interconnected to the grid to achieve special power quality, reliability, and voltage profile requirements.
- DG units can be operated for: Simultaneous compound heat and power, Peak load shaving to minimizing the required centralized reserve power, Stand-by generation in case of electric utility failure

- Customer- owned DGs can help customer by providing some portion of their demands during peak load periods and by feeding the excess power to the grid during the light load periods. This way, they can get some revenue back from the electric utility.

## 2.2 Challenges of DG Integration

In spite of several significant advantages, the inclusion of DGs may have the following negative impacts on the system:

- Integration of DG can disturb the co-ordination and rating of existing devices,
- For interconnection, use of invertors with asynchronous DG sources may inject harmonics into the system,
- DGs can adversely affect the system stability,
- DG units may increase the fault current levels of the system depending on their locations
- The capital costs per KW-installed power of DG are higher compared to large central plants.
- Small DG units are not capable of providing reactive power.

## 3. Particle Swarm Optimization

### 3.1 Introduction

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling [8]. The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a 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 neighboring particle (This value is called Gbest), made use of the best position encountered by itself and its neighbor (Fig 1).

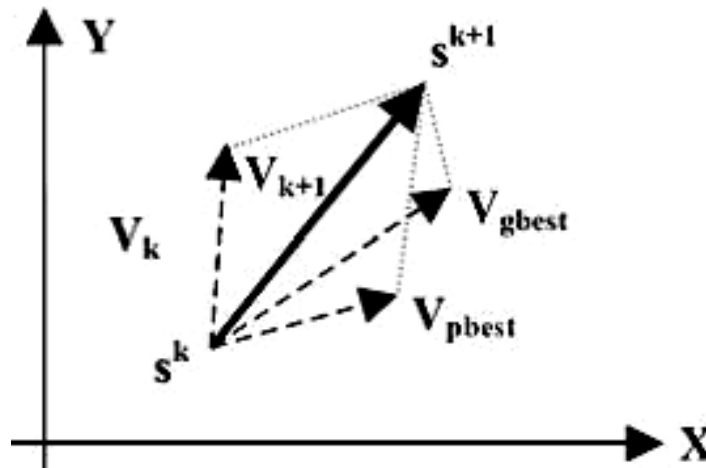


Figure 1: Concept of a searching point by PSO

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$v_{id}^{k+1} = \omega v_{id}^k + c_1 rand \times (pbest_{id} - s_{id}^k) + c_2 rand \times (gbest_{id} - s_{id}^k) \dots (1)$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$S_{id}^{k+1} = S_{id}^k + v_{id}^{k+1}, i = 1, 2, \dots, n, \dots (2) \\ d = 1, 2, \dots, m$$

Where,

$s^k$  is current searching point,

$s^{k+1}$  is modified searching point,

$v^k$  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,

$n$  is number of particles in a group,

$m$  is number of members in a particle,

$pbest_i$  is pbest of agent  $i$ ,

$gbest_i$  is gbest of the group,

$\omega_i$  is weight function for velocity of agent  $i$ ,

$c_i$  is weight coefficients for each term.

The following weight function is used:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}} \cdot k \quad \dots (3)$$

Where,

$\omega_{min}$  and  $\omega_{max}$  are the minimum and maximum weights respectively.  $k$  and  $k_{max}$  are the current and maximum iteration. Appropriate value ranges for  $C_1$  and  $C_2$  are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for  $\omega_{min}$  and  $\omega_{max}$  are 0.4 and 0.9 [9] respectively.

### 3.2 PSO PROCEDURE

The PSO-based approach for solving the OPDG problem to minimize the loss takes the following steps:

Step 1: Input line and bus data, and bus voltage limits.

Step 2: Calculate the loss using distribution load flow based on backward-forward sweep.

Step 3: Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter  $k = 0$ .

Step 4: For each particle if the bus voltage is within the limits, calculate the total loss in equation (4). Otherwise, that particle is infeasible.

Step 5: For each particle, compare its objective value with *the individual best*. If the objective value is lower than *Pbest*, set this value as the current *Pbest*, and record the corresponding particle position.

Step 6: Choose the particle associated with the minimum *individual best Pbest* of all particles, and set the value of this *Pbest* as the current *overall best Gbest*.

Step 7: Update the velocity and position of particle using (1) and (2) respectively.

Step 8: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index  $k = k + 1$ , and go back to Step 4.

Step 9: Print out the optimal solution to the target problem. The best position includes the optimal locations and size of DG or multi-DGs, and the corresponding fitness value representing the minimum total real power loss.

### 4. Loss sensitivity approach

The real power loss in the system is given by (4).

This formula is popularly referred as “Exact Loss” formula [10].

$$P_L = \sum_{i=1}^N \sum_{j=1}^N [\alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j)] \dots (4)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)$$

and

$Z_{ij} = r_{ij} + jx_{ij}$  are the  $ij^{\text{th}}$  element of [Zbus] matrix with  $[Zbus] = [Ybus]^{-1}$ . (Prefer Z-bus building algorithm).

The sensitivity factor of real power loss with respect to real power injection from the DG is given by

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2 \sum_{j=1}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) \dots (5)$$

Sensitivity factor are evaluated at each bus by using the values obtained from the base case load flow. The bus having lowest loss sensitivity factor will be best location for the placement of DG as shown in fig.(4). Conventional load flow studies like Gauss-seidal, Newton raphson and fast decoupled load flow methods are not suitable for distribution load flows because of high R/X ratio. A new load flow method for distribution systems that offers better solution was proposed [11].

#### 4.1 Mathematical expression for finding the Optimal Sizing of DG:

The total power loss against injected power is a parabolic function and at minimum losses, the rate of change of losses with respect to injected power becomes zero.

$$\frac{\partial P_L}{\partial P_i} = 2 \sum_{j=1}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) = 0$$

It follows that

$$\alpha_{ii} P_i - \beta_{ii} Q_i + \sum_{j=1, j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) = 0$$

$$P_i = \frac{1}{\alpha_{ii}} \left[ \beta_{ii} Q_i + \sum_{j=1, j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) \right] \dots (6)$$

Where  $P_i$  is the real power injection at node i, which is the difference between real power generation and the real power demand at that node:

$$P_i = (P_{DG_i} - P_{Di}) \dots (7)$$

Where  $P_{DG_i}$  is the real power injection from DG placed at node i, and  $P_{D_i}$  is the load demand at node i. By combining the above we get.

$$P_{DG_i} = P_{D_i} - \frac{1}{\alpha_{ii}} \left[ \sum_{j=1, j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) \right] \dots (8)$$

$$Q_{DG_i} = Q_{D_i} - \frac{1}{\alpha_{ii}} \left[ \sum_{j=1, j \neq i}^N (\alpha_{ij} Q_j + \beta_{ij} P_j) \right] \dots (9)$$

The equation (5) gives the optimum size of DG for each bus i, for the loss to be minimum. Any size of DG other than  $P_{DG_i}$  placed at bus i, will lead to higher loss.

#### 4.2 Optimal Location of DG:

The optimal location can be find for the placement of DG which will give the lowest possible total losses and to improve the voltage profile. The real power loss is calculated by using the Exact Loss formula (4) at each bus, the bus having least power loss will be best possible location for the placement of DG [12,13], or the bus having lowest loss sensitivity factor will be best location for the placement of DG.

##### Computational procedure:

Step 1: Run the base case load flow.

Step 2: Find the optimum size of DG for each bus using eq.(8).

Step 3: The optimum size of capacitor can be find by using eq.(9).

Step 4: Compute the approximate loss using eq. (4) for each bus by placing DG of optimum Size obtained in step 2 for that bus.

Step 5: Locate the bus at which the loss is minimum after DG placement that is optimum location of DG.

Step 6: Run the base case load flow with DG for final result.

##### Test system:

This methodology is tested on test system contains 33 buses and 32 branches as shown in fig.2. It is a radial system with a total load of 3.72 MW and 2.3 MVAR [14] with the bus data and line data given in Appendix-I and Appendix-II respectively. A computer program is written in MATLAB 7 to find the optimal size of DG at various buses and approximate total loss with DG at various locations to find out the best location for the improvement in voltage profile [15].

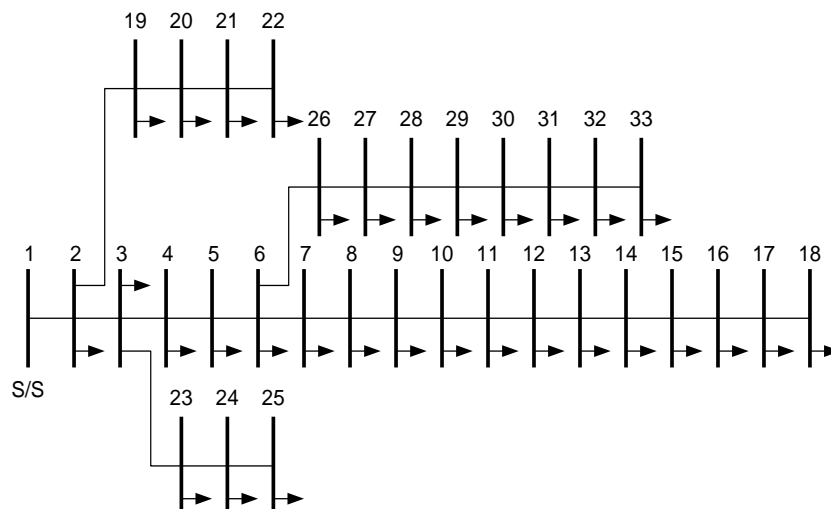


Fig.2 Single line diagram of 33 bus distribution test system.

### Results:

Based on the analytical expression and using PSO, the optimum size of DG is calculated at each bus for the test system. To identify the location, the losses at each bus are calculated after the placement of optimal size of DG at each bus. The bus having least total power loss will be the optimal location for the placement of DG. The table 1.shows the three cases for the placement of DGs and capacitors on a optimal locations with optimal sizes and the total losses for a particular case.

In 33 bus distribution system, the fig (3) shows the variation in voltage with and without placement of single DG, as the size of DG and bus number given in table 1. .fig (4) shows the variation in voltage with and without the placement of single DG and single capacitor on the same bus as case-2. fig. (5) there is variation of voltage when we place two DGs and two Capacitors with one DG and one Capacitor on the same bus as shown in case-3.

Table: 1.

Cases	Bus Number	Capacity		Loss in MW	method
		P	Q		
case 1	7	2.4216	-----	0.1175	analytical
case 2	6	2.53	1.7195	0.0738	analytical
case 3	14	0.8772	0.3656	0.030454	PSO
	30	1.1105	1.064		

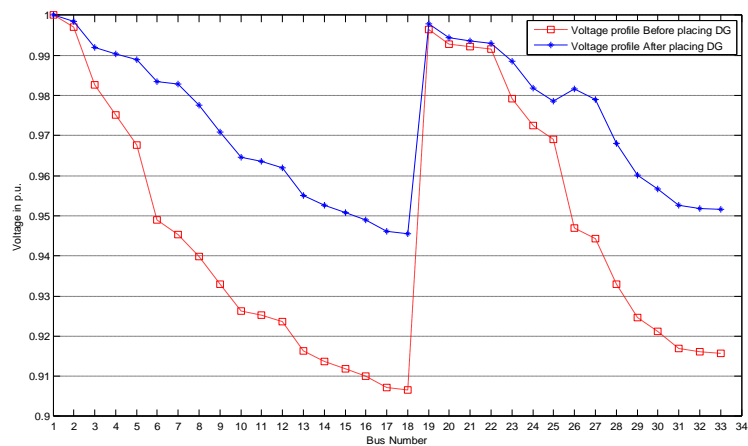


Fig 3: Variation in voltage with and without single DG placement.

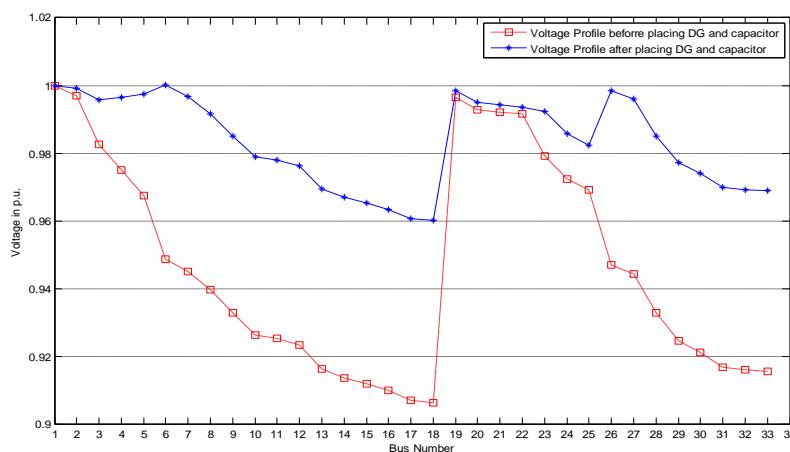


Fig 4: Variation in voltage with and without single DG and capacitor placement on same bus.

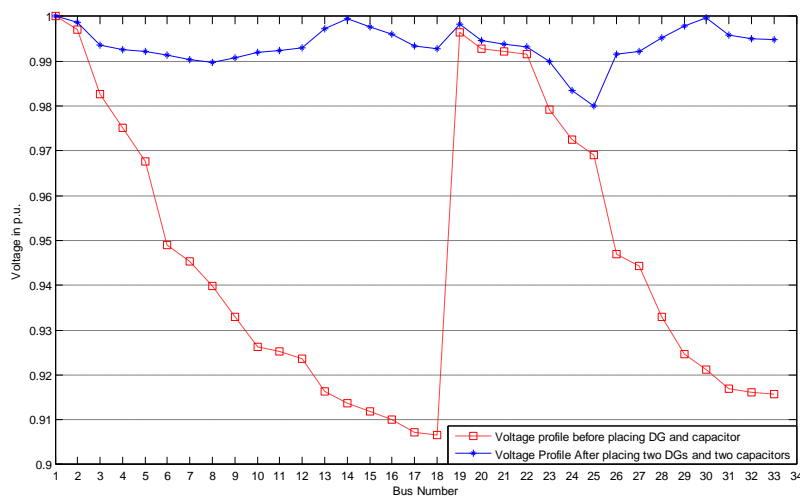


Fig 5: Variation in voltage with and without two DG and two capacitor placement on same bus.

### Conclusion:

From the results it is observed that optimal size and optimal location plays an important role for minimizing the total real power loss and to improve the voltage profile of the distribution system as shown in the fig.3-5.

### Appendix I Line Data (33-bus network)

Branch No.	Connections		Resistance in Ohm	Reactance in Ohm
	From	To		
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.03	0.74
9	9	10	1.044	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.164	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9774	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

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## Appendix II

**Load Data (33-bus network)**

Bus No.	Active power in kW	Reactive power in kVAR
1	0	0
2	100	60
3	90	40
4	120	80
5	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30

12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100
33	60	40

#### Biography

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