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Reduction of losses and improving voltage by Optimal Location of DG

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Abstract— This paper presents a comparison study between the Particle Swarm Optimization (PSO) technique and the exhaustive load flows which is tested on standard 33 bus system. PSO technique is applied to find the optimal size and location of DG in the radial distribution network. The optimal size of DG is calculated at each bus using the exact loss formula. The optimal location of DG is found by using the loss sensitivity factor. By using this technique, there will be reduction in real power losses for active power compensation and improvement in voltage profile.

Keywords— Include Distributed generation, Particle Swarm Optimization (PSO), optimal size, optimal location, power loss.

1.INTRODUCTION

Alternative energy sources are becoming more cost effective, and many utilities are now providing incentives for alternative power. Placing these alternative energy sources, as well as other smaller traditional energy sources, on the distribution power system, allows the development of a new paradigm related to distributed generation (DG). The general definition for DG is given as, “Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter”. Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators. In contrast to the use of a few large-scale generating stations located far from load centers--the approach used in the traditional electric power paradigm--DG systems employ numerous, but small plants and can provide power onsite with little reliance on the distribution and transmission grid.

Usually DGs are classified according to their different types and operating technologies. Different DG technologies are implemented to fulfill the requirements of a wide range of applications.

These applications differ according to the load requirements. As a result they affect the types of DGs used. Some of the applications are standby, peak load shaving, base load, providing combined heat and power, rural and remote applications. DG affects the flow of power and voltage conditions on the system equipment. These system support benefits which include voltage support, loss reduction, transmission and distribution capacity release, improved utility system reliability and power quality. On account of achieving above benefits, the DG must be of the proper size and at the proper locations.

DG has many advantages such as reliability, flexibility, upgradability, economy of scale, diversity and efficiency. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. The problem of DG allocation and sizing is of great importance.

2. LOCATION AND SIZING ISSUES

Fig. 1 shows a 3D plot of typical power loss versus size of DG at each bus in a standard 69-bus distribution test system. Fromthe figure, it is obvious that for a particular bus, as the size of DG is increased, the losses are reduced to a minimum value and increased beyond a size of DG (i.e. the optimal DG size) at that location. If the size of DG is further increased, the losses starts to increase and it is likely that it may overshoot the losses of the base case. Also notice that location of DG plays an important role in minimizing the losses. The important conclusion that can be drawn from Fig. 1 is that, given the characteristics of the distribution system, it is not advisable to construct sufficiently high DG in the network. The size at most should be such that it is consumable within the distribution substation boundary. Any attempt to install high capacity DG with the purpose of exporting power beyond the substation (reverse flow of power though distribution substation), will lead to very high losses (Lakshami et al, 2008). So, the size of distribution system in term of load (MW) will play important role is selecting the size of DG.

The reason for higher losses and high capacity of DG can be explained by the fact that the distribution system was initially designed such that power flows from the sending end (source substation) to the load and conductor sizes are gradually decreased from the substation to consumer point.

Thus without reinforcement of the system, the use of high capacity DG will lead to excessive power flow through smallsized conductors and hence results in higher losses.

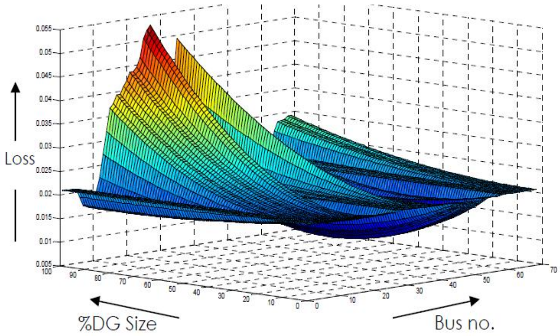


Figure 1. Effect of size and location of DG on system loss.

2.1 LOSS SENSITIVITY FACTOR:

The loss sensitivity factor is used for the placement of DG is explained as, the real power loss in the system is given by (1).This formula is popularly referred as “Exact Loss” formula (Elgerd, 1971; Kazemi et al, 2009).

$$P_L = \sum_{i=1}\sum_{i=1}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j + P_iQ_j)] \quad (1)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{v_i v_j}\mathrm{Cos}(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{v_i v_j}\mathrm{Sin}(\delta_i - \delta_j)$$

and

$z_{ij} = r_{ij} + jx_{ij}$ are the ijth element of [Zbus] matrix

$P_i = P_{Gi} - P_{Di}$ and $Q_i = Q_{Gi} - Q_{Di}$

P_{Gi} & Q_{Gi} are power injection of generators to the bus.
P_{Di} & Q_{Di} are the loads.

P_i & Q_i are active and reactive power of the buses.

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

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

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 (Acharya et al, 2006). Conventional load flow studies like Gaussseidal, Newton raphson and fast decoupled load flow methods are not suitable for distribution load flows because of high R/X ratio. A load flow method for distribution systems i.e backward sweep and forward sweep method for load flow that offers better solution was proposed (Haque 1996).

2.2 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 [9].

$$\frac{\partial P_L}{\partial P_i} = 2\alpha_{ii}P_i + 2\sum_{j=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \quad (3)$$

It follows that

$$P_i = \frac{1}{\alpha_{ii}}\left[\sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \quad (4)$$

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

$$P_i = (P_{DGi} - P_{Di})$$

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

$$P_{DGi} = P_{Di} - \frac{1}{\alpha_{ii}}\left[\sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \quad (5)$$

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 PDGi placed at bus i, will lead to higher loss.

2.3 Optimal Location of DG:

The optimal location can be find for the placement of optimal sizes of DG as shown in fig.(2) as obtained from eq. (5) which will give the lowest possible total loss due to placement of DG at the respective bus is as shown in fig. (3). The bus having least power loss will be optimal location for the placement of DG (Acharya et al, 2006).

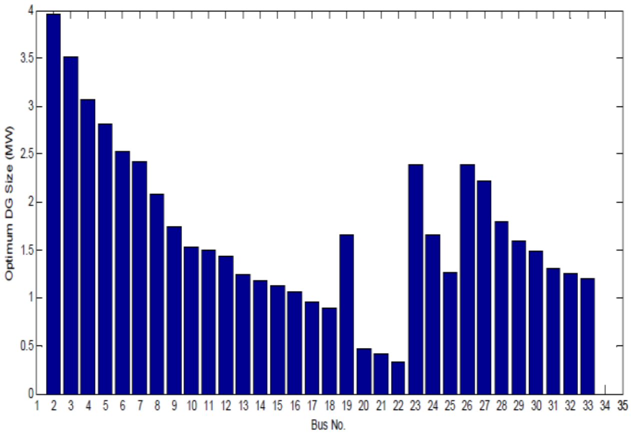


Figure 2. Optimum size of DG at various locations for 33 bus distribution system

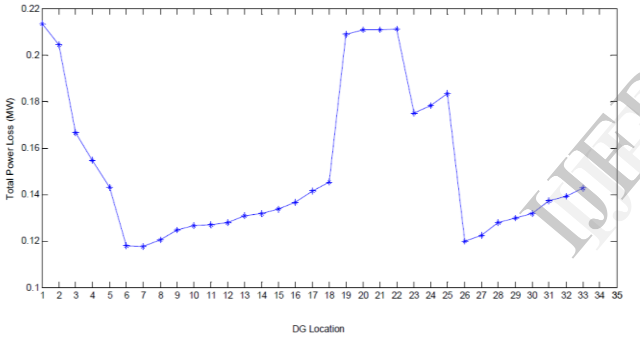


Figure 3. Accurate Total Power Loss of 33 bus distribution system.

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 (Kennedy et al, 1995). 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 4).

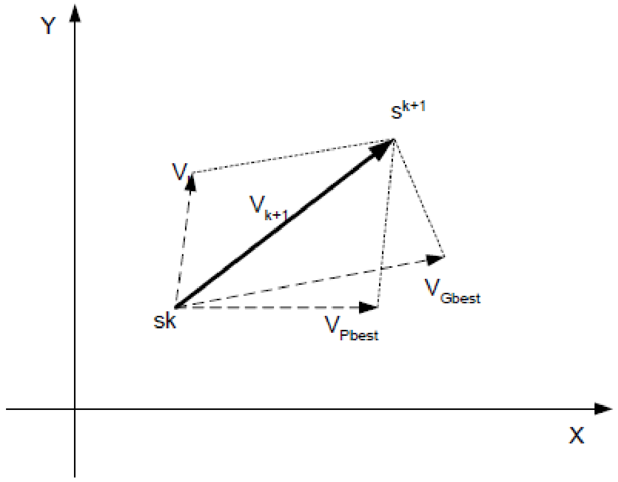


Figure 4. Concept of a searching point by PSO

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

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand \times (pbest_{id} - s_{id}^{k}) + c_2 rand \times (gbest_{id} - s_{id}^{k}) \quad (6)$$

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:

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1}, i = 1, 2, \dots, n. \quad (7)$$

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

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,
ω_i is weight function for velocity of agent *i*,
c_i is weight coefficients for each term.

The following weight function is used:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}}.k \qquad (8)$$

Where,
ωmin and ωmax are the minimum and maximum weights respectively. k and $k$max are the current and maximum iteration.
Appropriate value ranges for *C1* and *C2* are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for ωmin and
ωmax are 0.4 and 0.9 (Eberhart et al, 2000) respectively

3.2 Objective Function:

The main objective is to minimize the total power loss as given in eq. (1) while meeting the following constraints.

- The network power flow equation must be satisfied.
- The voltage at every bus in the network should be within the acceptable range (Utility's standard ANSI Std. C84.1-1989) i.e., within permissible limit (±5%) (Wills, 2004),

$Vmin \le Vi \le Vmax \ \forall \ i \in \{\text{buses of the network}\}$

3.3 PSO Procedure:

The PSO-based approach for solving the optimal placement of DG 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 sweep-forward sweep method.

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

Step 4: For each particle if the bus voltage is within the limits as given above, evaluate the total loss in equation (1). 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*.

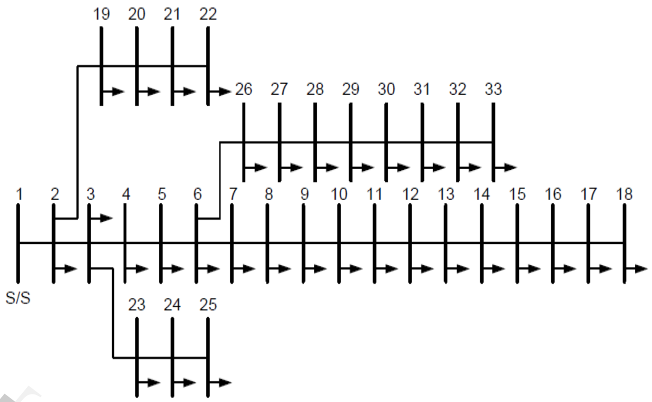
Step 7: Update the velocity and position of particle using (6) and (7) respectively.

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 and the corresponding fitness value representing the minimum total real power loss.

Test system

This methodology is tested on test system contains 33 buses and 32 branches as shown in fig.5. It is a radial system with a total load of 3.72 MW and 2.3 MVAR (Kashem et al, 2000). 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 by analytical method, repeated load flow (Acharya et al, 2006) and PSO.



4. Results and Discussions

Based on the analytical expression, the optimum size of DG is calculated at each bus for the test system and bus having least total power loss will be the optimal location for the placement of DG; the best location is bus 6 with a total power loss of 111.2kW, but this approach violates the voltage limits as shown in fig.(6).The optimal placement of DG by loss sensitivity approach is not able to identify the best location. The optimal placement of DG by repeated load flow with loss of 111.02kW as shown in Table I violate the voltage limits, If voltage limits are taken into consideration then size of DG will increase but if the same is done by PSO technique by taking the voltage limit constraints into consideration the size of DG will decrease drastically i.e. 240kW,with approximately same power loss as shown in table II, and voltage profile is as shown in fig.(7).

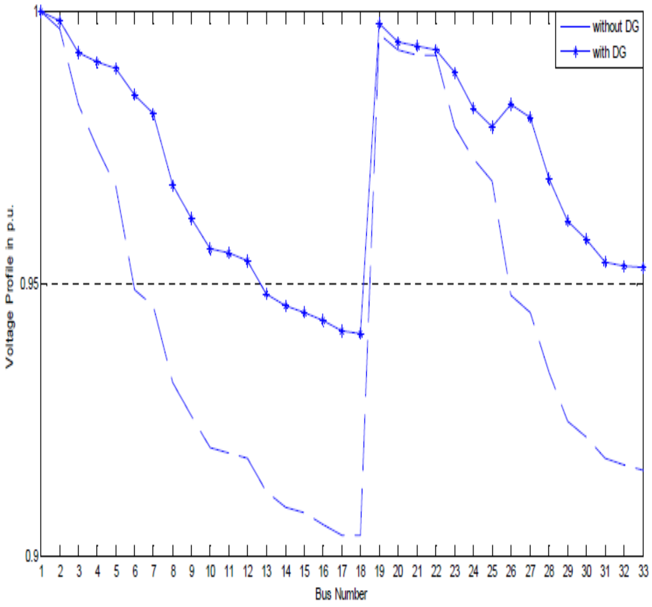


Figure 6. Variation of voltage profile by analytical method.

Table I Power loss with and without DG for 33 bus system without limits

Method	Optimum location	Optimum DG size (MW)	Power loss (KW)	
			Without DG	With DG
Analytical approach	Bus 6	2.49	210.97	111.2
Loss sensitivity factor	Bus 10	1.4	210.97	123.72
Repeated load flow	Bus 6	2.59	210.97	111.02

Table II Power loss with and without DG for 33 bus system with limits

Method	Optimum location	Optimum DG size (MW)	Power loss (KW)	
			Without DG	With DG
Repeated load flow	Bus 6	3.15	210.97	115.2
PSO	Bus 7	2.91	210.97	115.1

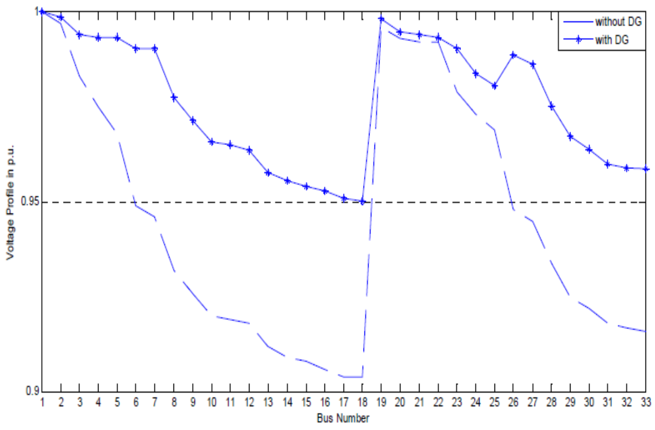


Figure 7. Variation of voltage profile by PSO.

5. Conclusion

Optimal placement of DG plays an important role for maximizing the total real power loss reduction in the distribution system with active power compensation. The optimal placement by analytical method violates the line voltage limits, if voltage is within limits then the size and line losses increases. The optimal placement of DG by PSO technique taking the voltage limits of the system into consideration to minimizing the real power loss improves the results drastically. But in practice the best location or size may not always be possible due to many constraints i.e. such size may not be available in the market.

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