

Effect of Dg penetration level on the real power losses in radial distribution systems

¹K Mercy Rosalina, ²N Prema Kumar

¹Research Scholar, Department of Electrical Engineering, Andhra University, Visakhapatnam

²Associate Professor, Department of Electrical Engineering, Andhra University

Abstract

Distributed Generation or localised generation of electrical power has been gained increasing popularity as a feasible element of electrical power systems. DG, as small scale generating source located near the load center, is usually integrated within the Distribution System (DS). Integration of DG has many benefits like reduction in transmission and distribution congestion, deferring investment on upgrades, meeting demand growth and improving distribution system performance by reducing power losses and enhancing voltage profile and security. To achieve most of the benefits from DG integration, the DG has to be placed and sized optimally. In this paper, implementation of a simple analytical algorithm based on distribution load flow studies for optimal sizing of distributed generators considering % DG penetration levels is presented. Later the impact of variation of DG on power loss is investigated and suggested the optimal DG levels for the maximum reduction of power losses in radial distribution systems. The algorithms are built in MATLAB platform.

Keywords: Radial Distribution System, Load Flow, Distributed Generation, DG Penetration Level, Real Power Losses

1. Introduction

Integration of generating resources like DGs into the distribution system can significantly impact the power flow and voltage conditions at consumer, utility equipment and etc. DG sources have been attracted serious attention due to their potential benefits and solution for some issues, like the power system deregulation, increased power consumption and the shortage of generation and transmission capacities. Optimal placement and sizing of DGs is necessary for maximizing the DG system support benefits in power system such as maintaining and/or improving stability and reliability. There are several research studies to determine the optimal allocation and capacity of DGs by their imposed objectives and system constraints. The main objective of DG placement techniques is to minimize the real power losses in the system. However, the other objectives like voltage profile improvement, reliability, DG capacity maximization, cost minimization and etc have also been considered in different studies. Selecting the better places for installation of DGs and their preferable sizes in large distribution systems is a complex multidimensional and combinatorial optimization problem. Thus, using an optimization technique which is capable of indicating the better solution for a given distribution network would help the system planning engineers. An optimization technique should be employed for the optimum allocation of energy resources. It is a tool that can be used for the design of a new distribution system and also for the resizing of an existing distribution system for loss minimization^[1]. Analytical techniques based on “2/3” rule for the optimum allocation DG in a radial feeder with uniformly distributed load, it is suggested that, install DG approximately 2/3 capacity of incoming generation at approximately 2/3 of the length of line”. In this approach, DG size is not optimized^[2]. A GA based approach for optimal allocation of DG for loss minimization at different loading conditions is investigated. Proposed approach is implemented

on different standard test system and results are presented^[3]. Optimal placement of distributed generators in a radial distribution system using GA based multi-objective performance index approach is presented. Effect of load model on location and size of DG is investigated and results are presented^[4]. A new optimization algorithm based on integrating the use of genetic algorithm and Tabu search to optimal allocation of distributed generators in radial distribution networks has presented^[5]. The effect of load models on planning of DG in radial distribution system is investigated. A comparative study on all system support benefits by installing DG sources with different load models has been presented^[6]. An analytical expression is derived to determine the optimum size and corresponding location for DG placement for minimization total real power losses in the distribution system. The approach is based on exact loss formula^[7]. This paper presents an analytical approach based on distribution load flow studies to enumerate the impact of DG size on the percentage of real power losses in the radial distribution systems.

2. Distribution Generation

Distributed Generation is defined as, the energy generation close to the point of use. Distributed generation capacity is range from 1 kilowatt to 10 Megawatts. Whereas central generating plants (500 MW to 3000 MW) usually located at long distance from where the energy consumed. Hence, the electricity needs transportation system through transmission and distribution to the end consumer^[6, 2]. The direction of the flow of power in the distribution networks was always almost from the higher voltage to the lower voltage levels. This system architecture was economical and a technical choice with new technology and a changed economical and commercial environment. Hence, the power system is now beginning to be modified by the reintroduction of small generation connected to

the distribution networks. Such generation is called distributed generation and this has been simulated by number of technological, commercial and environmental factors. The integration of small scale generation with the utility distribution network is one of the kinds of distributed generation. Today, distribution networks operating passively delivering power from transmission network through the distribution network to the end consumer. They have been built and are operated/regulated to work this way. Currently, the main aim of distribution network operators has to be built and maintain networks, which receive power from higher voltage transmission network and deliver it to consumers. This has result in passive networks with little distributed generation.

2.1 Advantages of Distributed Generation and Key Issues

The advantages of distributed generators are as follows: It can reduce or avoid up gradation of existing transmission and distribution lines. It can be used to meet peak power demand. It can increase the reliability of the grid network. It can deliver premium power when coupled with UPS. It can reduce the system losses and improve the voltage profile. It can be suited to the use of renewable energy technologies, because they are located near to the user. It can be installed in small increments to match the requirement of the load. The two key business issues for the growth of distributed energy are: Continued decline in the cost of distributed energy technologies. Co-operation from Utilities and local Governments firstly to ensure the appropriate physical infrastructure to accept distributed generation into the electricity grid, and secondly to facilitate the development of reasonable Connection Agreements.

2.2 Applications of Distributed Generating Systems

There could be many reasons from customer point of view for choosing a distributed generator, some of them are; DG can be used to generate a customer's entire electricity needs, for peak sharing (generating a portion of a customer's electricity need onsite to reduce the amount of electricity purchased during peak price periods from the utility) and for standby/emergency generation (as a backup to wires owner's power supply). In some remote areas/locations, DG can be less costly as it eliminates the need for the expansion of expensive construction of distribution and/or transmission lines.

3. Integration of Distributed Generator into the Distribution System

The single-line diagram of two bus power distribution system with integration of distributed generation is given in Figure 1

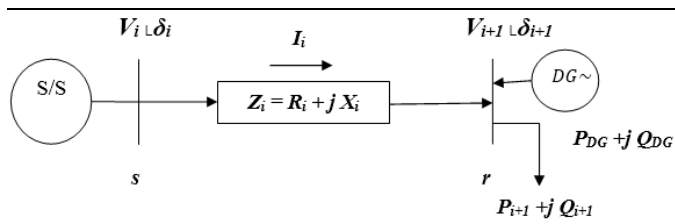


Fig 1: Single-line diagram of a main feeder with DG

P_{DG} = Real power supplied by DG
 Q_{DG} = Reactive power supplied by DG

If DG is modelled as PQ node model then generators are treated as negative loads. Hence, injected power at $i+1$ bus can written as

$$P_{inj} = P_{i+1} - P_{DG} \quad (1)$$

$$Q_{inj} = Q_{i+1} - Q_{DG} \quad (2)$$

By substituting Eq. (1) and Eq. (2) in node voltage Equation, then

$$|V_{i+1}|^2 - |V_i||V_{i+1}| + (P_{inj}^2 + Q_{inj}^2)^{\frac{1}{2}} * (R_i^2 + X_i^2)^{\frac{1}{2}} = 0 \quad (3)$$

Possible feasible solution for Eq. (3) is

$$|V_{i+1}| = \frac{|V_i| \pm \left(|V_i|^2 - 4 \left((P_{inj}^2 + Q_{inj}^2)^{\frac{1}{2}} \right) (R_i^2 + X_i^2)^{\frac{1}{2}} \right)^{\frac{1}{2}}}{2} \quad (4)$$

3.1 Effect of DG on Line Loss of a Distribution System

Installation of DG units in optimal locations of a distribution system results in several benefits. These include line loss reduction, improvement of voltage profile, peak demand saving, relieving over loading of distribution line etc. DG Penetration level is defined as the ratio of DG size to the total connected in the distribution system and is given

$$P_L = \frac{S_{DG}}{S_{load}} * 100\% \quad (5)$$

Where S_{DG} = Apparent power of DG.

S_{load} = Total apparent load of the network.

The power loss when DG is connected at $i+1$ bus in the network as shown in Figure 1, is given by

$$|I_i| = \frac{((P_{i+1} - P_{DG})^2 + (Q_{i+1} - Q_{DG})^2)^{\frac{1}{2}}}{|V_i|} \quad (6)$$

$$P_{Loss(i,i+1)}^{DG} = \frac{(P_{inj}^2 + Q_{inj}^2)}{|V_{i+1}|^2} * R_i \quad (7)$$

$$P_{Loss(i,i+1)}^{DG} = \frac{((P_{i+1} - P_{DG})^2 + (Q_{i+1} - Q_{DG})^2)}{|V_{i+1}|^2} * R_i \quad (8)$$

$$Q_{Loss(i,i+1)}^{DG} = \frac{((P_{i+1} - P_{DG})^2 + (Q_{i+1} - Q_{DG})^2)}{|V_{i+1}|^2} * X_i \quad (9)$$

$$P_{Loss(i,i+1)}^{DG} = R_i \frac{(P_{i+1}^2 + Q_{i+1}^2)}{|V_{i+1}|^2} + \frac{P_{DG}^2 + Q_{DG}^2 - 2P_{i+1}P_{DG} - 2Q_{i+1}Q_{DG}}{|V_{i+1}|^2} * R_i \quad (10)$$

Net power loss reduction, ΔP_{Loss}^{DG} in the system is the difference of power loss before and after installation of DG unit is given by

$$\Delta P_{Loss}^{DG} = \frac{P_{DG}^2 + Q_{DG}^2 - 2P_{i+1}P_{DG} - 2Q_{i+1}Q_{DG}}{|V_{i+1}|^2} * R_i \quad (11)$$

The positive sign of the ΔP_{Loss}^{DG} indicate that the losses in the system reduces with installation of DG. In contrast, the negative sign indicates that DG causes high power loss in the system.

The flow chart for distribution system load flow is given in Figure 2.

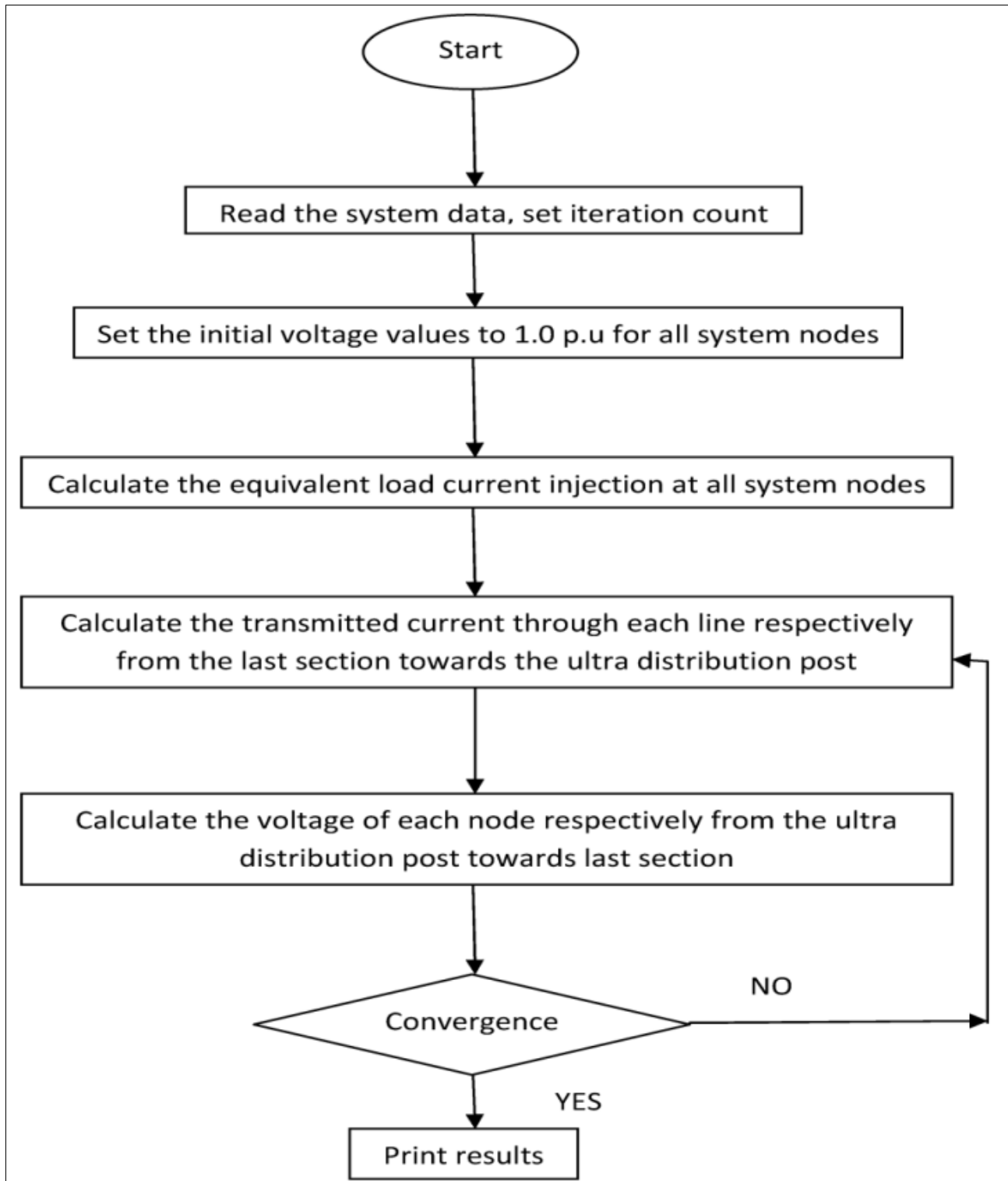


Fig 2: Flowchart for distribution system load flow

4. Results and Discussion

For the analysis of penetration level of DG Vs% of real power losses in a radial distribution system, the location of DG is varied from bus 2 to bus 30 except bus 1, since it is the source bus or sub-station bus. Note that addition of DG at bus 1 has no effect. For each location from bus 2 to bus 30 rated MW capacities of DG is varied from 10% to 80% of the total load in steps of 10% as shown in Table 1. For each case the total line loss in terms of percentage of total load is calculated. From the above Table it is noticed that minimum percentage of line losses

(3.97) is obtained at DG is 70% of the total load plus losses. After, 70% of DG penetration level the percentage of line losses will again increased. This was clearly noticed from figure3. So, the optimal penetration level of DG is around 70% only. And this value may be varied form system to system. The DG level may be varied from 0 to 100% of the total network load connected, but after certain level of DG penetration level, here it is 70%, the real power losses are increasing at various busses as expected.

Table 1: Analysis of penetration level of DG Vs% of real power losses in a 30 bus radial distribution system

Bus No.	Rated capacity of DG in percentage of total load								
	0%	10%	20%	30%	40%	50%	60%	70%	80%
2	10.09	9.91	9.73	9.57	9.42	9.29	9.18	9.09	9.01
3	10.09	9.74	9.39	9.09	8.82	8.58	8.39	8.22	8.09
4	10.09	9.47	8.89	8.39	7.94	7.57	7.25	7.00	6.81
5	10.09	9.24	8.46	7.78	7.20	6.71	6.31	6.00	5.77
6	10.09	9.01	8.05	7.22	6.51	5.93	5.46	5.11	4.87
7	10.09	8.88	7.84	7.00	6.33	5.84	5.51	5.33	5.30
8	10.09	8.81	7.75	6.92	6.30	5.88	5.66	5.61	5.73
9	10.09	8.74	7.67	6.88	6.36	6.07	6.01	6.17	6.52
10	10.09	8.71	7.65	6.91	6.46	6.27	6.34	6.63	7.14
11	10.09	8.70	7.66	6.96	6.56	6.44	6.58	6.97	7.58
12	10.09	8.71	7.69	7.02	6.67	6.61	6.82	7.28	7.97
13	10.09	9.74	9.42	9.17	8.97	8.83	8.75	8.72	8.75
14	10.09	9.74	9.47	9.28	9.18	9.17	9.24	9.39	9.62
15	10.09	9.75	9.49	9.34	9.30	9.35	9.49	9.73	10.06
16	10.09	9.75	9.51	9.38	9.36	9.44	9.62	9.91	10.29
17	10.09	8.83	7.74	6.81	6.04	5.43	4.96	4.64	4.46
18	10.09	8.69	7.48	6.48	5.67	5.05	4.61	4.33	4.21
19	10.09	8.52	7.20	6.13	5.29	4.68	4.28	4.08	4.06
20	10.09	8.39	6.98	5.87	5.03	4.44	4.09	3.97	4.05
21	10.09	8.27	6.80	5.66	4.83	4.29	4.01	3.97	4.16
22	10.09	8.14	6.60	5.46	4.67	4.20	4.03	4.13	4.48
23	10.09	8.04	6.46	5.33	4.60	4.22	4.17	4.42	4.93
24	10.09	7.95	6.36	5.27	4.63	4.38	4.49	4.92	5.63
25	10.09	7.91	6.33	5.29	4.72	4.57	4.79	5.34	6.19
26	10.09	7.90	6.34	5.34	4.82	4.74	5.03	5.66	6.59
27	10.09	7.91	6.37	5.41	4.94	4.90	5.26	5.95	6.96
28	10.09	8.88	7.87	7.07	6.48	6.08	5.86	5.81	5.93
29	10.09	8.88	7.90	7.16	6.64	6.34	6.23	6.31	6.56
30	10.09	8.89	7.95	7.26	6.83	6.61	6.62	6.82	7.21

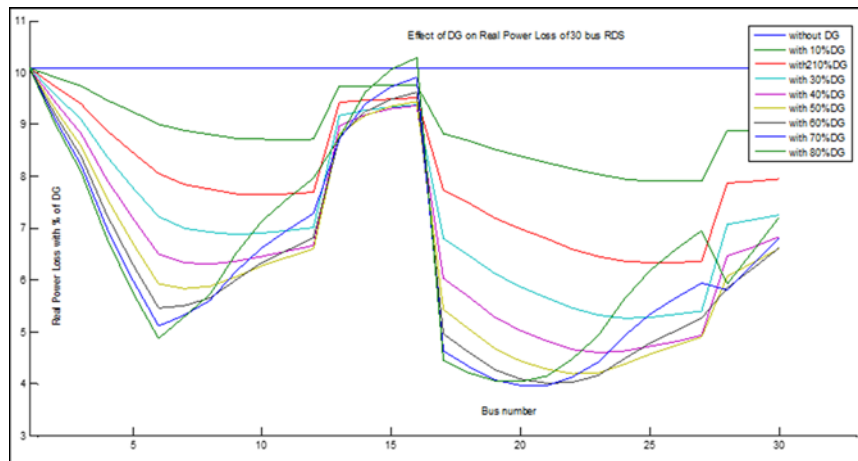


Fig 3: Variation of Real power losses with DG size

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