2012 IACSIT Coimbatore Conferences
IPCSIT vol. 28 (2012) © (2012) IACSIT Press, Singapore

Optimal Allocation of Distributed Generation in Distribution System for Loss Reduction

Gopiya Naik S. [1+], D. K. Khatod [2] and M. P. Sharma [2]

[1] Research Scholar, Alternate Hydro Energy Centre, IIT Roorkee, Roorkee-247667, India
[2] Faculty, Alternate Hydro Energy Centre, IIT Roorkee, Roorkee-247667, India

Abstract. Integration of renewable energy based distributed generation (DG) units provides potential benefits to conventional distribution systems. The power injections from renewable DG units located close to the load centers provide an opportunity for system voltage support, reduction in energy losses and emissions, and reliability improvement. Therefore, the allocation of DG units should be carefully determined with the consideration of different planning incentives. This paper presents a simple method for real power loss reduction, voltage profile improvement, substation capacity release and is based on voltage sensitivity index analysis. Power flow analysis is done using the forward-backward sweep method. Study carried out on an IEEE-33 bus test system validates the suitability of this proposed method.

Keywords: radial distribution system, distributed generation, renewable energy sources, voltage sensitivity index, real power loss.

1. Introduction

Due to limitation on fossil fuel resources, alternative solutions to traditional large power stations are under high priority in recent years to meet growing energy demand of the future. Also large power stations are discouraged due to many environmental concerns. On the other hand, renewable energy resources have been considered as the best alternative to traditional fossil fuels. The sizes of renewable energy based electricity generators would be very small as compared to large fossil fuel based power plant. Technically, they are suitable for installation at low voltage distribution system, near loads centres [1].

Electric power systems have been originally designed based on the unidirectional power flow, but the concept of distributed generation (DG) has led to new considerations concerning the distribution networks [2]. The penetration of DG may impact the operation of a distribution network in both beneficial and detrimental ways. Some of the positive impacts of DG are: voltage support, power loss reduction, support of ancillary services and improved reliability, whereas negative ones are protection coordination, dynamic stability and islanding. In order to maximize benefits and minimize problems, technical constraints concerning the interconnection of DG units and their penetration levels are being adopted worldwide. Furthermore, the presence of DG in the deregulated market has raised new regulatory issues, concerning financial incentives, cost allocation methods, generation management techniques, etc.

There are a number of approaches proposed for placement and sizing of DG units. Chiradeja and Ramkumar [3] presented a general approach and set of indices to assess and quantify the technical benefits of DG in terms of voltage profile improvement, line loss reduction and environmental impact reduction. Khan and Choudhry [4] developed an algorithm based on analytical approach to improve the voltage profile and to reduce the power loss under randomly distributed load conditions with low power factor for single DG as well as multi DG systems. Hung et al. [5] used an improved analytical method for identification of the best location and optimal power factor for placing multiple DGs to achieve loss reduction in large-scale primary

[+] Corresponding author. Tel.: +91-1332-286125; fax: +91-1332-273517.
E-mail address: gopiya.naik94@gmail.com.

distribution networks. For optimal placement of DG, Mithulanathan et al. [6] presented a genetic algorithm based approach to minimize the real power loss in the system and found a significant reduction in the system loss. The optimal sizing and siting of DGs was investigated by Ghosh et al. [7] to minimize both cost and loss with proper weighing factors using Newton-Raphson (NR) load flow method. Ziari et al. [8] proposed a discrete particle swarm optimization and genetic algorithm (GA) based approach for optimal planning of DG in distribution network to minimize loss and improve reliability. Kamel and Karmanshahi [9] proposed an algorithm for optimal sizing and siting of DGs at any bus in the distribution system to minimize losses and found that the total losses in the distribution network would reduce by nearly 85%, if DGs were located at the optimal locations with optimal sizes. Singh et al. [10] discussed a multi-objective performance index-based technique using GA for optimal location and sizing of DG resources in distribution systems.

This paper presents a simple method for real power loss reduction, voltage profile improvement, substation capacity release and is based on voltage sensitivity index analysis. Power flow analysis is done using the forward-backward sweep method. Test results carried out on an IEEE-33 bus system validates the suitability of this proposed method.

2. Methodology

2.1. Load Flow Analysis

Conventional NR and Gauss Seidel (GS) methods may become inefficient in the analysis of distribution systems, due to the special features of distribution networks, i.e. radial structure, high R/X ratio and unbalanced loads, etc. These features make the distribution systems power flow computation different and somewhat difficult to analyze as compared to the transmission systems. Various methods are available to carry out the analysis of balanced and unbalanced radial distribution systems and can be divided into two categories. The first type of methods is utilized by proper modification of existing methods such as NR and GS methods. On the other hand, the second group of methods is based on backward and forward sweep processes using Kirchhoff's laws. Due to its low memory requirements, computational efficiency and robust convergence characteristic, backward and forward sweep based algorithms have gained the most popularity for distribution systems load flow analysis. In this study, backward and forward sweep method [11] is used to find out the load flow solution.

2.2. Optimal Location of DG based on Voltage Sensitivity Index

In order to restrict solution space to few buses, voltage sensitive nodes are first identified by penetrating DG with 25% of the total feeder loading capacity at each node at a time and then, calculating the voltage sensitivity index (VSI) using (1). When DG is connected at bus *i*, VSI for bus *i* is defined as [12]:

$$\mathrm{VSI}_i = \sqrt{\frac{\sum_{k=1}^{n}\left(1-V_k\right)^2}{n}} \tag{1}$$

Where V_k is voltage at k^{th} node and n is the number of nodes.

The node with least VSI will be picked as the best location for the DG placement.

2.3. Optimal size of DG

To determine the optimal size of DG, the following steps are taken [13]:

1) First, the DG is placed at the node with least VSI.
2) Keeping the power factor of DG constant, its size is varied from a minimum value to a value equal to feeder loading capacity in constant steps until the minimum system losses is found.
3) The DG size which results in minimum losses is taken as optimal.

3. Results and Discussions

The system under study is an IEEE-33 bus network having system voltage of 12.66 kV and the total real and reactive power demand of 3.665 MW and 2.3 MVAr respectively. The relevant data for this test system are acquired from reference [15]. Following two cases are considered in this study for analysis:

1) Case I: DG is operated at power factor 0.9 lag
2) Case II: DG is operated at unity power factor

First base case load flow (without DG) analysis is done to calculate the bus voltage magnitudes and total network power loss in the radial distribution system (RDS). Further, load flow with DG capacity of 25% of the total feeder loading capacity (i.e. 1 MVA) is carried out to find VSI at various buses using (1). Fig. 1 shows the variation of VSI at various buses. As seen from this figure, bus number 16 is having the lowest VSI value of 0.03152. Therefore, bus 16 is considered as the candidate bus for the DG placement.

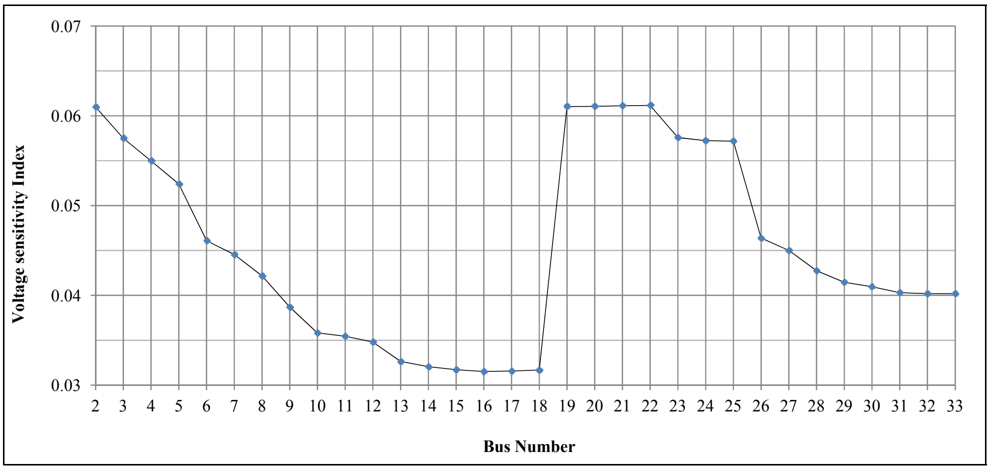

Fig. 1: Voltage sensitivity index at different buses

To find the optimal DG size, DG working at 0.9 power factor lag (for Case I) and unity power factor(for Case II) is considered and its size is increased from 0.5 MVA to 4.0 MVA in step of 0.5 MVA. Fig. 2 shows the variation of power loss with DG size.

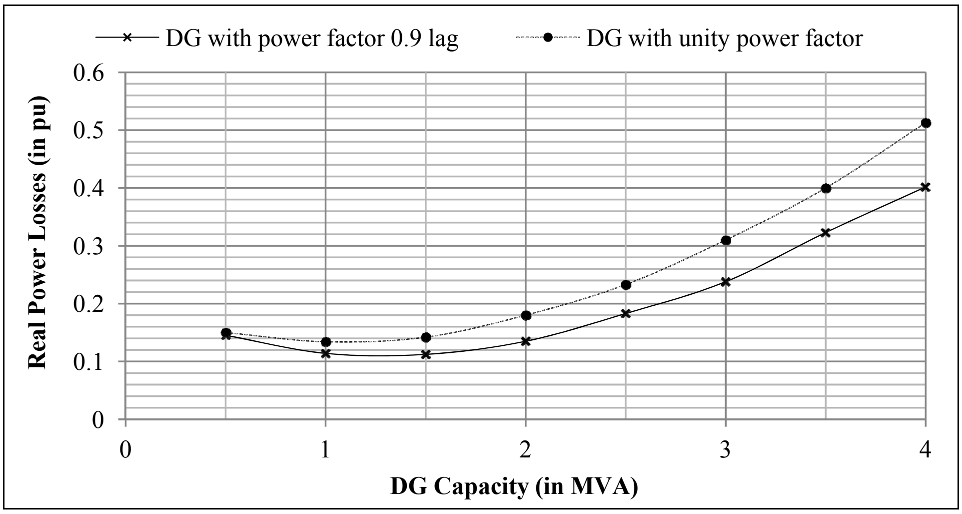

Fig. 2: Variation of power losses for different cases

From Fig. 2, it can be observed that the power losses are varying non-linearly with respect to generator capacity. The losses first decrease to some minimum values and then increase with increment in DG capacity. Table I shows optimal size of DG obtained and Table II shows the improvement in system performance for different cases.

Table I: Optimal Size of DG for Different Cases

Case	DG Size
Case I	1.5 MVA at 0.9 power factor lag
Case II	1.0 MVA at unity power factor

Table II: Improvement in system performance for different cases

Parameters	Base case	Case I	Case II
Active power losses (in pu)	0.213	0.1123	0.134
Reactive power losses (in pu)	0.143	0.0791	0.09
Real power from substation (in pu)	3.97	2.52	2.89
Reactive power from substation (in pu)	2.44	1.73	2.39

From the Table II, it is evident that the base case (without DG) total real and reactive power losses are 0.213 pu and 0.143 pu, respectively, whereas these losses for the optimal DG of size 1.5 MVA at 0.9 power factor lag results in the more loss reduction compared to optimal sizes and power factor of DG of 1.0 MVA at unity power factor. Therefore, higher power loss reduction in distribution networks in the presence of DG depends on the optimal size, location and also on the power factor (DG technology). Table II also shows the comparison of substation capacity release caused in different cases as a result of the introduction of DG. It can be seen that for the case I substation capacity release is more as compared to Case II.

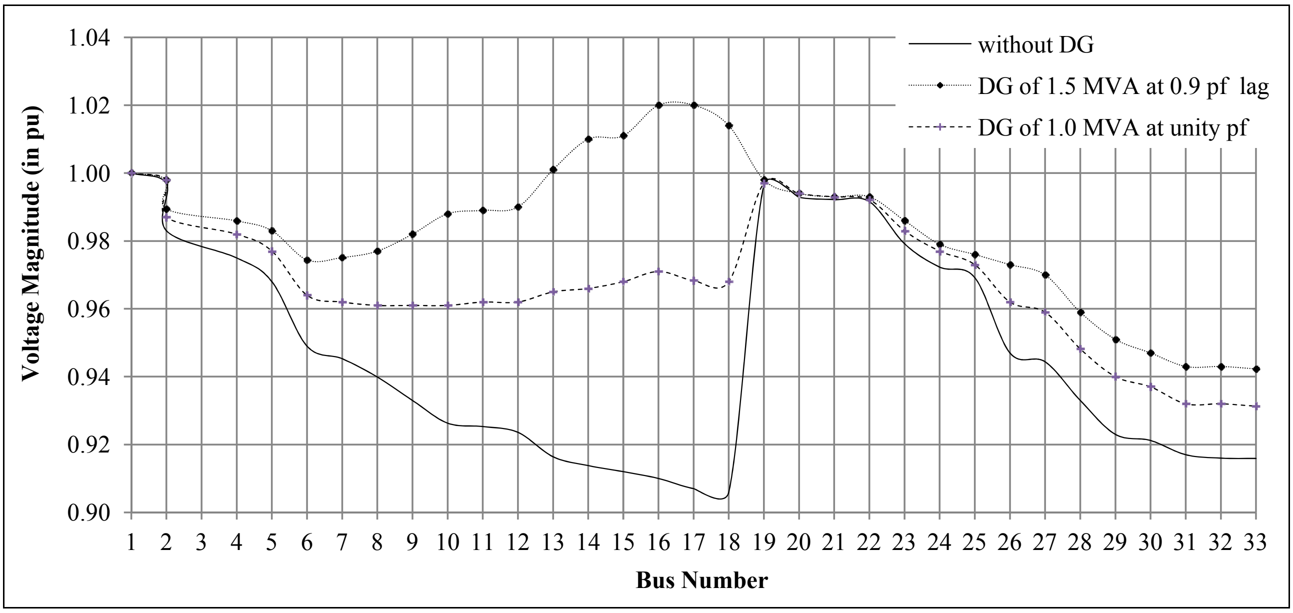

Fig. 3: Variation of voltage profile in different cases

The voltage profile when optimal DG size is placed at optimal location is shown in Fig. 3. By introducing DG in the system, voltage profile is improved because DG can provide a portion of the real and reactive power to the load locally, thus helping to decrease current along a section of the distribution line, which, in turn, results in a boost in the voltage magnitude at the customer site. The comparison of voltage profile variation for different cases viz. base case (without DG), Case I (1.5 MVA DG at 0.9 power factor) and Case II (1.0 MVA DG at unity power factor) shows that the voltage profile improvement for 1.5 MVA DG operating at 0.9 power factor is superior compared to other case.

4. Conclusions

Optimal allocation (sizing and siting) of DG at the existing distribution system network is crucial factors in the planning and operation of active distribution networks in order to improve the voltage profile and to minimize the power loss. By introducing DG in the system, voltage profile can be improved because DG can provide a portion of the real and reactive power to the load locally, thus helping to decrease current along a section of the distribution line, which, in turn, will result in a boost in the voltage magnitude at the customer site. Among the many benefits of distributed generation is a reduced line loss, but depending on the ratings and locations of DG units, it is possible to have an increase in loss at very high penetration levels. Further, these benefits are very much depends on the DG type.

5. Acknowledgements

Authors are thankful to AICTE Quality Improvement Programme (QIP) Scheme and Principal, P.E.S. Engineering College, Mandya (Karnataka) for allowing me to pursue the Ph.D. work.

6. References

[1] A. Ipakchi and F. Albuyeh. Grid of the future. *IEEE Power and Energy Magazine*. 2009, 7 (2): 52-62.

[2] T. Ackermann, G. Andersson and L. Soder. Distributed generation: a definition, *Electrical Power System Research*. 2001, 57 (3): 195-204.

[3] P. Chiradeja and R. Ramkumar. An approach to quantify the technical benefits of distributed generation. *IEEE Transaction on Energy Conversion*. 2004, 19 (4): 764-773.

[4] H. Khan and M.A. Choudhry. Implementation of distributed generation algorithm for performance enhancement of distribution feeder under extreme load growth. *International Journal of Electrical Power and Energy Systems*. 2010, 32 (9): 985-997.

[5] D.Q. Hung, N. Mithulanathan and R.C. Bansal. Multiple distributed generators placement in primary distribution networks for loss reduction. *IEEE Transactions on Industrial Electronics*. (In Press).

[6] N. Mithulanathan, T. Oo and L. V. Phu. Distributed generator placement in power distribution system using Genetic Algorithm to reduce losses. *Thammasat International Journal on Science and Technology*. 2004, 9 (3): 55-62.

[7] S. Ghosh, S.P. Ghoshal and S. Ghosh. Optimal sizing and placement of DG in network system. *International Journal of Electrical Power and Energy Systems*. 2010, 32 (8): 849-856.

[8] I. Ziari, G. Ledwich, A. Ghosh, D. Cornforth and M. Wishart. Optimal allocation and sizing of DGs in distribution networks. *Proc of IEEE Power and energy society general meeting*. 2010:1-8.

[9] R.M. Kamel and B. Karmanshahi. Optimal size and location of DGs for minimizing power losses in a primary distribution network. *Transaction on Computer Science and Electrical and Electronics Engineering*. 2009, 16 (2): 137-144.

[10] D. Singh, D. Singh and K.S. Verma. Multi-objective optimization for DG planning with load models. *IEEE Transactions on Power Systems*. 2009, 24 (1): 427-436.

[11] M.H. Haque. Efficient load flow method for distribution systems with radial or mesh configuration. *IEE Proc. on Generation, Transmission and Distribution*. 1996, 143 (1): 33-38.

[12] J.V.B. Subramanyam and C. Radhakrisna. Distributed Generation placement and sizing in unbalanced radial distribution system. *World Academy of Science, Engineering and Technology*. 2009, 52: 737-744.

[13] N. Acharya, P. Mahat and N. Mithulananthan. An analytical approach for DG allocation in primary distribution network. *International Journal of Electrical Power and Energy Systems*. 2006, 28 (10): 669–678.

[14] N. Upadhyay and A.K.Mishra. A method for suitable location and capacity of distributed generation units in a distribution system. *Proc. of 20th Australian university power engineering conference* (AUPEC). 2010.

[15] M.A. Kashem, V, Ganapathi, G.B. Josman and M.I. Buhari. A novel method for loss minimization in distribution networks. *Proc. of International Conference Electric Utilization, Deregulation Restructure*, *Power Tech*. 2000: 251-256.