Electrical Power and Energy Systems 78 (2016) 401–413

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Novel analytical method for the placement and sizing of distributed generation unit on distribution networks with and without considering *P* and *PQV* buses

Avisha Tah, Debapriya Das *

Department of Electrical Engineering, Indian Institute of Technology, Kharagpur 721 302, India

ARTICLE INFO

Article history:
Received 26 October 2014
Received in revised form 29 November 2015
Accepted 4 December 2015
Available online 22 December 2015

Keywords:
Distributed generation
Distribution networks
Analytical method
P and *PQV* buses

ABSTRACT

This paper proposes a new analytical method for placement and sizing of distributed generation (DG) units for loss reduction. This analytical method for DG placement in the distribution network is developed based on a new mathematical formulation which does not require bus impedance matrix. This is the main advantage of the proposed method. This paper also proposes the placement and sizing of DG unit considering two novel bus types, i.e., *P* and *PQV* buses. The '*P*' bus is represented by real power specification only whereas the '*PQV*' bus is one whose voltage magnitude is remotely controlled by the '*P*' bus. A simple method is suggested to select '*P*' bus in a distribution network to control the voltage magnitude of '*PQV*' bus. The effectiveness of the proposed method is demonstrated through examples of 33 bus and 69 bus distribution networks.

Introduction

With the electricity market getting deregulated, an endless opportunity is available to play with the distribution networks. This era began with the incorporation of distributed generation (DG) units in the distribution network. DG units changed the way distribution networks looked like. The passive radial structure is gone and the networks become active with DG units allowing the power flow in either direction. Advantages of DG units are that they can support system voltage, reduce system losses, improvement of reliability and security, relieved T & D congestion and deferring the system up gradation. DG can be defined as "electric power generation within distribution networks or on the customer side of the network" [1]. The main objectives of DG units are: (i) To provide a continuous power supply to the load. (ii) To provide power where main grid can't supply electric power. (iii) Provide for load growth with enhanced stability and with minimum growth of the transmission system. (iv) Make greater use of renewable energy sources. (v) Increase energy efficiency and reduce power transmission losses. (vi) Reduce pollution and greenhouse gas emissions. (vii) Increase the availability of high power quality for sensitive loads. There may be four types of DGs [6]: (1) Type 1: only inject real power. (2) Type 2: only inject reactive power. (3) Type 3: inject both real and reactive power. (4) Type 4: inject real power but consume reactive power.

Researchers have used various methodologies for the placement of DGs in the distribution networks. Wang and Nehrir [2] derived analytical expressions for optimal placement of DG units with unity power factor for different types of load distribution along the radial feeder in power distribution systems to minimize the real power loss. Acharya et al. [3] developed analytical expressions for optimal location and sizing of DG unit for minimizing total real power losses in distribution systems. Gozel et al. [4] have proposed an analytical method based on the equivalent current injection without the necessity of Jacobian matrix for the determination of the optimum size and location of distributed generation to minimize total power losses. Lee and Park [5] developed analytical expressions based on generator power distribution factor for optimal allocation of DG and used Kalman filter algorithm for the optimal sizing of DG units. Hung et al. [6] have developed analytical expressions for determining optimal size of distributed generators supplying both real and reactive power for reducing real power losses in distribution systems. Aman et al. [7] have proposed analytical expressions for a novel power stability index based voltage sensitivity analysis for optimal location of DG units and proposed a step by step iterative algorithm for optimal DG sizing to improve the voltage profile and minimize the losses. Many researchers proposed heuristic methods based on iterative techniques and algorithms for optimum location and sizing of DG units for

* Corresponding author.
E-mail address: ddas@ee.iitkgp.ernet.in (D. Das).

http://dx.doi.org/10.1016/j.ijepes.2015.12.009
0142-0615/

Nomenclature

$TPloss$ total real power loss
$TPloss_{dg_m}$ total real power loss after the placement of DG unit at bus m
V_n voltage magnitude of bus-n
δ_n voltage angle of bus-n
V_m voltage magnitude of bus-m
δ_m voltage angle of bus-m
$\tilde{\mathbf{V}}_n$ complex voltage of bus-n
$\tilde{\mathbf{V}}_m$ complex voltage of bus-m
$R_{mn} + jX_{mn}$ mn-th element of $[Z_{bus}]$ impedance matrix.
P_m active power injection at bus-m
Q_m reactive power injection at bus-m
P_{dg_n} and Q_{dg_n} active and reactive power injected by DG unit at bus-n
PL_n and QL_n real and reactive power load respectively at bus-n
$Ploss_{jj}$ and $Qloss_{jj}$ real and reactive power loss respectively of branch-jj
I_{jj} current magnitude of branch-jj
$\tilde{I}_{jj}$ complex current of branch-jj
TP_n and TQ_n total real and reactive power load respectively fed through bus-n
$\cos\phi_n$ power factor of DG unit connected at bus-n
r_n and x_n resistance and reactance respectively of branch-n of the distribution network.
NB total number of buses
NL total number of laterals

distribution systems. Keane and Malley [8] have proposed a linear programming based methodology to obtain optimal allocation and sizing of embedded generation considering technical constraints for accommodating maximum DG power penetration on the distribution network. Hedayati et al. [9] have used power flow continuation program based voltage sensitivity analysis for obtaining optimal allocation of DG units to improve voltage profile and reduce real power losses. Ettehadi et al. [10] have proposed voltage stability based DG unit placement method using continuous power flow algorithm and modal analysis. They also proposed a qualified load index to obtain a priority list of DG units locations for overcoming reactive power shortages. Naik et al. [11] have proposed an analytical method for placement of DG units and shunt capacitors together for real power loss reduction in the distribution system. Abri et al. [12] have also proposed a method of locating and sizing DG units to improve the voltage profile and voltage stability margin of the network. Recently several authors have proposed artificial intelligent based techniques especially using the genetic algorithm or swarm optimization techniques for obtaining optimum DG unit location and sizing for distribution systems to improve system performance and reliability. Celli et al. [13] have proposed a multiobjective cost function optimization methodology based on genetic algorithm and ∈-constrained method for optimal allocation and capacity of DG units into distribution networks. Abou et al. [14] have presented genetic algorithm based optimization of multiobjective function approach to determine the optimal sitting and sizing of DG units with multi-system constraints. Moradi and Abedini [15] have used combined genetic algorithm and particle swarm optimization for optimal location and sizing of DG capacity considering system operation and security constraints in distribution systems. Sajjadi et al. [16] have used a memetic based optimization for simultaneous placement of DG units and shunt capacitors for voltage profile improvement and reduction in the power loss of distribution system. Shaaban et al. [17] have proposed a GA-based multiobjective approach for optimal allocation of different types of DG units to minimize investment costs of system up gradation, the cost of annual energy losses and to improve the reliability of the system. Kansal et al. [18] have used particle swarm optimization technique for the placement of DGs in a distribution network. Injeti and Kumar [19] have used the simulated annealing technique to identify optimal access point and capacity of DG units. Murthy and Kumar [20] have studied the optimal DG allocation methods based on sensitivity approaches. Mistry and Roy [21] have studied enhancement of loading capability of a distribution network considering DGs. Hung et al. [22] have studied the optimal placement of DG units for minimizing energy loss by using an exact loss formula. Hamedi and Gandomkar [23] have computed energy not served index for every branch of the distribution network to allocate DG resources for the improvement of power quality and reduction of real power loss.

Walling et al. [24] have discussed different issues like voltage issue, protection issue which occur due to the introduction of distributed resources into the conventional distribution system. Haghifam et al. [25] have proposed a strategy to place DG in an uncertain environment considering minimization of cost, technical risk and economic risk as objectives. They have used a fuzzy optimization technique to solve the problem. Ayres et al. [26] have proposed a method based on single power flow and one matrix operation, to determine the maximum power injected by the DGs without violating the steady state voltage limit. They have also proposed a method to find out the responsibility of each generator for voltage rise in a multi DG system. Singh et al. [27] have proposed a method to determine the locations of DGs for different load models and have shown that the optimal sizes and locations of DG units vary with the load models. Zou et al. [28] have proposed a method to place DG units and capacitor optimally in the distribution network to reduce the system loss and to provide the voltage support, and the cost of DG units has also been taken into consideration. Willis [29] has discussed different advantages and disadvantages of DGs. Gautam and Mithulananthan [30] have proposed a method to optimally place DG units to maximize social welfare and profit. Singh and Goswami [31] have suggested a methodology based on nodal pricing for optimally allocating distributed generation for profit, loss reduction, and voltage improvement including voltage rise phenomenon. Maria et al. [32] have presented a new approach based on nonlinear bilevel programming framework to determine the location, contract pricing of DGs and to increase the voltage stability margin. Esmaili [33] has presented a methodology for optimization and location of DG units in the framework of non-linear programming approach. Objective function has been formulated in the fuzzy environment to include minimum no of DG units, reduction in power loss and maximization of voltage stability margin. Karimyan et al. [34] have proposed a method to determine the optimum location of DG for continuously changing the load. Hamedani et al. [35] have proposed a method to solve the distributed-generation-planning problem taking into account of the mutual impact of distributed generation, reactive power and network configuration planning. They have solved the problem to determine the amount of distributed generation resources and reactive power sources to be connected at the selected buses in the distribution system. Elsaiah et al. [36] have also proposed an analytical method for placement and sizing of DGs using a linearized power flow model.