Swarm and Evolutionary Computation 15 (2014) 58–65

Contents lists available at ScienceDirect

Swarm and Evolutionary Computation

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

Regular Paper

Optimal size and siting of multiple distributed generators in distribution system using bacterial foraging optimization

Mohamed Imran A*, Kowsalya M

School of Electrical Engineering, VIT University, Vellore-632014, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 20 April 2013
Received in revised form
5 October 2013
Accepted 8 December 2013
Available online 17 December 2013

Keywords:
Distributed generation
Bacterial Foraging Optimization Algorithm
Power loss minimization
Voltage stability
Operational cost minimization

ABSTRACT

Optimal location and size of distributed generation (DG) in the distribution system play a significant role in minimizing power losses, operational cost and improving voltage stability. This paper presents a new approach to find the optimal location and size of DG with an objective of minimizing network power losses, operational costs and improving voltage stability. Loss sensitivity factor is used to identify the optimal locations for installation of DG units. Bacterial Foraging Optimization Algorithm (BFOA) is used to find the optimal size of DG. BFOA is a swarm intelligence technique which models the individual and group foraging policies of the *Escherichia coli* bacteria as a distributed optimization process. The technical constraints of voltage and branch current carrying capacity are included in the assessment of the objective function. The proposed method has been tested on IEEE 33-bus and 69-bus radial distribution systems with various load models at different load levels to demonstrate the performance and effectiveness of the technique.

1. Introduction

The importance of DGs in future smart grid increases considering their impacts on the modern power system. The number of DG units installed in the distribution system has been increasing significantly, and their technical, economical, and environmental impacts on power system are being analyzed. Currently, the technical impacts of interest are voltage profile, power loss, power quality, reliability, protection, power control and stability [1–3]. The most critical factors that influence the technical and economic impacts are type, size, and location of DG units in the power system. The location and size of DG unit should be optimal to maximize the benefits and reduce their impact on the power system. Inappropriate placement in some situations can reduce the benefits and even endanger the entire system operation [4]. Hence, optimal location and sizing of DG units have fascinated many researchers working in the DGs.

An analytical and Improved Analytical (IA) expression for finding the optimal location and size of DG units for reducing power loss had been presented along with methodologies for identifying the optimal location in [4,5]. A new index considering stable node voltages referred as Power Stability Index (PSI) to find the most sensitive bus for DG placement was developed, and a search algorithm was used for finding the optimum size of DG at optimum location to minimize power loss in [6]. A simple conventional iterative search technique along with the Newton Raphson method of the load flow study was implemented in [7]. The objective was to lower down both the cost and loss more effectively. It also focuses on optimizing weighting factor, which balances the cost and the loss factors and helps to build up desired objectives with maximum potential benefit.

The artificial neural network based method was developed to find optimal DG size and locations due to complexity of multiple DG concepts in [8]. Genetic Algorithm (GA) was used to determine the optimal size and location of multiple DG units to minimize the system losses and power supply by the main grid, considering the voltage limits at each bus of the system [9]. A combination of Particle Swarm Optimization (PSO) and GA was introduced to find the optimal location of a fixed capacity of DG units installed in the system to minimize the total power loss, to improve voltage profile and voltage stability index [10]. The PSO algorithm was employed for a multiobjective index based approach to identify optimal size and location of multiple DGs in the distribution system with different load models [11].

Modal analysis and continuous power flow are used to determine the candidate bus for DG placement by using the loading parameter as the comparison index for selecting the best places [12]. Authors justified that the best candidate for DG placement is different from the best location for reactive power compensation. The loss sensitivity factor (LSF) used in [13], finds the optimal candidate locations for reactive power compensation (i.e. capacitor placement) but not an optimal site for DG installation.

The above methods discussed have gained encouraging results in finding the optimal location and size of DGs, but they also have some

* Corresponding author.
E-mail address: mohamedimran.a@vit.ac.in (Mohamed Imran A).

2210-6502/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.swevo.2013.12.001

Nomenclature

P_k	real power load at bus k
$P_{k,k+1}$	real power flowing in the line between buses k and $k+1$
$P_{k+1,\text{eff}}$	total effective real power supplied beyond the bus $k+1$
V_k	voltage magnitude at bus k
$J_{k,k+1}$	branch current in the line section between buses k and $k+1$
$V_{\min}$	minimum voltage limits of the buses
$\Delta V_{\max}$	maximum voltage drop limit between buses 1 and k
$R_{k,k+1}$	resistance of the line section between buses k and $k+1$
$P_{\text{Loss}}(k,k+1)$	power loss in the line section between buses k and $k+1$ without DGs
$P_{\text{DGT}}^{\min}$	minimum total power generation limit of the system
$P_{\text{DG,Loss}}(k,k+1)$	power loss in the line section between buses k and $k+1$ with DGs
n	total number of buses
Q_k	Reactive power load at bus k
$Q_{k,k+1}$	reactive power flowing in the line between buses k and $k+1$
$Q_{k+1,\text{eff}}$	total effective reactive power supplied beyond the bus $k+1$
I_k	equivalent current injected at node k
$J_{k,k+1,\max}$	maximum branch current limit of line section between buses k and $k+1$
$V_{\max}$	maximum voltage limits of the buses
V_{worst}	worst voltage magnitude of the system
$X_{k,k+1}$	reactance of the line section between buses k and $k+1$
$P_{\text{DG,TLoss}}$	total power loss of the system with DGs
$P_{\text{DGT}}^{\max}$	maximum total power generation limit of the system
$P_{\text{DG},k}$	power supplied from DG at the bus k
b	total number of branches
$S_{\text{DG,T}}$ (MVA)	total MVA supplied by DG in the system

shortcomings such as computation time in solving real large-scale systems, calculation efficiency and convergence. The effect of load models on distributed generation planning in the distribution system was investigated and stated that load models can significantly affect the DG planning [14]. Most of the researches mentioned in the literature that they used DGs with unity power factor in the distribution system with only constant power loads. Also most of the authors did not consider the operating cost of DGs, and achieved power loss minimization and voltage stability by installing multiple DGs of large sizes.

The present work is aimed to develop a fast and novel computation technique to find the optimal location and size of multiple DGs for loss minimization, operational cost minimization and to improve voltage stability in the radial distribution system with different types of loads. In this paper, LSF that determines the most sensitive bus for DG installation has been used. The LSF at each bus is ranked in descending order and the top three sensitive buses are selected as candidate location for DG installation. BFOA, a distributed optimization technique, is employed to minimize the objective function by determining the optimal size of DG units at candidate locations. The advantage of exempting BFOA from the determination of optimal candidate location of DGs is to reduce the search space, computation time and to improve convergence characteristics. The novelty of this work lies in the combined technique used to identify the optimal placement and sizing of multiple-DG units in order to minimize power losses, operational costs and to improve voltage stability at different load models. The proposed method is tested on a well-known 33-bus and 69-bus test system, and the results obtained are statistically compared with other classical methods.

2. Problem formulation

2.1. Power flow equations

Power flow in a distribution system is calculated by the following set of recursive equations derived from the single line diagram as shown in Fig. 1.

From Fig. 1, the equivalent current injected at node k is calculated as

$$I_k = \left(\frac{P_k + jQ_k}{V_k}\right)^* \quad (1)$$

Branch current in the line section between buses k and $k+1$ is calculated by using Kirchhoff's current law as

$$J_{k,k+1} = I_{k+1} + I_{k+2} \quad (2)$$

The above equation is generalized in matrix form by using the Bus current Injection to Branch Current matrix (BIBC) [15]. Now the branch current at each line can be calculated in a matrix form as follows:

$$[J] = [\text{BIBC}][I] \quad (3)$$

From Fig. 1, by Kirchhoff's voltage law, the voltage at the bus $k+1$ can be calculated as

$$V_{k+1} = V_k - J_{k,k+1}(R_{k,k+1} + jX_{k,k+1}) \quad (4)$$

The power loss in the line section between buses k and $k+1$ is computed as

$$P_{\text{Loss}}(k, k+1) = R_{k,k+1}\left(\frac{P_{k,k+1}^2 + Q_{k,k+1}^2}{|V_k|^2}\right) \quad (5)$$

The total power loss of the system, P_{TLoss}, is determined by the summation of losses in all line sections, which is given as

$$P_{\text{TLoss}} = \sum_{k=1}^{b} P_{\text{Loss}}(k, k+1) \quad (6)$$

2.2. Power loss with DG

DG units installation at optimal location will lead to line loss reduction, improved voltage stability, peak demand saving, improved reliability and security. The power loss of a line section connecting between buses k and $k+1$ after DG installment is computed as

$$P_{\text{DG,Loss}}(k, k+1) = R_{k,k+1}\left(\frac{P_{\text{DG},k,k+1}^2 + Q_{\text{DG},k,k+1}^2}{|V_k|^2}\right) \quad (7)$$

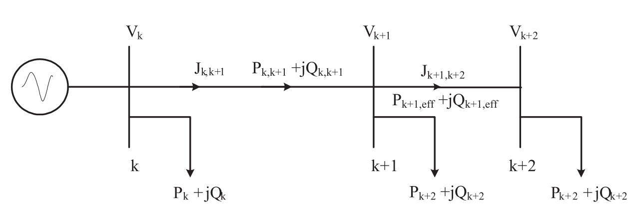

Fig. 1. Sample distribution system.