Electrical Power and Energy Systems 64 (2015) 1197–1205

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm

Attia El-Fergany *

Department of Electric Power and Machines, Faculty of Engineering, Zagazig University, P. O. Box 44519, Zagazig, Egypt

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 6 September 2014
Accepted 12 September 2014
Available online 1 October 2014

Keywords:
Distributed generation
Loss minimization
Cumulative voltage deviations
Loss sensitivity factors
Backtracking search optimization algorithm

ABSTRACT

In this article, a very recently swarm optimization technique namely a backtracking search optimization algorithm (BSOA) is addressed to assign the distributed generators (DGs) along radial distribution networks. One of the main features of the BSOA is a single control parameter and not over sensitive to the initial value of this factor. The objective function is adapted with weighting factor to reduce the network real loss and enhance the voltage profile with the purpose of improving the operating performance. In addition, the combined power factor and reduction in network reactive power loss are spotted. Set of fuzzy expert rules using loss sensitivity factors and bus voltages are employed to identify the initial DG's locations. The proposed approach is attuned to tackle the shortfall of loss sensitivity factors and to decide the final placement of the DGs. Two types of the DGs are studied and investigated. The proposed method is demonstrated and validated thru many radial distribution networks with different sizes and complexities. The BSOA-based methodology can efficiently generate high-quality solutions compared to other competitive techniques in the literature.

Introduction

Installations of the distributed generations (DGs) can be purposefully implemented in power systems for grid strengthening, reducing network power losses (active and reactive), peak load shaving, improving voltage profiles, and load factors, reducing for system upgrade investments, and improving system security, dependability, and efficacy [1–3]. The network loss minimization is one of the significant points in operating the power system networks. In a typical distribution system, particularly, in developing countries, network losses are as much as 20% of total power generated is wasted in the form of power losses [4–7], which would cost millions of dollars every year.

The losses in a distribution area are mainly of two types; technical and non-technical either active or reactive types. The two bus system depicted in Fig. 1 represents a distribution level feeder between buses i and j. The active and reactive power losses in line i–j are given by Eqs. (1) and (2), respectively:

$$P_{ij}^{loss} = R_{ij}.\frac{(P_j^2 + Q_j^2)}{|V_j|^2} \quad (1)$$

$$Q_{ij}^{loss} = X_{ij}.\frac{(P_j^2 + Q_j^2)}{|V_j|^2} \quad (2)$$

According to Eqs. (1) and (2), the feeder power loss is closely related to the active and reactive power flows. This concludes that the reductions of these power flows will certainly lead to reduce network losses accordingly.

The DG is anticipated to become more essential in the future power system deregulations. The main reason of using DG units in power system is technical and economic benefits that have presented in [1,2,8–10]. Placement of DG on the system might lead to reduce losses (DG impact on losses is similar to placement of capacitors). The only big difference is that some types of DGs have both real and reactive power flow loss impacts, and a capacitor affects only the reactive flow loss. Like Capacitors, too much DG at the wrong placement will increase losses on the lines. It is crucially important to determine the size and location of DG unit to be placed. Studies indicate that poor selection of location and size would lead to higher losses than the losses without DG [11,12].

In the last few years various techniques have been developed to find for the optimal location and size of the DG. Different analytical approaches minimizing line losses were utilized and proposed for the DG allocation [11–17] and optimal power flow [18,19].

Many different evolutionary algorithms (EAs) with different search operators have been reported in literature and exhaustively used in solving numerical optimization problems [20]. However, No single algorithm is consistently able to solve all types of optimization problems [20,21]. Unlike classical optimization techniques, the EAs do not guarantee finding the optimum solutions for

* Tel.: +20 100 5705526; fax: +20 55 2304987.
E-mail address: el_fergany@ieee.org

http://dx.doi.org/10.1016/j.ijepes.2014.09.020
0142-0615/

Nomenclatures

P_{Loss}	total network active power loss
Q_{Loss}	total network reactive power loss
P_{ij}^{loss}	active power losses of the line between the nodes *i* and *j*
Q_{ij}^{loss}	reactive power losses of the line between the nodes *i* and *j*
R_{ij}	resistance of the line between the nodes *i* and *j*
X_{ij}	reactance of the line between the nodes *i* and *j*
$\|V_i\|$	voltage magnitude of bus *i*
$\|V_j\|$	voltage magnitude of bus *j*
P_j	total effective real power load fed through bus *j*
Q_j	total effective reactive power fed through bus *j*
N_B	number of network buses
nbr	total number of lines
ω	weighting factor (ranges from 0 to 1)
N_{DG}	number of distributed generators (DGs)
N_L	number of connected loads
P_{Slack}	active power supplied by slack bus
Q_{Slack}	reactive power supplied by slack bus
$P_{DG,i}$	injected active power of *i*th DG
$Q_{DG,i}$	injected active power of *i*th DG
$P_{D,i}$	active power demand of load at bus *i*
$Q_{D,i}$	reactive power demand of load at bus *i*
$P_{Loss}(i)$	active power loss of branch *i*
$Q_{Loss}(i)$	reactive power loss of branch *i*
$I_{SC}(i)$	short circuit level at bus *i*
W/DG	with DG's installations
WO/DG	without DG's installations
$P_{DG,min}$	lower limit of DG active output power
$P_{DG,max}$	upper limit of DG active output power
$PF_{DG,min}$	lower limit of DG power factor
$PF_{DG,max}$	upper limit of DG power factor
S_i	actual line flow of line *i*
S_i^{rated}	rated line *i* transfer capacity
μ	penetration level
λ_{VC}	penalty function for the voltage constraints
λ_{LFC}	penalty function for the line flow constraint
λ_{PtC}	penalty function for the maximum allowable DG penetration
λ_{SC}	penalty function for the bus short level
LSF(*j*)	loss sensitivity factor (LSF) of bus *j*
LSF_{max}	maximum value of LSFs
LSF_{min}	minimum value of LSFs
LF	load flow
LR	loss reduction
N	population size
D	problem dimension
rand(...)	uniform distribution
LB_j	lower bound of the optimised parameter *j*
UB_j	upper bound of the optimised parameter *j*
P_i	target individual *i* in the population P

a problem, only close to optimal solutions. However, the EAs are sufficiently flexible to solve different types of optimization problems without going in depth to the problem. The EAs should have global exploration and local exploitation abilities [21,22]. For the same purpose of DG allocation, an EA uses genetic algorithm [23,24] and other heuristic algorithm methods through goal programming [25], harmony search algorithm [26], cat swarm optimization [27], particle swarm optimization (PSO) [28,29], artificial bee colony (ABC) algorithm [30], and differential evolution (DE) [31] have been applied to place single and/or multi-DGs for various objectives.

A wide variety of DG technologies and types exists [17]: (i) non-renewable energy technologies, and (ii) renewable energy technologies. The first group consists of internal combustion engines, gas turbines, micro-turbines, etc. The second group produces electricity using renewable energy sources, i.e solar energy, wind energy, tidal energy, wave energy, geothermal energy, biomass, etc. Although DG has relatively small size compared with central generation, it is large enough to satisfy electricity requests of a group of local customers. The DG resources are classified into four categories [17,29] as depicted in Table 1.

The backtracking search optimization algorithm (BSOA) is a new meta-heuristic algorithm developed in 2013 [32]. The BSOA has a unique mechanism for generating a trial individual enables it to solve numerical optimization problems successfully and quickly. The BSOA uses three basic genetic operators: selection, mutation and crossover to generate trial individuals. The BSOA has a random mutation scheme that uses only one direction individual for each target individual, in contrast with many genetic algorithms such as differential evolution. The BSOA randomly picks the direction individual from individuals of a randomly chosen previous generation [32].

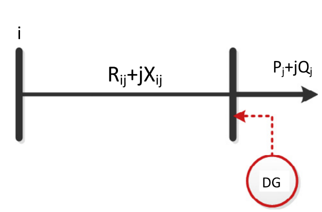

Fig. 1. Portion of a radial distribution network of *i*–*j* bus.

The development of an optimization methodology capable of defining the DG unit placement and sizing that improves the system operation characteristics when dealing with the avalanche of DG penetration is a necessity. This work proposes the solution of DG allocation (bus number and size) using the BSOA-based approach. One of main interests of the article is to examine the performance of the BSOA in defining the optimal locations and sizes of DGs. LSFs and bus voltages are utilized for the initial identification of locations using fuzzy expert rules. DG types (*A*) and (*C*) are considered and analysed; their effects on network performance in terms of the loss reduction and voltage profile enhancement. The proposed methodology is applied to the 33-bus and the 94-bus radial distribution networks to examine its viability. Comparisons to the analytical and other heuristic methods in the literature validate the cropped results.

Objective function formulation and constraints

Great attention should be paid to the problem of DG allocation. For this reason, the formulation of objective function and specific constraints should be modelled carefully. The objective function is adapted to reduce the system active losses and improving the bus voltage profile with a weighting factor. The cumulative voltage deviation (CVD) at each bus must be made as small as possible. The CVD is utilized to indicate the voltage profile improvement and calculated using:

$$CVD = \begin{cases} 0 & if\ 0.95 \leqslant |V_i| \leqslant 1.05 \\ \sum_{i=1}^{N_B} |1 - V_i| & else \end{cases} \tag{3}$$