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A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems

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ABSTRACT

Distributed generation (DG) sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy. Locations and capacities of DG sources have profoundly impacted on the system losses in a distribution network. In this paper, a novel combined genetic algorithm (GA)/particle swarm optimization (PSO) is presented for optimal location and sizing of DG on distribution systems. The objective is to minimize network power losses, better voltage regulation and improve the voltage stability within the frame-work of system operation and security constraints in radial distribution systems. A detailed performance analysis is carried out on 33 and 69 bus systems to demonstrate the effectiveness of the proposed methodology.

1. Introduction

Distribution systems are usually radial in nature for the operational simplicity. Radial distribution systems (RDSs) are fed at only one point which is the substation. The substation receives power from centralized generating stations through the interconnected transmission network. The end users of electricity receive electrical power from the substation through RDS which is a passive network. Hence, the power flow in RDS is unidirectional. High *R*/*X* ratios in distribution lines result in large voltage drops, low voltage stabilities and high power losses. Under critical loading conditions in certain industrial areas, the RDS experiences sudden voltage collapse due to the low value of voltage stability index at most of its nodes.

Recently, several solutions have been suggested for complementing the passiveness of RDS by embedding electrical sources with small capacities to improve system reliability and voltage regulation [1,2].

Such embedded generations in a distribution system are called dispersed generations or distributed generations (DG).

Distributed generation is expected to play an increasing role in emerging electrical power systems. Studies have predicted that DG will be a significant percentage of all new generations going on lines. It is predicted that they are about 20% of the new generations being installed [3].

Main reasons for the increasingly widespread usage of distributed generation can be summed up as follows [4]:

- It is easier to find sites for small generators.
- Latest technology has made available plants ranging in capacities from 10 KW to 15 MW.
- Some technology have been perfected and are widely practiced (gas turbines, internal combustion engines), others are finding wider applications in recent years (wind, solar energy) and some particularly promising technologies are currently being experimented or even launched (fuel cell, solar panels integrated into buildings).
- DG units are closer to customers so that Transmission and Distribution (T&D) costs are ignored or reduced.
- Combined Heat and Power (CHP) groups do not require large and expensive heat networks.
- Natural gas, often used as fuel in DG stations is distributed almost everywhere and stable prices are expected for it.
- Usually DG plants require shorter installation times and the investment risks are not so high.
- DG offers great values as it provides a flexible way to choose wide ranges of combining cost and reliability.

In order to achieve the aforementioned benefits, DG size has to be optimized. Researchers have developed many interesting algorithms and solutions. The differences are about the problem which is formulated, methodology and assumptions being made. Some of the methods are mentioned in [5] as analytical approaches [6] numerical programming, heuristic [7,8]. All methods own their

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Nomenclature

n_n	total number of buses in the given RDS
n_i	receiving bus number (n_i = 2,3,...,n)
m_i	bus number that sending power to bus n_i ($m_2 = n_1 = 1$)
i	branch number that fed bus n_i
$N = n_n - 1$	total number of branches in the given RDS
N_{DG}	total number of DG
C_{DG}	capacity of DG
n_{DG}	bus number of DG installation
P_{gni}	active power output of the generator at bus n_i
Q_{gni}	reactive power output of the generator at bus n_i
P_{dni}	active power demand at bus n_i
Q_{dni}	reactive power demand at bus n_i
$P_{ni}(n_i)$	total real power load fed through bus n_i
$Q_{ni}(n_i)$	total reactive power load through bus n_i
P_{gni}^{min}	minimum active power of DG at bus n_i
P_{gni}^{max}	maximum active power of DG at bus n_i
P_{RPL}	real power losses of n_n-bus distribution system
V_{ni}	voltage of bus n_i
V_{mi}	voltage of bus m_i
V_{ni}^{min}	minimum voltage at bus n_i
V_{ni}^{max}	maximum voltage at bus n_i
V_{rated}	rated voltage (1 p.u.)
$\|s_{ni}^{max}\|$	maximum apparent power at bus n_i
Y_{ni}	admittance between bus n_i and bus m_i
θ_{ni}	phase angle of $Y_i = Y_{ni}\angle\theta_{ni}$
δ_{ni}	phase angle of voltage at bus n_i ($V_{ni} = V_{ni}\angle\delta_{ni}$)
δ_{mi}	phase angle of voltage at bus m_i
I_{ni}	current of branch i
R_{ni}	resistance of branch i
X_{ni}	reactance of branch i
$SI(n_i)$	voltage stability index of node n_i. (n_i = 2,3,...,n)
β_1	penalty coefficient, 0.32
β_2	penalty coefficient, 0.3
K_1	penalty coefficient (k_1 = 0.6)
K_2	penalty coefficient (k_2 = 0.35)
C_1, C_2	constants
r_1, r_2	random numbers in [0,1]
J_{best}	global best position associated with the whole neighborhood experience
W	weight inertia
f_1	network real power losses (pu)
f_2	network voltage profile (pu)
f_3	network voltage stability index (pu)

advantages and disadvantages which rely on data and system under consideration. Generally the allocation problem formulation of distributed generation is non linear, stochastic or even a fuzzy function as either an objective function or constraints. Generally, in all formulations the objective function is to minimize the real power losses and improve voltage; while abiding into all physical constraints equations in terms of voltage and power. The variable limits in the optimization procedure must also be obeyed.

The problem of optimal DG location and sizing is divided into two sub problems, where the optimal location for DG placement is the one and how to select the most suitable size is the second. Many researches proposed different methods such as analytic procedures as well as deterministic and heuristic methods to solve the problem. Kean and Omalley [9] solved for the optimal DG sizing in the Irish system by using a constrained linear programming (LP) approach. The objective of their proposed method was to maximize the DG generation. The nonlinear constraints were liberalized with the goal of utilizing them in the LP method. A DG unit was installed at all the system buses and the candidate buses were ranked according to their optimal objective function values. Kashem et al [10] developed an analytical approach to determine the optimal DG sizing based on power loss sensitivity analysis. Their approach was based on minimizing the distribution system power losses. The proposed method was tested using a practical distribution system in Tasmania, Australia. Griffin et al. [11] analyzed the DG optimal location analytically for two continuous load distributions types, uniformly distributed and uniformly increasing loads. The goal of their studies was to minimize line losses. One of the conclusions of their research was that the optimal location of DG which is highly dependent on the load distribution along the feeder; significant losses reduction would take place when DG is located toward the end of a uniformly increasing load and in the middle of uniformly distributed load feeder.

Acharya et al. [12] used the incremental change of the system power losses with respect to the change of injected real power sensitivity factor developed by Elgerd [13]. This factor was used to determine the bus and causing the losses to be optimal when hosting a DG. They proposed an exhaustive search by applying the sensitivity factor on all the buses and ranked them accordingly. The drawback of their work is the lengthy process of finding candidate locations and the fact that they sought to optimize only the DG real power output. Rosehart and Nowicki [14] dealt with only the optimal location portion of the DG integration problem. They developed two formulations to assess the best location for hosting the DG sources. The first is a market based constrained optimal power flow that minimizes the cost of the generation DG power, and the second is voltage stability constrained optimal power that maximizes the loading factor, distance to collapse. Both formulations were solved by utilizing the interior point (IP) method. Outcomes of the two formulations were used in ranking the buses for DG installations. The optimal DG size problem was not considered in their paper.

Carmen et al. [15] describes a methodology for optimal distributed generation allocation and sizing in distribution systems, in order to minimize the electrical network losses and to guarantee acceptable reliability level and voltage profile. The optimization process is solved by the combination of genetic algorithms (GA) techniques with other methods to evaluate DG impacts in system reliability, losses and voltage profile.

Haesen and Espinoza [16] considered optimal DG problem for single and multiple DG sizing. They used GA method to minimize the distribution systems active power flow. Gandomkar et al. [17] hybridized two methods to solve DG sizing problem. They combined GA and simulated annealing meta-heuristic methods to solve optimal DG power output. Nara et al. [18] assumed that the candidate bus locations for DG unit to be installed were pre-assigned by the distribution planner. Then they used the tabo search (TS) method for solving the optimal DG size. The objective of their formulation was to minimize system losses. Golshan and Arefifar [19] applied the TS method to size the DG optimally, as well as the reactive sources within the distribution system. He formulated the constrained nonlinear optimization problem by minimizing an objective function that sums the total cost of active power losses, line loading and the cost of adding reactive sources. Falaghi and Haghifam [20] proposed the ant colony optimization method as an optimization tool for solving the DG sizing and location problems. Minimized objective function for used method was the global network cost. Khalesi et al. [21] considered multi-objective