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Optimal placement and sizing of voltage controlled distributed generators in unbalanced distribution networks using supervised firefly algorithm

M.M. Othman [a,*], Walid El-Khattam [a], Y.G. Hegazy [b], Almoataz Y. Abdelaziz [a]

[a] Electrical Power & Machines Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt
[b] Information Engineering & Technology, German University in Cairo, Cairo, Egypt

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ABSTRACT

This paper presents an efficient and fast converging optimization algorithm based on a modification of the traditional firefly method for optimal sizing and siting of voltage controlled distributed generators in balanced/unbalanced distribution systems. The proposed algorithm modifies the traditional firefly method to be able to deal with the practically constrained optimization problems by proposing formulas for tuning the algorithm parameters and updating equations. The proposed algorithm is implemented in MATLAB environment and tested on the 69-bus feeder system, the IEEE 37 nodes feeder and the IEEE 123-nodes feeder in order to minimize the system power loss via robustly detection of the optimal location and size of the distributed generators without violating the system constraints. Validation of the proposed method is done by comparing the obtained results with published results obtained from other competing methods.

Introduction

The concept of integrating small generating units in the power system attracted the attention in the last few decades. Distributed generator (DG) reinforces the main generating station in covering the growing power demand. DG can be connected or disconnected easily from the network unlike the main power stations, thus providing higher flexibility. Good planned and operated DG has many benefits as economic savings, decrement of power losses, greater reliability and higher power quality.

The integration of the distributed generators in the distribution network changes the nature of the network from radial to meshed. Several studies were done for development of load flow method that are capable of dealing with radial distribution systems [1–8]. Cheng and Shirmohammadi [9] address the power flow problem, incorporating DG modeled according to its mode of operation, either as PV or constant power (PQ) node. Sarika Khushalani and Noel Schulz present a development of the power flow including distributed generation based on the backward–forward sweep method in [10] and perform studies on the IEEE 37-node feeder to assess system losses and voltage deviations with varying penetration in [11]. Zhu and Tomsovic [12] present extensions for the compensation based method presented in [9] by modeling of distribution system elements, including lines, capacitors, loads, transformers and distributed generators.

Optimal location and capacity of DGs plays a pivotal rule in achievement of gaining the maximum benefits from DGs. On the other side, improper placement or sizing of DGs may cause undesirable effects. The search space of optimal location and capacity of DGs is roomy, different optimization methods have been used to solve different DG optimization problems. The optimization methods could be analytical [13–16], numerical [17–20] and heuristic [21–36]. The objective functions include power loss minimization, cost reduction; profit maximization, distribution system investments deferral and environmental emission reduction. Two analytical methods to optimize the location of a single DG for radial and meshed power systems were introduced in [13]. Authors in [14] presented a non iterative analytical method to minimize power loss by the optimal placement of DG in radial and meshed systems. Analytical expressions for finding optimal size and power factor of different types of DGs were suggested in [15]. In [16] the authors proposed an improved analytical method for allocating four types of multiple DG units for loss reduction in primary distribution networks. Moreover, an approach for the optimal selection of the DG power factor was also presented. In spite of its simplicity,

* Corresponding author.
E-mail addresses: almoatazabdelaziz@hotmail.com (M.M. Othman), walid_el_khattam@hotmail.com (W. El-Khattam), Yasser.higazi@guc.edu.eg (Y.G. Hegazy), eng_mmo@yahoo.com (A.Y. Abdelaziz).

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analytical methods are not able to deal with the optimization problems concerning the optimal allocation of DGs in unbalanced distribution networks due to the complexities of the problems. Linear programming was used to solve optimal DG power optimization problem in [17,18] for achieving maximum DG penetration and maximum DG energy harvesting, respectively. A multiobjective performance index, taking into account the time-varying behavior of both demand and generation, when optimized by an exhaustive search, was suggested in [19]. An optimization method was developed in [20] for specifying the locations and sizes of multiple DGs to achieve DG capacity maximization and loss minimization. A probabilistic-based planning technique was proposed for determining the optimal fuel mix of different types of renewable DG units in order to minimize the annual energy losses in the distribution system is presented in [21]. In [22] another probabilistic-based planning technique was presented to determine the optimal capacity and location of wind-based DG units to minimize the annual energy losses in the distribution system. A multi-period optimal power flow was solved using non linear programming in [23]. Genetic algorithm (GA) and optimal power flow were combined to solve the optimization problem in [24], and GA was applied to solve a DG optimization problem with reliability constraints in [25] and for maximizing the profit by the optimal placement of DGs in [26,27]. The DG optimal power was evaluated by the Tabu Search (TS) method for the case of uniformly distributed loads [28] and a continuous stochastic DG model optimal power was evaluated by a GA as well as by a combined TS and scatter search [29]. Paper [30] proposed a method that integrates constant power factor DG units in balanced distribution networks for minimum power loss. However, the modeled DG power factor in the proposed technique is limited to four values only. In [31] an optimization approach that utilizes an artificial bee colony (ABC) algorithm to determine the optimal DG size, power factor, and location in order to minimize the total system real power loss was proposed.

Although GA, ABC and TS are able to solve the constrained optimization problems concerning the optimal sizing and siting of DGS but they have some shortcomings; they easily suffers from partial optimization and fall in local extreme solutions, they have many parameters to be tuned and false tuning of these parameters badly affect the convergence behavior and some methods as GA suffers from low convergence speed [32].

Firefly Algorithm (FA) was first introduced by Yang [33] for solving nonlinear multidimensional optimization problems. The method was successfully applied for optimizing the power flow problem [34–37]. In [34] the authors applied the FA algorithm to solve economic dispatch problem. The results were compared with continuous genetic algorithm to show the effectiveness of FA. Authors in [35,36] use FA to evaluate the optimal location and size of one or two distributed generators on a balanced radial feeder for power loss minimization. In [37] an application of FA on optimal allocation of DG based on real and reactive power losses and voltage profile optimization for different load models. In comparison with the other evolutionary algorithms, FA has many major advantages to be used in solving complex multidimensional nonlinear optimization problems. Some of these advantages are simple concepts, easy implementation, and higher stability mechanism. Despite these features, it often experiences inappropriate convergence because the fireflies are trapped in local optima, loss of diversity through the fireflies, or slow proceeding of the algorithm search.

This paper presents a supervised firefly algorithm for finding the optimal location and capacity of dispatchable DGs connected to balanced/unbalanced distribution feeders for power/energy loss minimization without violating the system constraints. The proposed algorithm modifies the traditional firefly method by proposing formulas for the FA parameters and updating equations in order to be applicable for the current optimization problem. The DG in the proposed algorithm is modeled as voltage controlled (PV) node with the flexibility to be converted to constant power (PQ) node in case of reactive power limit violation. The proposed algorithm is implemented in MATLAB and tested on the 69-bus feeder, the IEEE 37-node feeder, and the IEEE 123 nodes feeder and the results obtained are validated by comparing it to published results show the effectiveness and speed of convergence of the proposed method.

The paper is structured as follows: second section describes the optimization problem under study. The proposed method algorithm is introduced in third section. The characteristics of the systems under study are presented in fourth section and also summarizes the test cases and results. Finally, the conclusions are displayed in fifth section.

Problem statement

The optimization problem under study can be stated in:

Given: the input data comprise the distribution feeder structure, series impedances, mutual impedances, shunt capacitances, feeder loads values and load types.
Objective functions: the objective functions are to minimize the active power loss using (1) or to minimize the daily energy loss using (2)

$$\text{Minimize Obj. Fun.} = \sum_{f=1}^{Nf} P_{loss,f} \tag{1}$$

$$\text{Minimize Obj. Fun.} = \sum_{h=1}^{24} P_{loss,h} \tag{2}$$

where f is feeder number, Nf is total number of feeders, $P_{loss,f}$ is the power loss at certain feeder f, h is the hour number and $P_{loss,h}$ is the total system power loss at certain hour h.

Required: exactly determine the optimal DG active power and optimal DG location for the sake of minimizing the distribution feeder active power loss as well as energy loss without violating the following system constraints:

– Voltage limits:

Voltage at each bus should be within a permissible range usualy:

$$0.95\,\text{p.u.} \leqslant V \leqslant 1.05\,\text{p.u.} \tag{3}$$

– DG power limits:

Active, reactive and complex powers of the DG unit are constrained between minimum and maximum value and this range should not be violated.

$$0 \leqslant P_g \leqslant P_g^{max} \tag{4}$$

$$Q_g^{min} \leqslant Q_g \leqslant Q_g^{max} \tag{5}$$

$$0 \leqslant S_g \leqslant \sum S_{load} \tag{6}$$

In the proposed method DG maximum active power is limited by:

$$P_g^{max} \leqslant \sum P_{loads} \tag{7}$$