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An efficient approach for the siting and sizing problem of distributed generation

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ABSTRACT

This paper deals with the subject of finding the site and size of distributed generation in distribution systems. This problem corresponds to a mixed-integer nonlinear problem which is difficult and hard to solve with classical optimization techniques. Many approaches and with different objective functions have been applied to solve it. In this paper, the problem to solve comprises multiple distributed generation sources and the objective of minimizing power losses and generation costs, both for the distributed and conventional generators. Since it is highly combinatorial, a search space reduction is needed. So, an approximate model is used to reduce the search space of the possible buses where the distributed generation has to be located. Then, for each combination of the reduced space search, a nonlinear equations system is solved by a numerical method to get the size of the distributed generation, checking the voltage limits and the lines' capacities. To test the method, a comparison between the proposed algorithm and a force brute algorithm is performed on a 69 and 118 bus test systems. The obtained results indicate that this method find the optimal or near optimal solution in a reasonable computation time.

Introduction

Distributed Generation (DG) is the concept of decentralizing the power generation by connecting small generating units to the distribution system. These generation units can be both renewable (PV solar, wind, geothermal, mini-hydro, biomass, etc.) and nonrenewable (fuel cell, gas turbines, etc.) energy. Nowadays, centralized power plants are the main source of power supply, though DG technology is gaining wide spread interest in the electric power system because of their benefits like economical, technical and especially environmental.

Distributed generation has meaningful effect on the network losses, voltage profile of the system, grid stability, critical loads and generation costs, among others. Technical literature has shown that the advantages of distributed generation can be achieved only by choosing the proper size of the DG and connecting it at the appropriate location in the power network. On the other hand, not everything is advantageous, the presence of distributed generation needs protection strategies as it brings many changes in the system, which is the major disadvantage of this technology. However, the growing use of distributed generation also is causing advances in protection techniques.

Siting and sizing problem of distributed generation is continuously being studied by researches, applying different approaches and optimizing various objective functions.

One of the first studies addressing optimal placement was proposed by Wang and Nehrir [1] which is primarily concerned to find the optimal locations of DG, but not to optimize the size. In that work, the authors proposed different analytical methods for optimizing radial and meshed networks. Other references that also used analytical approaches were [2–4]. Acharya et al. [2] also proposed an analytical expression to calculate the optimal size, and for identifying the best location, an approximate loss formula was used. Using the same methodology, Gozel and Hocaoglu [3] solved the problem in a faster way because of they did not make use of admittance, impedance or Jacobian matrices; however, it was only suitable for radial systems. Similarly, Hung et al. [4] extended the work presented by Acharya et al. to DG types which are capable of delivering both real and reactive power. Recently, a new algorithm using MTLBO and the approximate loss formula used in [2] has been proposed by the authors [5] to solve the size and placement problem minimizing only the power losses. Another analytical study has been proposed in [6]. A methodology for the integration of dispatchable and nondispatchable renewable Distributed Generation (DG) units for minimizing annual energy losses has been introduced. In that methodology, analytical

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expressions were first proposed to determine the optimal size and power factor of DG unit simultaneously for each location.

In the papers mentioned above [1–5], the objective function was the power losses. When new terms are added to the objective function, conventional techniques lose interest due to the nonlinearity of the problem, that is, the computational effort is greater. In Ref. [7] the objectives were to minimize network power losses, better voltage regulation and improve the voltage stability. To overcome the optimal DG placement and sizing in distribution systems a combined genetic algorithm (placement) and particle swarm optimization (sizing) was employed.

Classical optimization techniques are mostly used to optimize the sizing problem. Keane and O'Malley [8] made use of linear programming, determining the optimal allocation with respect to all of the relevant technical constraints. The objective of their proposed method was to maximize the DG generation. The main drawback is that to reduce the models into a set of linear constraints the authors approximated the constraints by linear functions obtained from multiple load flows of the network in question. Koutroumpezis and Safigianni [9] proposed a method based on [8] to determine the optimum allocation of the maximum distributed generation penetration in a real medium voltage power distribution network.

Artificial intelligence techniques are becoming an alternative tool for solving the siting and sizing problem since is highly combinatorial. These techniques have the property that the two sub-problems (size and location) are addressed simultaneously. Refs. [10–14] are examples of these techniques. Alrashidi and AlHajri [10] addressed the problem of optimally placing and sizing multiple DGs in a given distribution network via enhanced PSO (Particle Swarm Optimization) algorithm. In the same way, but with the addition of production and loss costs in the objective function, Gómez-González et al. [11], dealt with the problem of multiple distributed generation sources employing discrete particle swarm optimization and optimal power flow. Injeti and Kumar [12] presented a technique composed of two parts. The first part was optimal siting by applying the power loss sensitivity factor (LSF) and the second one dealt with finding the optimal size of DGs at the feasible locations by applying simulated annealing. The objective function was minimizing the power losses and improving the stability voltage. A more complex problem was presented by Moradi et al. [13], where an efficient hybrid method for solving the optimal sitting and sizing problem of DG and shunt capacitor banks simultaneously was introduced. The method is based on imperialist competitive algorithm and genetic algorithm. Recently, a multi-objective optimization problem (voltage stability, power losses and network voltage variations) has been presented in [14], where a Pareto Frontier Differential Evolution (PFDE) algorithm has been used to solve it.

With regard to artificial intelligence techniques, their main limitation is the difficulty in determining the optimal controlling parameters. Thus, they generally provide a near optimal solution for a problem with a large number of variables, and change in the selection of the algorithm parameters changes the effectiveness of it.

In this paper, the proposed solution comprises multiple distributed generation sources and the objective of minimizing power losses and generation costs, both for the distributed and conventional generators. Since it is highly combinatorial, a search space reduction is needed. So, an approximate model of the optimization problem is used to reduce the search space of the possible buses where the distributed generation has to be located.

The results obtained on the two test systems (69 and 118 buses) suggest that the proposed approach can effectively ensure minimizing power losses and generation costs, and it is efficient in finding the optimal solution.

To conclude, the contents of this paper are briefly outlined below. In Section 'Problem approach', the formulation, the objective function, the search space reduction technique and the procedure for solving the optimization problem for each combination is presented. Section 'Proposed algorithm' describes the structure of the proposed algorithm. Numerical results are explained in Section 'Results and discussion' and finally, in Section 'Conclusions', the final conclusions are presented.

Problem approach

Optimal distributed generation placement and sizing is a mix-integer nonlinear problem. One idea is to separate it into two sub-problems: one for finding the optimal location for DG placement and the other for calculating the optimal generation for that placement. The obvious inconvenient is that the two problems are dependent on each other. On the other hand, the siting problem is an integer one, more difficult to solve a priori than the sizing one, which is continuous. So, an approximate solution technique for the placement problem that produce some possible results taking into account the size of the DG, would be a good trial. To solve it, many different methods have been proposed in the technical literature. Most of them use techniques for solving the first sub-problem by selecting potential candidate buses based on sensitivity indices. Then, the second one is solved by using an optimization technique.

In this paper, the problem has been separated into two problems. Firstly, since it is highly combinatorial, a search space reduction is made by solving a simplified mix-integer nonlinear model. To this purpose, the problem has been solved by relaxing the binary variables, and after that, a threshold has been used to get a set of candidate buses for locating the distributed generation. Secondly, for each combination of the reduced space search an optimization problem is solved by a numerical method to get the size of the distributed generation, checking the voltage limits and the lines' capacities.

Objective function

Different objectives can be included in the function to optimize. In the present case, the objective function is a cost function that has three terms: firstly the generation costs of the conventional units, secondly generation costs of distributed generators and finally, power losses costs.

The power supplied by the feeder is represented by traditional thermal generator, that is, the cost curve is represented by a quadratic function. With regards to distributed generators, their cost curves are described by a linear function proportional to the injected power. The third term of the objective function is formed by power losses costs which are proportional to real power losses. So, the objective function can be formulated as:

$$OF = aP_f^2 + bP_f + c + \sum_{k=1}^{n_{DG}} d_k P_{DGk} + mP_{loss} \tag{1}$$

where a, b, c, d_k and m are cost coefficients, P_f is the real power injected from the feeder, P_{DGk} is the real power injection from DG placed at node k, n_{DG} is the number of distributed generators and P_{loss} is the real power loss of the network expressed by Eq. (2).

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)\right] \tag{2}$$

In this expression the losses are function of the net active (P) and net reactive (Q) power injected on each bus of the network, n is the number of buses and the coefficients α_{ij} and β_{ij} are calculated by the following equations: