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A probabilistic methodology for distributed generation location in isolated electrical service area

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ABSTRACT

Distributed generation unlike centralized electrical generation aims to generate electrical energy on small scale as near as possible to load centers, interchanging electric power with the network. This work presents a probabilistic methodology conceived to assist the electric system planning engineers in the selection of the distributed generation location, taking into account the hourly load changes or the daily load cycle. The hourly load centers, for each of the different hourly load scenarios, are calculated deterministically. These location points, properly weighted according to their load magnitude, are used to calculate the best fit probability distribution. This distribution is used to determine the maximum likelihood perimeter of the area where each source distributed generation point should preferably be located by the planning engineers. This takes into account, for example, the availability and the cost of the land lots, which are factors of special relevance in urban areas, as well as several obstacles important for the final selection of the candidates of the distributed generation points. The proposed methodology has been applied to a real case, assuming three different bivariate probability distributions: the Gaussian distribution, a bivariate version of Freund's exponential distribution and the Weibull probability distribution. The methodology algorithm has been programmed in MATLAB. Results are presented and discussed for the application of the methodology to a realistic case and demonstrate the ability of the proposed methodology for efficiently handling the determination of the best location of the distributed generation and their corresponding distribution networks.

1. Introduction

Distributed generation (DG) represents a change in the paradigm of electrical energy generation. The emergence of new technological alternatives (photovoltaic systems, wind power, cogeneration, etc.) allows to generate part of the required energy closer to the places of consumption, improving quality levels and minimizing the investments costs associated with of transmission and distribution systems [1]. In general terms, the development of DG plants aims at improving environmental aspects and quality of energy (uninterrupted provision of electrical energy with suitable voltage level, current, frequency, amongst others) [1–3]. These generation types can benefit from a decision-support tool able to assist decision making in the scope of a project of installation of DG plants. In a first stage, a programming tool determines the location of the DG point's candidates. After this, we can proceed to optimize the capacities, number of units and technology to be implemented.

The objective of this research work is determining the region of higher probability for location of DG plants that will feed the loads under study. These loads have been previously estimated [4–6].

In order to determine the region of greater probability for location of DG plants, a probabilistic methodology, previously used for the optimal location of electric substations, will be adapted [7,8]. To achieve this objective, three distribution probability functions are used: normal, Freund's bivariate exponential distribution and Weibull. The obtained solution must fulfil the parameters of reliability and electrical power quality for the study developed in this work. It should be noticed that this methodology considers the fact that the load center for a group of consumers varies with time [7].

The decision of the location of DG plants is a crucial aspect in the model, with a strong impact on the operation and investment costs.

In [9] an algorithm using primal-dual interior point method for solving non-linear optimal power flow problems was proposed. The main purpose is to optimize location and sizing of DG on distributed systems for solving the problem of line loss reduction. Most of the benefits of employing DG in existing distribution networks have both economic and technical implications and they are interrelated.

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In [10], a general approach is presented to quantify the technical benefits of DG. A set of indices is proposed to quantify some of the technical benefits of DG. They are:

- voltage profile improvement index;
- line loss reduction index;
- environment impact reduction index;
- DG benefit index.

The basic idea behind the above proposed indexes' is to compare the voltage profile, the total line losses, and the emission of a particular pollutant with and without the employment of DG.

In [11], a multi-objective formulation for the sitting and sizing of DG resources into existing distribution networks has been proposed. This method permits the planner engineers to decide the best compromise between costs of network upgrading, power losses and energy not supplied. A genetic algorithm and ε-constraint method have been proposed that allows obtaining a set of non-dominated solutions.

In [12] a multi-objective performance index-based size and location of DG in distribution systems with different load models has been presented. A constant real and reactive power load model is assumed. In this reference, it is shown that the load models can significantly affect the optimal location and sizing of DG resources in distribution systems.

In [13] an analytical method has been presented to determine the optimal location to place DG in radial as well as networked systems to minimize the power loss of the system. In [14] the analytical method is only proposed for sizing and location of DG in radial distribution systems. In this study, a loss sensitivity factor, based on the equivalent current injection, is formulated for distribution systems. The formulated sensitivity factor is employed for the determination of the optimum size and location of DG so as to minimize total losses by the analytical method without use of admittance matrix, inverse of admittance matrix or Jacobian matrix. It is shown that, the proposed method is in close agreement with the classical grid search algorithm based in successive load flows.

Ref. [15] presents a genetic algorithm-based method to determine optimal location and size of the DG to be placed in radial, as well as networked, systems with an objective to minimize the power losses. Several simulation studies have been conducted on radial feeders, as well as networked systems, considering single-distributed generation and multiple-distributed generations separately to minimize the power loss of the system subjected to no voltage violation at any of the distribution network buses.

The location of the DG site depends upon several factors, such as the voltage level, voltage regulation, DG cost and power losses level. In general, some considerations should be taken into account for the selection of the candidate points where the DG will be located, such as [4,16]:

- The DG system must be as close as possible to the load center of its service area, in order to reduce the voltage drop, power losses and the product of the load and the distance from the DG source.
- Proper voltage regulation should be obtainable without taking extensive measures.
- Proper access for the future interconnection with the distribution or transmission electrical networks should be provided, considering future growth.
- The DG fixing project must comply with land regulations, local ordinances and neighbors.
- The DG installation project should reduce the number of customers affected by any unavailability of electricity supply.

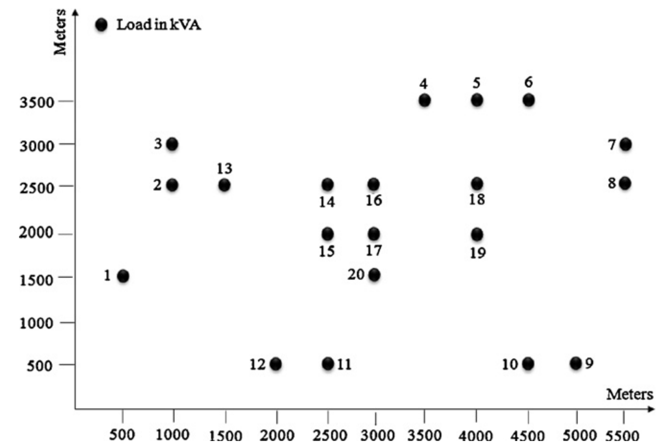

Fig. 1. Geographical locations on the X–Y plane of the loads.

- Other considerations, such as adaptability, emergency, etc., should also be taken into account.

This paper proposes a new probabilistic methodology conceived to assist the electric system planning engineers in the selection of the DG location, taking into account the hourly load changes or the daily load cycle. These location points, properly weighted according to their load magnitude, are used to calculate the best fit probability distribution. This distribution is used to determine the maximum likelihood perimeter of the area where each DG source point should preferably be located by the planning engineers. When all the load centers are determinate, then the planning engineers can better calculate the load nodes that can be feed by each source or DG by the simple calculation of the product (kVA × distance) minimum. The algorithm is stopped when the sum of the load nodes is lower or equal than the capacity of the source or DG, taking into account a certain reserve for the future grows of the load.

This paper is organized in the following way. Section 2 expands the probabilistic methodology used to locate the DG and the proposed statistical distributions. After that, Section 3 presents the test system, the application of the three distributions probabilities to a realistic case and the main results of the best location of the DG and their distribution networks. Finally, Section 4 states the conclusions.

2. Proposed statistical distribution

The proposed calculation procedure starts with the application of a deterministic methodology to a given set of load curves given in 1 h periods, associated to a set of points in the plane (as presented in Fig. 1).

The set of hourly load centers is calculated using expressions (1) and (2) where X_i and Y_i are the coordinates of the load center; S_{ij} is the apparent power of the load curve j for hour i; nh is the number of hours for the discretization of the load curves; nc is the number of load curves.

For hour i, we have:

$$X_i = \frac{\sum_{j=1}^{nc} S_{ij} X_j}{\sum_{j=1}^{nc} S_{ij}}, \quad \text{for } i = 1, \ldots, nh \tag{1}$$

$$Y_i = \frac{\sum_{j=1}^{nc} S_{ij} Y_j}{\sum_{j=1}^{nc} S_{ij}}, \quad i = 1, \ldots, nh \tag{2}$$

Any other methodology may be applied at this stage to define the best candidate of source location point for each hourly load, without loss of generality. In order to apply the proposed methodology, the