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Decision support for grid-connected renewable energy generators planning

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ABSTRACT

Recent technological advances and the incremental demand for electrical energy are leading a growth in the prevalence of distributed generation. There are some off-the-shelf tools to support grid planners in locating and sizing a given number of Distributed Generators (DGs), but they approach the problem using a single set of the variables (either location, size or number of DGs). This paper reviews the problem and provides a new pathway for supporting grid planning with an integrated view; hence, a new planning problem is formulated to jointly determine how many new DGs are needed, of which type, their location and size, while attempting to maximise the profit of the generators, minimise the system losses and improve the voltage profile. Accompanying the new grid planning problem, solution approaches based on meta-heuristic methods are provided. A detailed performance analysis of the proposed approaches is carried out on 14- and 57-bus systems to illustrate what could be the outcomes of the new problem. In so doing, particle swarm optimisation-based approaches are able to find the best optimised solutions.

1. Introduction

Technological advances have made it possible to install small distributed generators. The installation of new DGs aims to improve the general performance of power grids in addition to obtaining a profit. In other words, installing new DGs, besides being economically profitable, can improve the quality of the voltage of a given grid and reduce power loss due to energy transport and distribution.

However, the potential benefits of installing new DGs depend on making good decisions regarding how many DGs should be installed, which kinds of DGs are the most appropriate (PV generators, wind turbines, fuel cells, etc.), where they should be connected and which generation capacity is the most appropriate. These questions cannot be solved in isolation since they depend on one another, the given grid (topology, load, etc.) and access to the availability of the sources harvested by generators. For example, the benefits of installing a PV generator depend on the solar radiation, the correlation between the load and solar radiation, the bus where the generator is placed, the size of the generator, etc.

Therefore, there is a need for tools and methods that help grid planners to work out the number, type, location and size of new DGs in order to optimise the performance of the power grid (voltage profile and power loss) and the profit. However, due to the complexity of the problem, many efforts have been made to provide approaches to partially solve the problem (i.e. seeking the best locations and sizes of a set of DGs). In this way, this paper is the first attempt to globally tackle the problem taking into account the availability of the resources harvested by the candidate new DGs.

Summing up, the contribution of the paper is twofold: (i) a new formulation of the DGLS problem, which uses a set of types of generators, a grid, a time-dependent load and certain meteorological conditions to jointly determine the location, size, number and most appropriate type of DGs; and (ii) the recommendation of a meta-heuristic method to solve the problem based on the comparison analysis of several different meta-heuristic methods in two IEEE bus configurations.

This paper is organised as follows: first, Section 2 presents some work related to the DGLS problem; Section 3 formalises the problem and presents the formulation used; next, meta-heuristic approaches are described in Section 4, showing how they could be used for solving the posed problem; Section 5 explains the simulations performed in order to analyse the proposed approaches for providing a useful recommendation; finally, the paper ends with

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Nomenclature Table: List of acronyms

DG	Distributed Generator
DGLS	Distributed Generation Location & Sizing
GA	Genetic Algorithm
GA + SAacc	Combination of GA and SAacc
GA + SAran	Combination of GA and SAran
LRS	Linear Random Search
PSO	Particle Swarm Optimisation
PSO + SAacc	Combination of PSO and SAacc
PSO + SAran	Combination of PSO and SAran
PV	Photovoltaic
SA	Simulated Annealing
SAacc	SA with the accumulating neighbourhood function
SAran	SA with the random replacement neighbourhood function
SFLA-DE	Shuffled Frog Leaping Algorithm - Differential Evolution

Section 6, which establishes the conclusions of the paper and makes suggestions for future work. Nomenclature Table summarises the acronyms used in this paper.

2. Related work

The literature presents several interesting models to the DGLS problem. These models aim to answer various questions related to the DGLS problem (see Fig. 1), i.e., location of new DGs, the most suitable type of DG, etc. In particular [1], presents a model that seeks to answer the same questions as this paper; that is, the best number, type, location and size of DGs to connect in a given grid with a given load. However, it restricts the type of DGs to small-size combined heat power generators and boilers. Conversely to [1], this paper proposes the placement of DGs, such as PV generators or wind turbines, that harvest renewable resources. Since the considered type of generators and the fuel or energy source are completely different, the formulation of the problem presented in Ref. [1] differs greatly to that presented in this paper. For example, the generation capacity of DGs harvesting renewable resources (henceforth renewable DGs) depends on the weather conditions, which are stochastic, while the fuel used by combined heat power generators is a storable energy source. As in this paper [1], seeks to optimise the costs (or the profit) of installing new DGs and, as the authors do not consider the placement of renewable DGs, the formulation seeks to minimise the CO_2 emissions. This paper, however, does not incorporate the CO_2 emissions in the target function, but includes the power losses throughout the grid and the voltage index in each bus (voltage profile).

Authors in Ref. [2] present a model to seek the most appropriate location, size and type of a given number of generators without restricting the type of DG to combined heat power generators. Instead, renewable DGs (i.e. PV generators) are considered in Ref. [2]. As a consequence, the formulation of the problem tackles the problem of the availability of the energy sources (i.e. solar radiation or wind speed) when there is the demand for energy. Accordingly, time-dependent load profiles are considered, as in this paper, and used to evaluate the suitability of the different types of generators. The model proposed in Ref. [2] seeks the minimisation of power losses using a mixed integer non-linear programming solver. Conversely to [2], this paper seeks to optimise more objectives (i.e. costs and voltage profile) and also seeks to find the best number of generators. Furthermore, this paper analyses the use of metaheuristic methods to solve the problem. Following the line of [2], authors in Ref. [3] also present a model to find the best location, size and type (considering different renewable DG) to minimise power losses and the costs of installing new DGs. Therefore, the work also tackle the problem of the availability of the energy sources. However, they propose the use of GA to solve the problem. Similarly, the authors in Ref. [4] present a combination of ant colony optimisation and artificial bee colony to determine the location, size and type of a given number of different DGs in order to optimise power losses, CO_2 emissions, voltage stability and energy costs. In particular [4], considers gas turbines, fuel cells and wind turbines, but the authors do not perform and hourly analysis of the load and the generation. Instead, they consider constant loads and generation outputs and model the uncertainty of wind turbines production using a given probability density function and they deal with it using a point estimate method. Conversely to the presented paper [4], limits the number of each type of DG.

The authors in Ref. [5] also seek the optimal location, type and size of a given number of DGs. However, they distinguish generators according to whether they can supply either active power or reactive power or both, instead of distinguishing them by the energy source. The authors consider them a constant load and output of the generators instead of hourly profiles and stochastic energy sources. Moreover, the authors propose to solve the problem by iteratively testing various promising locations and types while

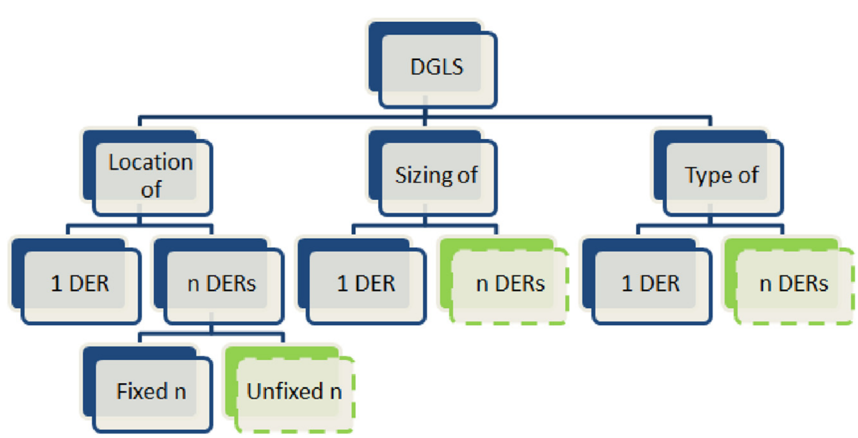

Fig. 1. Classification of the questions tackled by the DGLS problem. The questions tackled in this paper are displayed in green.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)