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The effects of photovoltaic electricity injection into microgrids: Combination of Geographical Information Systems, multicriteria decision methods and electronic control modeling

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ABSTRACT

This article presents a model to calculate the impact on the grid of the injection of electricity generated from photovoltaic systems. The methodology combines the use of Geographical Information System tools to classify the optimal locations for the installation of photovoltaic systems with the calculation of the impact into microgrids of the electricity generated in such locations. The case study is focused on Murcia region, in South-east Spain, and on medium size photovoltaic systems. The locations have been selected from a Geographical Information System database including several parameters, and evaluated and classified using a fuzzy version of the multicriteria decision method called Technique for Order Preference by Similarity to Ideal Solution. In order to obtain the weights for the criteria used in the evaluation, the Analytic Hierarchy Process has been used. Finally, using meteorological data from a small set of possible locations, the impact on the grid arising from the injection of power generated from photovoltaic systems that are connected to the grid via a module implementing different control electronic strategies has been calculated. Different electronic control strategies have been modeled to demonstrate that stabilization of the electrical parameters of a microgrid can be obtained within 500 ms in all cases, even when a relatively large power surge, or slower variations, are injected into the grid from the medium size photovoltaic systems.

1. Introduction

Nowadays, industrial and urban development are mostly driven by fossil fuels thus creating important environmental problems, being green-house-gases (GHG) emissions the most known. Alternative resources in power generation are being developed with the aim of attending the increase in energy demand and at the same time reducing the GHG emissions; renewable energy technology is the best choice for this purpose [1]. The booming renewable energy market despite representing only 2% of global energy consumption has been growing steadily and thus has demonstrated that it can become an alternative option to fossil fuels, especially for electricity generation in order to provide a sustainable electricity supply with reduced environmental problems [2].

Within the broad range of renewable options, photovoltaic technology has been one of the fastest growing technologies worldwide in recent years, and particularly in Spain, where up to 4.5 GWp of new installed photovoltaic capacity has been connected to the grid since 2004 [3]. This renewable energy technology development establishes the conditions for a new and improved energy framework which has as its center the generation of electric power near the consumption area, in contrast to the traditional concept, in which generation and consumption areas are far away from each other [4]; in this way, a new future emerges in which the distribution and transport systems are responsible for supplying power from renewable sources to a large number of small households which are connected to the low voltage electrical grid, which can be considered a Microgrid (MG) [5].

Among the benefits provided by the new concept of microgrid, a few can be emphasized:

- to ensure the quality and reliability of power supply, with a more efficient use of natural resources.

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- To improve efficiency in energy transport (reduction of energy losses).
- To generate electricity with low or zero emissions of CO_2 and SO_2 into the atmosphere.

It is a confirmed trend that the electricity generation mix of many countries in the world is increasingly incorporating a larger contribution of renewable energy supply [6]. The electricity grid of such countries needs to match in real time the supply and demand of electricity, i.e. the electricity injected to the grid at a given time has to be the same as the electricity consumed by the users at the same time. This is a challenge when renewable sources represent a large share of the electricity mix, and the road toward sustainability will require management of different intermittent sources probably with a storage back-up [7]. This matching is usually guaranteed by the grid manager, which has the authority to allow or block the electricity input to the grid from different suppliers, and usually prioritizes generation from renewable sources [8]. It has been alleged that a large amount of renewable electricity supply could become unmanageable because it depends strongly on uncontrollable environmental parameters such as wind speed or irradiance, which may vary strongly with geographical location or time (during same day or seasonal variations) [9]. Nevertheless, contrary to these allegations, a larger input of renewable energy, in particular from wind and photovoltaic sources in a given geographical region of large enough size can have a stabilizing effect to the grid, for example: a combination of wind and wave power [10], or even for PV-only integration with enough geographical dispersion to smooth the power fluctuations originated by local weather changes [11]. In order to benefit from this complementarity, a careful selection of the best location for installing the energy system is required.

The search and selection of optimal locations to install renewable energy facilities, requires not only to have an advisory group able to assess and analyze alternatives, but also to apply a set of tools and methods to facilitate the decision making process. The problem of selecting the optimum location for renewable energy facilities is a complex problem because it needs to handle a great variety of criteria of different nature and origin, as well as to evaluate, in most cases, a large number of alternatives. For this purpose, Multicriteria Decision Methods (MCDM), among which are the most widely used, the Analytic Hierarchy Process (AHP) [12] and the method called Technique for Order Preference by Similarity to Ideal Solution [13] are the main methods to tackle this type of problems in renewable energy for example in [14] when MCDM is apply to evaluation of cooking energy alternatives by solar energy or in [15] using MCDM in wind farm land suitability, finally combining them, on the one hand with Geographical Information Systems (GIS) as in [16] using GIS modeling for wind and solar farms in Colorado and in [17] for evaluating the carrying capacity of land areas for grid-connected photovoltaic power plants that will be used as support database to our problem, and on the other hand, with soft computing tools such as fuzzy logic [18] applied to the own decision methodologies which gives them the uncertainty modeling and vagueness typical of the data used in this type of problems. These tools have been used in numerous occasions to solve problems in the energy field. In the late 90 s, [19] compared the ELECTRE multicriteria analysis approach with a fuzzy-sets methodology with the aim of decision making in energy planning. Nowadays several examples of the application of the fuzzy logic in the energy sector can be found in the scientific literature. Cziesla and Tsatsaronis [20] used fuzzy inference systems to improvement thermal power plants, Laghari et al. [21] carried out a review of computational intelligence techniques for load shedding in power systems. Furthermore, in the PV systems it is common the application of fuzzy logic algorithms such as Yahyaoui et al. [22] who applied this technique for off-grid photovoltaic systems with non-controllable loads or Sallem et al. [23] who optimized a p photovoltaic water pumping system.

Once the first step of selection of the optimum location is accomplished, it is necessary to monitor the environmental parameters (or access to databases) to provide a measure of the potential renewable energy resource which are required. From this data, simple models to calculate the electricity output provided by the technology of choice can be easily implemented, thus completing the required amount of information before taking any decision about the final installation of the energy systems, which usually involves a large economic investment.

For the particular case study proposed in this article, a combination of multicriteria decision methods with GIS as support database and soft computing, specifically the fuzzy logic [24] and simple analytical modeling implemented in MatLab-Simulink has been applied for searching optimal locations to install photovoltaic solar farms in Murcia and evaluate the impact on the stability of a microgrid provided that medium size photovoltaic systems are connected to it. In Section 2, a detailed explanation of the methodology is provided, with special focus on the multicriteria decision methods, followed by a presentation and discussion of the results in Section 3, organized in two blocks: description of the optimum geographical locations and calculations of generated power and effect on the grid. Finally the conclusions are presented in Section 4.

2. Methodology: Soft computing combined with numerical modeling for the simulation of photovoltaic energy generation and its impact on the grid

In this article, a GIS methodology will be used as a first step to create a database of locations available to host photovoltaic plants. In a second stage, those locations will be evaluated using a fuzzy TOPSIS method, for which the weights of the criteria to be used had been previously obtained using a fuzzy AHP method. Back to GIS, the average temperature and irradiance for the selected locations will be gathered and used in the final stage in which the impact of connecting the facilities to the local grid is evaluated. These final results will also provide additional information to a decision maker, and therefore can also be considered as a part of the multi-criteria decision method, although at this stage of the study there is no feedback of these results to the fuzzy AHP methodology used in the previous stage.

The methodology of the study is based on a combination of soft computing tools used for the selection of the optimum locations for photovoltaic systems and numerical modeling (based on Matlab-Simulink) which is used to calculate the impact on the grid from the injection of power from these systems; this impact is obtained from real-time simulation of control electronics and a statistical analysis of voltage, current and phase injected to the grid.

The starting point for this kind of studies is the selection of the best geographical locations to install the renewable energy systems under consideration (in this case, photovoltaic systems). For this purpose, the use of computational tools such as Geographical Information Systems (GIS) are required; the additional benefit of GIS methods is that an estimation of the maximum use of land can be achieved, this will provide a cap for the photovoltaic capacity that can be installed at a given location, which is usually of the order of several MW_p, in this article we will not focus on the maximum power achievable, but on the impact on the grid of a medium size system (tens or a few tenths of kW_p) installed in the selected optimum location. In order to evaluate the best location a large amount of variables and criteria need to be analyzed and