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Sizing optimization of grid-independent hybrid photovoltaic/wind power generation system

A. Kaabeche [a,*], M. Belhamel [a], R. Ibtiouen [b]

[a] Centre de Développement des Energies Renouvelables, B.P. 62 16340 Bouzareah, Algiers, Algeria
[b] Ecole Nationale Supérieure Polytechnique d'El Harrach, Algiers, Algeria

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ABSTRACT

To allow a real penetration of the huge dispersed naturally renewable resources (wind, sun, etc.) intermittent and more or less easily predictable, optimal sizing of hybrid renewable power generation systems prove to be essential. This paper recommends an optimal sizing model based on iterative technique, to optimize the capacity sizes of different components of hybrid photovoltaic/wind power generation system using a battery bank. The recommended model takes into account the submodels of the hybrid system, the Deficiency of Power Supply Probability (DPSP) and the Levelised Unit Electricity Cost (LUEC). The flow chart of the hybrid optimal sizing model is also illustrated. With this incorporated model, the sizing optimization of grid-independent hybrid PV/wind power generation system can be accomplished technically and economically according to the system reliability requirements. A case study is conducted to analyze one hybrid project, which is designed to supply residential household located in the area of the CDER (Center for Renewable Energy Development) situated in Bouzaréah, Algeria (36° 48′N, 3° 1′E, 345 m).

1. Introduction

Energy consumption in the last century has considerably increased due to massive industrialization. The forecast of energy needs for years to come only confirm this trend, especially given demographic trends and development in some world regions, particularly in Asia. On the one hand, the fields of traditional energy resources of fossil origin can be exploited for several decades, which suggests a situation of energy shortage globally which will be imminent. On the other hand, nuclear waste poses further problems in terms of pollution of radioactive waste, decommissioning of old plants and industrial hazard. To meet the energy needs of today's society, it is necessary to find solutions and to diversify them.

Alternative energy resources such as solar and wind have attracted energy sectors to generate power on a large scale. However, common drawback with solar and wind energy is their unpredictable nature and dependence on weather and climatic changes. Stand-alone photovoltaic (PV) or wind energy systems do not produce usable energy for considerable portion of time during the year.

In order to efficiently and economically utilize the renewable energy resources, one optimum match design sizing method is essential. The sizing optimization method can help to endorse the lowest investment with adequate and full use of the solar system, wind system and battery bank, so that the hybrid system can work at optimum conditions in terms of investment and system power reliability requirement.

Different optimization techniques for hybrid PV/wind systems sizing have been reported in the literature such as dynamic programming, graphical construction technique, probabilistic approach, artificial intelligence methods, multi-objective design, linear programming and iterative technique [1].

Thus, Musgrove [2] presented a dynamic programming model, RAPSODY, which is designed to determine optimal operating strategies for a hybrid wind power system incorporating battery storage and an auxiliary diesel generator. The model takes capital, operating and maintenance, and fuel costs into account to calculate the average daily cost of satisfying an electrical load profile. The developed model is provided with an efficient optimizing routine which allows the user to obtain optimal component sizes for a particular load profile and wind or solar resource. A graphical construction technique to follow the optimum combination of PV array and battery for a hybrid solar–wind system has been presented by Borowy and Salameh [3]. For a given load and a desired LPSP, the number of batteries and PV modules were calculated based on the minimum cost of the system. The minimum cost will be at the point of tangency of the curve that represents the relationship between

* Corresponding author. Tel.: +213 21 90 15 03; fax: +213 21 90 15.
E-mail address: h.kaabeche@hotmail.com (A. Kaabeche).

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the number of PV modules and the number of batteries. Then the optimum sizing of the battery bank and the PV array can be achieved. Another graphical technique has been given by Bin et al. [4], Kaabeche et al. [5] and Markvart [6], to optimally design a hybrid solar–wind power generation system. However, in both graphical methods, only two parameters (either PV and battery, or PV and wind turbine) were included in the optimization process.

Tina et al. [7] presented a probabilistic approach based on the convolution technique [8] to incorporate the fluctuating nature of the resources and the load, thus eliminating the need for time-series data, to assess the long-term performance of a hybrid solar–wind system for both stand-alone and grid-connected applications. Disadvantage of this probabilistic approach is that it cannot represent the dynamic changing performance of the hybrid system.

A methodology for optimum design of a hybrid PV/wind system has been proposed by Koutroulis et al. [9]. The purpose of the proposed methodology is to suggest, among a list of commercially available system devices, the optimum number and type of units ensuring that the 20-year round total system cost is minimized by Genetic Algorithms subject to the constraint that the load energy requirements are completely covered, resulting in zero load rejection. Yang et al. [10] proposed one optimum sizing method based on Genetic Algorithms by using the Typical Meteorological Year data. This optimization model is proposed to calculate the system optimum configuration which can achieve the desired LPSP with minimum Annualized Cost of System. Another Heuristic technique based on the evolutionary algorithms have been performed by Ekren et al. [11] for optimizing size of a PV/wind integrated hybrid energy system with battery storage. The proposed methodology uses a stochastic gradient search for the global optimization. In the study, the objective function is the minimization of the hybrid energy system total cost.

Bernal-Agustín et al. [12] present a multi-objective optimization (NPC versus CO2 emissions) for a hybrid solar/wind/diesel system with battery storage based on Multi-Objective Evolutionary Algorithms (MOEAs). A triple multi-objective optimization to minimize simultaneously the total cost throughout the useful life of the installation, pollutant emissions (CO2) and unmet load has been presented by Dufo-López and Bernal-Agustín [13]. For this task, a MOEAs and a Genetic Algorithm have been used in order to find the best combination of components and control strategies for the hybrid system. According to the methods proposed by Chedid and Rahman [14] and Yokoyama et al. [15] the optimal sizes of the PV and wind power sources and the batteries are determined by minimizing the system total cost function using linear programming techniques. The total system cost consists of both the initial cost and yearly operation and maintenance costs.

Yang et al. [16,17] have proposed an iterative optimization technique following the loss of power supply probability (LPSP) model for a hybrid solar–wind system. The number selection of the PV module, wind turbine and battery ensures the load demand according to the power reliability requirement, and the system cost is minimized. Similarly, an iterative optimization method was presented by Kellogg et al. [18] to select the wind turbine size and PV module number needed to make the difference of generated and demanded power (DP) as close to zero as possible over a period of time. From this iterative procedure, several possible combinations of PV/wind generation capacities were obtained. The total annual cost for each configuration is then calculated and the combination with the lowest cost is selected to represent the optimal mixture.

Another iterative optimization technique for a stand-alone hybrid photovoltaic/wind system (HPWS) with battery storage is presented by Diaf et al. [19]. The main objective of the presented study is to find the optimum size of system, able to fulfill the energy requirements of a given load distribution, for three sites located at Corsica island and to analyze the impact of different parameters on the system size. In the proposed stand-alone system, the supply of wind power via an uninterruptible power supply (UPS) is used and therefore the energy produced by the wind generator can be sent directly to the load.

In this paper, a grid-independent hybrid PV/wind system optimization model, which utilizes the iterative optimization technique to follow the Deficiency of Power Supply Probability (DPSP) model and the Levelised Unit Electricity Cost (LUEC) model for power reliability and system cost respectively, is presented. At the difference of the system configuration used by Diaf et al. [19] in which the wind generator is taken as the primary source of energy and the PV generator as the secondary source of energy. This configuration is good especially for high wind potential regions. The configuration adopted in this study corresponds to the hybrid PV/wind system in which both wind and PV generators present the primary source of energy thereby represent the best complementarity between the two renewable energy sources photovoltaic and wind and leads to an energy management strategy different from that presented in [19]. Also, the algorithm developed in this study does not allow the unballasting of the production in the event of surplus energy: power produced from natural sources intermittent (wind, sun) greater than the amount of power consumed and the maximum acceptable power storage device. Moreover, this algorithm permits the calculation of the excess energy. So, the surplus energy produced could be used in the production of hydrogen from an electrolyzer for Long-term energy storage, helping to improve the total efficiency of the hybrid system. Using the DPSP objective function, the configurations of a hybrid system which can meet the system reliability requirements can be obtained. There are three sizing parameters in the simulation, i.e. the capacity of PV system, the rated power of wind system and the capacity of the battery bank. The optimum configuration can be identified from the set of the above obtained configurations by reaching the lowest Levelised Unit Electricity Cost (LUEC). Écouter Lire phonétiquement.

2. Grid-independent system description

A schematic diagram of a stand-alone hybrid PV/wind system is shown in Fig. 1. Battery chargers, connected to a common DC bus, are used to charge the battery bank from the respective PV and wind input power sources. Depending on the battery charger technology, the maximum available power can be extracted from the PV and wind power sources (Maximum Power Point Tracking, MPPT). The battery bank is used to store the energy surplus and to supply the load in case of low wind speed and/or irradiation

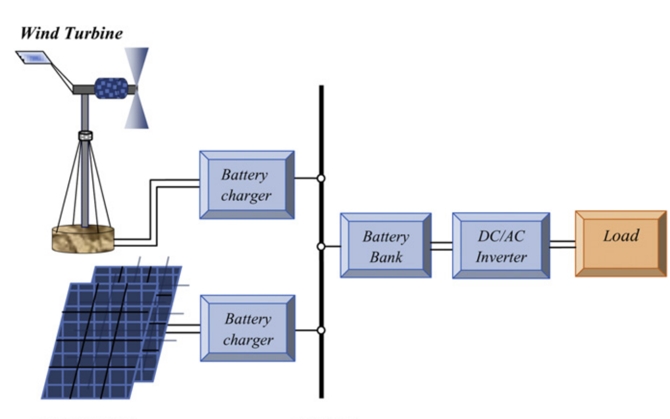

Fig. 1. Block diagram of a hybrid PV/wind system.