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Techno-economic valuation and optimization of integrated photovoltaic/wind energy conversion system

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Abstract

Decentralized electricity generation by renewable energy sources offer greater security of supply for consumers while respecting the environment. But the random nature of these sources requires us to develop sizing rules and use these systems to exploit them. This paper proposes an integrated PV/wind hybrid system optimization model, which utilizes the iterative optimization technique following the Deficiency of Power Supply Probability (DPSP), the Relative Excess Power Generated (REPG), the Total Net Present Cost (TNPC), the Total Annualized Cost (TAC) and Break-Even Distance Analysis (BEDA) for power reliability and system costs. The flow chart of the hybrid optimal sizing model is also illustrated. With this merged model, the optimal size of PV/wind hybrid energy conversion system using battery bank can be performed technically and economically according to the system reliability requirements. Additionally, a sensitivity analysis was carried out in order to appreciate the most important parameters influencing the economic performances of the hybrid system. A case study is conducted to analyze one hybrid project, which is designed to supply small residential household situated in the area of the Center for Renewable Energy Development (CDER) localized in Bouzaréah, Algeria (36°48′N, 3°1′E, 345 m).

Keywords: Renewable energy system; Unit sizing; Economic viability; Optimization

1. Introduction

Energy generation is a challenge of great importance for years to come. Indeed, the energy needs of industrialized societies are increasing, moreover, developing countries will need more energy to complete their development. Consumption of these sources leads to emissions of greenhouse gases and thus increasing pollution. The rapid depletion and price volatility of fossil fuels worldwide have necessitated urgent search for new energy sources to meet current requirements.

Alternative energy resources such as hydropower, wind, solar and geothermal 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, and the variations of solar and wind energy may not match with the time distribution of load demand. This short-coming not only affects the system's energy performance, but also results in batteries being discarded too early. Generally, the independent use of both energy resources may result in considerable over-sizing, which in turn makes the design costly. It is prudent that neither a stand-alone solar energy system nor a wind energy system can provide a continuous power supply due to seasonal and periodical variations (Yang et al., 2008) for stand-alone systems.

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

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to endorse the lowest investment with adequate and full use of the renewable energy systems (photovoltaic, wind, thermal systems, etc.). Thus, Chel et al. (2009) presented the methodology to evaluate size and cost of PV power system components. The PV array size is determined based on daily electrical load and number of sunshine hours on optimally tilted surface specific to the country. Based on life cycle cost (LCC) analysis, capital cost (US$/kW$_P$) and unit cost of electricity (US$/kW h) were determined for PV systems such as stand-alone PV (SAPV) and building integrated PV (BIPV). Effect of carbon credit on the economics of PV system showed reduction in unit cost of electricity for SAPV and BIPV systems, respectively. The developed methodology was illustrated using actual case study on 2.32 kW$_P$ PV system located in New Delhi (India).

Another study on performance evaluation of 2.32 kW$_P$ photovoltaic (PV) power system located in New Delhi (India) has been performed by Chel and Tiwari (2010). The considered PV system feeds an electric air blower of an earth to air heat exchanger (EAHE) used for heating/cooling of adobe house, computer, submersible water pump, etc. The outdoor efficiencies, power generated and lost in PV system components were determined using hourly experimental measured data for 1 year on typical clear day in each month. The energy conservation, mitigation of CO_2 emission and carbon credit potential of the existing PV integrated EAHE system is presented too. Also, the energy payback time (EPBT) and unit cost of electricity were determined for both stand-alone PV (SAPV) and building roof integrated PV (BIPV) systems.

One more experimental outdoor performance of a 2.32 kW$_P$ stand-alone photovoltaic (SAPV) system for four weather types have been performed by Chel and Tiwari (2011). The number of days and daily power generated corresponding to four weather types in each month were used to determine monthly and subsequently annual power generation from the existing SAPV system. There are three daily load profiles with and without earth to air heat exchanger suitable for three seasons like summer, winter and rainy. The life cycle cost (LCC) analysis for the existing typical SAPV system is carried out to determine unit cost of electricity. The effect of annual degradation rate of PV system efficiency is also presented.

A performance experiments and economic analysis of a horizontal ground source heat pump (GSHP) system have been performed by Esen et al. (2006). The GSHP system was compared to conventional heating methods (electric resistance, fuel oil, liquid petrol gas, coal, oil and natural gas) in the economical analysis using an annualized life cycle cost method. It was shown that the GSHP system offers economic advantages over the mentioned first five conventional heating methods. However, it is not an economic alternative system to natural gas. Another techno-economic comparison between a ground-coupled heat pump (GCHP) system and an air-coupled heat pump (ACHP) system has been presented by Esen et al. (2007). The test results indicate that system parameters can have an important effect on performance, and that GCHP systems are economically preferable to ACHP systems for the purpose of space cooling.

A graphical construction technique to follow the optimum combination of PV array and battery bank for a hybrid solar–wind system has been presented by Borowy and Salameh (1996). 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 the number of PV modules and the number of batteries. Another graphical technique has been given by Ai et al. (2003), Kaabeche et al. (2006) and Markvart (1996), to optimally design a hybrid solar–wind power generation system.

Tina et al. (2006) presented a probabilistic approach based on the convolution technique (Karaki et al., 1999) 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. Yang et al. (2008) 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 and Ekren (2010) for optimizing size of a PV/wind integrated hybrid energy system with battery storage. In the study, the objective function is the minimization of the hybrid energy system total cost.

Bernal-Agustín et al. (2006) present a multi-objective optimization (NPC versus CO_2 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 (CO_2) and unmet load has been presented by Dufo-López and Bernal-Agustín (2008). 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 (1997) and Yokoyama et al. (1994) 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. (2003, 2007) 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. Another iterative optimization technique to optimize the