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Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system

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Abstract

This paper focuses on development of optimal sizing model based on an iterative approach to optimize the capacity sizes of various stand-alone PV/wind/diesel/battery hybrid system components for zero load energy deficit. The suggested model takes into consideration the hybrid system submodels, the Total Energy Deficit (TED), the Total Net Present Cost (TNPC) and the Energy Cost (EC). The flow diagram of the hybrid optimal sizing model is also demonstrated. Exploiting the developed model, all configurations giving the rate of 0% of Total Energy Deficit (TED) are retained. Afterward, the optimal configuration is predicted on the basis of the minimum cost. Using solar radiation, ambient temperature and wind velocity data collected on the site of Ghardaïa (Algeria), the optimized system is compared to other energy source choices. The optimization results show that a PV/wind/diesel/battery option is more economically viable compared to PV/wind/battery system or diesel generator (DG) only.

Keywords: PV/wind/diesel hybrid system; Unit sizing; Economic evaluation

1. Introduction

For many applications of sensitive and strategic interest such as telecommunication relay, border crossings, isolated households and refrigerators for transport and storage of vaccines, out of conventional electricity network, the continuous availability of the primary energy source is vital and determines to a large extent, systems reliability and their continuous operation.

Conventional technology solutions provided by diesel generators are on the one hand, costly because of high maintenance and fuel supply costs and have drawbacks related to noise and especially the emanation of greenhouse gas emissions, on the other hand (Nayar et al., 1993; Mahmoud and Ibrik, 2006; Kamel and Dahl, 2005). New technological solutions provided by renewable energy systems based essentially on wind and solar energy are experiencing extremely high growth rates in recent years. Solar and wind energy systems are omnipresent, freely available, environmental friendly, and they are considered as promising power generating sources due to their availability and topological advantages for local power generations (Zhou et al., 2010; Kaabeche et al., 2011a,b).

To reap benefits of each technology solution, coupling – in a hybrid system – a diesel generator with renewable energy sources is so often the most economical option (Valente and de Almeida, 1998; Rehman and Al-Hadhrami, 2010). In this context, various optimization techniques for hybrid systems sizing have been reported in the literature.

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Thus, Schmid and Hoffmann (2004) reported that the PV/diesel hybrid generation systems with energy storage provide the lowest energy costs. The authors suggested that in Northern Brazil, it is economical to convert diesel systems up to 50 kW peak power into hybrid systems. Pursuant to works of Wies et al. (2005) and Dufo-López and Bernal-Agustín (2005), the PV/diesel hybrid power systems lead to a substantial reduction in operation and maintenance costs and air pollutants emitted into the local atmosphere compared to that of an only diesel system.

Hrayshat (2009) presented a thorough techno-economic analysis of an optimal independent hybrid PV/diesel/battery system to satisfy the load of an off-grid house, situated in a secluded Jordanian settlement. The hybrid system with 2 kW PV array, a 4 kW DG and two storage batteries in addition to 2 kW sized power converter was found to be the optimal one for diesel fuel prices greater than 0.15 $/L. Lau et al. (2010) studied the implementing opportunity of the hybrid PV/diesel energy system in isolated regions of Malaysia. The authors highlighted the impact of PV penetration and battery storage on energy production, energy cost and number of operational hours of DG for the given hybrid configurations.

Lately, Belfkira et al. (2011) presented a sizing optimization method of a stand-alone hybrid wind/PV/diesel energy system. A deterministic algorithm is employed to minimize the total system cost while satisfying the energetic load requirements. A comparison between the total cost of the hybrid wind/PV/diesel system with batteries and the hybrid wind/PV/diesel system without batteries is presented. The reached results illustrate the need to use the sizing methodology and demonstrate the impact of the battery storage on the total hybrid system cost.

In the work of Hong and Lian (2012), the investment and fuel costs are minimized while the reliability requirement and CO_2 emission constraint are retained. First, the fuzzy-c-means (FCM) is used to group the operation states for system load, wind turbine (WT), and PV generator. Then, the Markov models for the system load, WT, and PV are established. The genetic algorithm (GA) incorporated with the Markov models are used to determine optimal sizes for WT, PV, and DG.

A techno-economic assessment and the design of a hybrid PV/diesel/battery generation system for a typical Malaysian village household are presented by Ismail et al. (2013). A scenario depending on a standalone PV and other scenario depending on a DG only were also analyzed. The scenario based on hybrid PV/diesel/battery generation system was found to be the most economically feasible one. The two other scenarios analyzed exhibit higher values for COE. Taking CO_2 emission into account, it was found that the hybrid system has less CO_2 emissions throughout operation compared to a DG only.

Latterly, a wind/PV/diesel hybrid system has been designed for a village in Saudi Arabia which is currently powered by a diesel power plant is presented by Rehman et al. (2012). The major aim of the study is to lessen the diesel consumption and at the same time maintain a continuous power supply to the village inhabitants. The study found that a wind/PV/diesel hybrid system with 35% renewable energy penetration to be the viable system with energy cost of 0.212 US$/kW h.

Tazvinga et al. (2013) presented an optimal energy dispatch model of a PV/diesel/battery hybrid system and the optimal energy flows are analyzed. The optimization model developed is shown to achieve more savings than the diesel only scenario. The results show how daily and seasonal variations in demand variations affect the operational cost of the PV–diesel–battery power supply system. For both summer and winter seasons, the weekend fuel costs are higher than weekday costs. Winter fuel costs are found to be higher than the summer fuel cost due to higher demand in winter and also the lower winter radiation levels mean more use of supplementary sources. This shows that the daily and seasonal demand changes are important aspects to be considered as they considerably affect the operation cost and the energy flows.

Recently, a techno-economic optimization of a hybrid system consisting of PV panels and a wind turbine as renewable energy sources, batteries for energy storage and diesel generator as a back-up system was presented by Merei and Berger (2013). Initially three different battery technologies in combination with the renewable energy sources were considered (lead acid, redox-flow and lithium-ion batteries). The optimization results show that combining the batteries with the renewable energy systems is effective, economical and ecological. However, the best solution is to combine redox-flow batteries with these systems. In addition, a power supply system consisting only of batteries, PV and wind generators may be applicable as well to satisfy the power demand.

In this paper, an iterative optimization approach following the Total Energy Deficit (TED), the Total Net Present Cost (TNPC) and the Energy Cost (EC) has been developed for sizing the components of a stand-alone PV/wind/diesel/battery hybrid system in order to match the load demand in the most cost effective manner. Two sizing parameters have been used in the simulation, i.e. the PV subsystem capacity and the rated power of wind subsystem. Regarding the diesel generator, it is sized to meet the peak electrical demand (according to the suggested strategy). Applying the developed methodology, all configurations which verify the rate of 0% of TED are retained. Thereafter, the optimal configuration is predicted on the basis of the minimum cost. Using solar radiation, ambient temperature and wind speed data, collected on the site of Ghardaïa, Algeria (32°29′N, 3°40′E, 450 m), the optimized system is compared to other energy source choices.

2. Hybrid system overview

In this study, Fig. 1 shows the configuration considered in this paper. This configuration consists of PV subsystem, wind power subsystem, battery bank storage, charge