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Optimal sizing of stand-alone photovoltaic/wind/hydrogen hybrid system supplying a desalination unit

Mariem Smaoui, Achraf Abdelkafi, Lotfi Krichen *

National Engineering School of Sfax, Control and Energy Management Laboratory (CEMLab), BP 1173, 3038 Sfax, Tunisia

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Abstract

The real penetration of renewable energy sources (RES) under varying weather conditions required an optimal sizing of hybrid renewable power generation systems. The present paper proposes a methodology based on iterative technique, to perform the optimal sizing of a stand-alone hybrid photovoltaic/wind/hydrogen system supplying a desalination unit which feeds the area's inhabitants with fresh water. The methodology aims at finding the optimal technical–economic configuration among a set of systems components. Taking into account the models of the main hybrid system components and the hourly meteorological data and load profile for any site located worldwide, the recommended algorithm gives all possible configurations that can completely cover the fresh water requirements of isolated consumers. Afterward, the optimal configuration is predicted on the basis of the minimum initial investment cost. A case study is conducted to analyze a hybrid project, which is designed to supply a seawater desalination unit installed on the Kerkennah islands located in the south of Tunisia.

Keywords: Hybrid photovoltaic/wind system; Fuel cell/electrolyzer storage system; Desalination unit; Optimal sizing; Techno-economic evaluation

1. Introduction

Today, the world is facing a great challenge for saving its future in terms of providing one of the main requirements of humankind: Energy. Nowadays, the majority of the consumed energy all around the world comes from conventional fossil fuels like coal, natural gas, crude oil, etc. (Dursun et al., 2012). Due to the limited reserves of fossil fuels, their rising prices, their polluting of nature and the increasing worry over global warming, the interest in renewable energy sources (RES) has significantly increased (Nasiraghdam and Jadid, 2012; Li et al., 2013).

Compared to available renewable energy options, solar and wind are considered as the most preferred RES for their availability and inexhaustibility (Erdinc and Uzunoglu, 2011; Askarzadeh, 2013). However, a common drawback of these renewable sources is their unpredictable nature and dependence on weather and climatic changes. This issue causes the fact that renewable power production may not totally satisfy the power demand of the load at each instant. To solve this problem, an energy storage unit is usually required to reduce power production fluctuations. Traditionally, batteries have been used in this regard. The short life cycle, the high-cost maintenance and the environmentally unfriendly content of this storage system are the constraining factors for its use in stand-alone applications (Spyrou and Anagnostopoulos, 2010). Recent researches have focused on using fuel cell

* Corresponding author. Tel.: +216 74 274 418; fax: +216 74 275 595.
E-mail address: lotfi.krichen@enis.rnu.tn (L. Krichen).

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Nomenclature

A_{pv}	surface of PV generator (m^2)
C_{EL}	unit cost of the electrolyzer ($/kW)
C_{FC}	unit cost of the fuel cell ($/kW)
C_{Inv}	unit cost of the inverter ($/kW)
$Cons_{elec}$	average electrical energy consumption to produce one m^3 of fresh water (kW h)
C_{PV}	unit cost of the photovoltaic generator ($/kW)
$C_{r\cdot hyd}$	unit cost of the hydrogen tank ($/kg)
C_W	unit cost of the wind system ($/kW)
G_{ir}	global solar irradiation (W/m^2)
M_{HT}	margin coefficient
N_{da}	number of autonomy days
$Need_{FW}$	hourly average fresh water consumption in July (m^3/h)
N_{oct}	nominal cell operating temperature (°C)
$P_{EL}(t)$	electrolyzer input power (kW) during step Δt
$P_{FC}(t)$	fuel cell output power (kW) during step Δt
P_{Tank}	equivalent power of the fresh water tank content (kW)
$P_{Tank\cdot C}$	equivalent power of the fresh water tank capacity (kW)
P_{Wr}	wind turbine rated power (kW)
T_a	ambient temperature (°C)
T_c	solar cell temperature (°C)
T_{ref}	reference solar cell temperature (°C)
V_C	cut-in wind speed (m/s)
V_F	cut-off wind speed (m/s)
V_R	rated wind speed (m/s)
V_{Tank}	fresh water tank content (m^3)
$V(h)$	wind speed at hub height h (m/s)
$V(h_{ref})$	speed measured at the reference height h_{ref} (m/s)
α	power law exponent
α_{EL}	required energy to produce one kilogram of H_2 (kW h/kg)
α_{FC}	produced energy by one kilogram of H_2 (kWh/kg)
ρ_{H_2}	hydrogen density (0.089 kg/m^3)
η_{EL}	electrolyser efficiency
η_{FC}	fuel cell efficiency
Δt	step time (1 h)

(FC)/electrolyzer (EL) as the storage device due to its reliability and its environmentally-friendly operation (Li et al., 2009; Andrews and Shabani, 2012; Maleki and Askarzadeh, 2014).

In order to efficiently and economically employ the RES, an optimum sizing is quite necessary. The optimal sizing of a hybrid system allows to endorse the lowest investment with a reasonable and full use of the RES, so that the hybrid system can work at optimum conditions in terms of investment and system power reliability requirement. In this context, various optimization techniques for hybrid systems sizing have been reported in the literature.

Tina et al. (2006) presented a probabilistic approach based on the convolution technique to assess the long-term performance of a hybrid solar–wind power system for both stand-alone and grid-connected applications. The disadvantage of this probabilistic approach is that it cannot represent the dynamic changing performance of the hybrid system. A methodology of sizing optimization of a stand-alone hybrid wind/photovoltaic (PV)/diesel energy system has been proposed by Belfkira et al. (2011). This approach makes use of a deterministic algorithm to suggest the number of PV panels, wind turbines (WTs) and diesel system so that the total annual cost of the hybrid system subject be minimized while guaranteeing the availability of the energy. Belmili et al. (2014) present an iterative optimization technique following the loss of power supply probability (LPSP) model for a hybrid solar/wind system. The obtained optimum configuration ensures a reliable power supply with the lowest investment. A methodology for optimal sizing of stand-alone hybrid system based on genetic algorithms has been performed by Koutroulis et al. (2006). The purpose of the proposed methodology is to suggest, among a list of commercially available system devices, the optimal number and type of units ensuring that the 20-year round total system cost is minimized subject to the constraint that the load energy requirements are completely covered. Dufo-López et al. (2011) present a multi-objective optimization for a stand-alone PV–wind–diesel system with batteries storage. The objectives to be minimized are the levelized cost of energy (LCOE) and the equivalent carbon dioxide (CO_2) life cycle emissions (LCE).

In the present work, a new optimal sizing algorithm that utilizes the iterative optimization technique is developed. This optimization approach determines the optimum configuration of a stand-alone PV/wind/hydrogen system supplying a desalination unit that would guarantee a reliable energy supply with the lowest initial investment cost for any site. There are six sizing parameters which can be obtained by this algorithm: the rated power of wind system, the number of PV panels, the rated power of FC, the rated power of EL, the capacity of hydrogen tank and the size of desalination unit.

The paper is organized as follows: Section 2 describes the hybrid system and indicates the relationship between the different components. Section 3 discusses the modeling of the hybrid system components. The proposed optimal sizing algorithm is explained in details in Section 4. The simulation results are discussed in Section 5, and finally, Section 6 establishes the conclusion.