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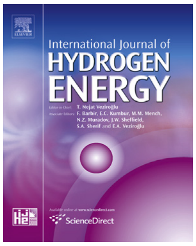

An imperialist competitive algorithm approach for multi-objective optimization of direct coupling photovoltaic-electrolyzer systems

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ABSTRACT

In the context of sustainable clean hydrogen production pathways, photovoltaic-electrolyzer systems are one of the most promising alternatives for acquiring hydrogen from renewable energy sources.

In fact, determining the optimal set of design and operating variables are always a key issue while coupling directly renewable electricity sources to PEM electrolyzers. Few previous studies have attempted to find the optimal size and operational condition of directly coupled photovoltaic-electrolyzer (PV/El) systems in order to maximize the hydrogen production or to minimize energy transfer loss between photovoltaic devices and the electrolyzer. Nevertheless an easy and efficient approach still remains to be found. Because of the nonlinear nature of the system, in this framework, multi-objective nonlinear optimization is employed, an approach based on the method of imperialist competitive algorithm (ICA). It considers the effect of ambient temperature and radiation weather data during a whole year.

Multi-objective optimization provides a wide range of optimal design and operating conditions, from which these variables can be selected based on objectives with different weight values. This allows performing the system optimization by considering two different objectives, namely, minimization of energy transfer loss and maximization of hydrogen production.

The optimum system that focuses solely on maximum hydrogen production can produce 2.2% more hydrogen than with its objective being minimum energy transfer loss. However, it results in 68% more energy transfer loss in the process. The values can be adjusted with options that include a combination of the two objectives. Additionally, optimal variables can be found through the ICA method.

Introduction

Hydrogen is a future energy medium which can be produced from various energy sources including renewable energy and fossil fuels [1,2]. In recent years, research work aimed towards assessing the potential of intermittent renewable energy sources like wind and solar power systems for the production of hydrogen has received widespread interest throughout the scientific community [3,4]. Some of the most common

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Nomenclature

A_m	membrane area, cm^2
c_n	cost of *n*th imperialist
E	open circuit voltage, V
E_0	open circuit voltage in reference condition, V
F	faraday constant, 96485 C mol^{-1}
G_{eff}	effective irradiation on PV module, W m^{-2}
I_D	diode current for the PV system, A
I_{elec}	operation current for the electrolyzer, A
I_L	light current for the PV system, A
i_{Lim}	limiting current density, A cm^{-2}
I_o	diode reverse saturation current for the PV, A
I_p	current of parallel resistance, A
I_{PV}	operation current for the PV system, A
I_{SC}	short circuit current PV module, A
I^*_{SC}	short circuit current in standard condition, A
i_0	exchange current density, A cm^{-2}
ICA	imperialist competitive algorithm
l_m	membrane thickness, cm
MONLO	Multi-objective Nonlinear optimization
N_{col}	number of colonies in ICA
N_{imp}	number of imperialists in ICA
N_P	number of electrolyzer cells in parallel
N_S	number of electrolyzer cells in series
PV	photovoltaic
P_i	optimization problem variable
PEM	proton exchange membrane
R	universal gas constant, 83.14 bar m^3 mol^{-1} K^{-1}
R_p	parallel resistance for the PV-system, Ω
R_s	series resistance for the PV-system, Ω
T_a	ambient temperature, K
T_c	temperature of solar cell, K
T^*_c	temperature of solar cell in reference condition, K
T_{elec}	operation temperature of electrolyzer, K
V_{act}	activation overvoltage, V
V_{elec}	operation voltage for the electrolyzer system, V
V_{diff}	mass transport losses, V
$V_{OC_{PV}}$	open circuit voltage for the PV-system, V
$V^*_{OC_{PV}}$	open circuit voltage for the PV-system in reference condition, V
V_{ohm}	ohmic losses, V
V_{PV}	operation voltage for the PV-system, V
V_t	thermal voltage, V

Greek symbols

α	electron transfer coefficient
a_{H_2O}	water activity
β	experimentally defined coefficient
λ_m	water content of membrane
$\mu_{V_{oc}}$	temperature coefficient of open circuit voltage, V K^{-1}

methods for producing hydrogen include solar thermochemical cycles, water electrolysis, and conversion of biomass [5,6].

The use of photovoltaic energy for producing hydrogen through the water electrolysis process is considered to be one of the most favorable pathways suited for stand-alone power systems [7–9]. One of the biggest advantages of this pathway is that there is no greenhouse gas emissions incurred when hydrogen is produced. Other than that, since hydrogen is an energy vector that can be easily produced and stored for long periods of time in compressed storage systems, using it to manage the intermittency associated with solar irradiation is considered to be one of the alternatives to installing large scale capital intensive battery energy storage systems that can only store the surplus power for short periods of time [10].

Despite being mature and commercially available technologies, improving the coupling of both the photovoltaic (PV) arrays and the electrolyzers (EL) has been a topic of interest for many researchers [11]. Due to the mismatch between the output specifications of a PV module and the electrolyzer load at different irradiance, syncing of the two technologies to maximize hydrogen production and minimize energy transfer losses is very important for the entire system to be utilized effectively [12].Although the use of power controlling devices such as DC to DC convertor, and maximum power point (MPP) trackers is considered to be a way to couple PV/EL systems indirectly, it also results in an additional cost and complexity [13–16].

There are number of studies about direct coupling of PV/EL systems [17–21]. A proper matching of current–voltage (*I*–*V*)[1] curves of PV curves and voltage–current (*V*–*I*) curve of the electrolyzer bring about minimum distance between the operating points of the electrolyzer and the MPP of the PV. As a result, the performance of the system becomes more acceptable. Optimization of the direct coupling process provides the most economic option for low power application with low DC current [11]. The PV/EL systems, which is directly coupled, can be optimized regarding to the design and operating conditions of both PV and the electrolyzer. The design variables can be the number of cells in series and parallel. García-Valverde et al. [11] used a method to obtain the optimum number of cells in series and Atlam et al. [22] applied a linear method to optimize the number of electrolyzer cells in series and parallel. The above mentioned studies have been focused on a single objective which is maximum hydrogen production or minimum energy transfer loss. However divergence of maximum hydrogen production and minimum energy transfer loss was addressed clearly with detail theoretical analysis regarding series–parallel combination of PV and electrolyzer cells by Paul [4].

Multi-objective nonlinear optimization (MONLO) methodology provides the necessary information for a detailed analysis of the design and operational trade-offs among conflicting objectives. The first objective focuses on energy transfer loss minimization, which is necessary to ensure that the maximum available solar energy is used; the second objective aims at maximizing hydrogen production which is necessary to achieve maximum conversion of the solar energy received by electrolyzer to hydrogen. The work done in this

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[1] which is a graph that demonstrates the relation of the electric current through a device and the corresponding voltage.