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Optimized method for photovoltaic-water electrolyser direct coupling

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ABSTRACT

Photovoltaics and electrolyser coupling is one of the most promising options for obtaining hydrogen from a renewable energy source. Both are well known technologies and direct coupling is possible; however, due to high variability of the solar radiation, an efficient relative sizing still presents some challenges. In fact, relative sizing is always a key issue when coupling renewable electric sources to water electrolysers. Few previous works addressed the relative sizing and an easy and efficient method is still missing. This work presents a new method for relative sizing between both components based on simple modelling of both polarisation curves. Modelling and simulation is used for extracting a cloud of maximum power points at all the radiation and temperature conditions for a normalised PV generator. Then, the ideal ratio between the size of components is obtained by fitting a normalised polarisation curve for the electrolyser to this cloud of maximum power points. PV generator and PEM electrolyser models are proposed and the method is applied, as example, to two different PEM water electrolysers. The method helps the relative sizing issue for designing solar hydrogen production systems based on water electrolysis, because it is derived from manufacturer parameters and the used of uncomplicated numerical methods.

1. Introduction

One of the most promising options of obtaining hydrogen from a clean renewable energy source is via electrolysis using electricity from a photovoltaic generator [1–6]. A photovoltaic-hydrogen (PV–H_2) system usually consists of supplying electric power to a water electrolyser by a PV generator. Both photovoltaics and water electrolysis are well known technologies. However, coupling both technologies still presents some challenges. Barbir [7] pointed out specific issues related to the operation of a PEM electrolyser in conjunction with renewable energy sources, and particularly with a PV panel or array.

The intermittent operation and the highly variable output power due to the nature of PV energy are the principal handicaps. At very low loads the rate at which hydrogen and oxygen are produced (which is proportional to current density) may be lower than the rate at which these gases permeate through electrolyte, and mix with each other, this may create hazardous conditions inside the electrolyzer [7]. Hence, typically a minimum load is required in commercial electrolysers (5% and 25% as minimum output flow for PEM

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Nomenclature

a	activity of species
AIST	Advance Industrial Science and Technology, Japan
E_{exc}	activation energy for the anode reaction, J/mol
E_{pro}	activation energy for transport in the PEM, J/mol
F	Faraday's constant (96485 C/mol)
i	current density at the electrolyser, A/cm^2
i_0	exchange current density, A/cm^2
I_0	solar cell reverse saturation current, A
I_{dark}	solar cell equivalent diode current, A
I_{nom}	nominal current for a WE, A
I_{ph}	solar cell photogenerated current, A
I_{sc}	PV module short-circuit current, A
k_B	Boltzmann constant, 1.3806×10^{-23} J/K
m	solar cell diode ideality factor
n_c	number of series-connected electrolytic cells
N_s	number of series-connected cells in the PV module
p	electrolyser pressure, atm
PEM	proton exchange membrane
q	electron charge, 1.6×10^{-19} C
R	gas constant, 8.3144 J/(Kmol)
R_I	PEM interfacial resistance, Ω/cm^2
R_s	solar cell series resistance, Ω
R_{sh}	solar cell shunt resistance, Ω
STC	standard test conditions (1000 W/m^2 and 25 °C)
t_m	PEM thickness, m
T	temperature, K
UMU	University of Murcia, Spain
UPCT	Technical University of Cartagena, Spain
U_{rev}	reversible voltage, V
V_{cell}	electrolyser cell voltage, V
V_{oc}	PV module open circuit voltage, V
WE	water electrolyser
α	charge transfer coefficient
β	electrodic symmetry factor
η	overpotential, V
σ	PEM conductivity, S/cm

and alkaline commercial electrolysers are respectively required for a safe operation [8,9]). This problem is stressed in applications where the electrolyser supply cannot be supported from the grid and an energetic buffer (e.g.: bank of batteries) is not desired.

Also a PV–H_2 coupling system should be able to maximize the energy output of the PV generator, which should operate always at its maximum power point (MPP) in order to get a maximum global efficiency.

Some authors have supported the direct coupling between the PV generator and the electrolyser [10–15]. I–V curves of the PV generator and V–I curves for the electrolyser show a good matching. Moreover, if the relative sizing of the electrolyser and the PV generator is optimized, then the working point in direct coupling is quite near from the MPP of the PV generator, so that the global efficiency of the system is acceptable. However, direct coupling reduces the flexibility in the sizing, since the voltage range of the electrolyser should match with the range of possible voltages at the MPP in the PV generator.

Other authors have shown or suggested higher efficiencies using a DC/DC converter with MPP tracker as a coupling system [4,16–19]. This option offers higher design flexibility and the DC wiring can be thinner, cheaper and safer. Modern DC/DC converters have an excellent nominal efficiency, but they add some power losses to the system and obviously some extra costs.

A few authors suggested another coupling option based on the variation of the number of series-connected electrolytic cells according to the level of irradiance [20–22]. Although they demonstrated very good global efficiency values, this coupling method seems not be very practical regarding the need of switching high current DC connections.

Each one of the coupling options can be suitable according to the targeted application. However, an optimised direct coupling seems to be the cheapest and most efficient option for low power applications, where DC currents are not as high to represent a cost and safety problem. Gibson and Kelly [13] demonstrated a total PV–H_2 system efficiency of 12.4% optimising the choice of the PV module directly coupled to a PEM electrolyser working around 31.7 V and 4.7 A at nominal conditions. Similarly, Paul and Andrews [14] demonstrated high expected efficiencies for optimised direct coupled PV–H_2 systems, but also for low power applications (<300 W).

This article presents a new method to optimise the direct coupling option for photovoltaic-water electrolyser systems. Since the method uses simple photovoltaic generator and water electrolyser models, section 2 is devoted to present simple modelling options for both components. section 3 describes the proposed optimisation method. For a better understanding of the method, it is applied to two cases of study. Finally, conclusions are given in section 4.

2. Modelling

2.1. *PV Generator model*

An assessment of the operation of solar cells and the design of power systems based on solar cells must be based on the electrical characteristics, i.e., the voltage–current relationships of the cells under various levels of radiation and at various cell temperatures. Many cell models have been developed, ranging from simple idealized models to detailed models that reflect the details of the physical processes ocurring in the cells.

The basic procedure for PV modelling can be summarised in three steps:

1. Selection of the complexity of the model to be used. Usually the core of the model is the one diode equivalent model for a single solar cell (Fig. 1 and equation(1)).
2. Extraction of the model parameters for nominal conditions.
3. Recalculation of the model parameters for new irradiance and ambient temperature conditions.