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Analysis of the performance of the photovoltaic array through the exergy efficiency

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Abstract. This work is part of an exergy analysis conducted during the operation of a test-bed hybrid wind/solar generator with hydrogen support, designed and constructed at the Industrial Engineering School of the University of Extremadura, Badajoz (Spain). An exergy balance analysis has been made of the different components of the system, calculating their exergy efficiencies and exergy losses, and proposing future improvements to increase the efficiency of the use of the surplus energy produced by the wind/solar generator. Here we only present the results corresponding to the photovoltaic generator's exergy analysis.

Key words

Wind-solar hydrogen system, photovoltaic array, exergy of the solar radiation, exergy efficiency.

1. Introduction

The integration into the energy mix of renewable resources such as solar and wind power is becoming increasingly attractive. They are already widely used as substitutes for fossil-fuel produced energy, and will help to minimize atmospheric degradation. The major advantage of their combined use in a hybrid system is that the reliability of the system is enhanced [1]. Nevertheless, renewable energy (RE) sources such as solar and wind clearly have to be included in the design with recognition of their intermittent nature, and power supply systems based on them will be subject to strong short-term and seasonal variations in their energy output. There is therefore a need for storage systems that can accumulate the energy produced in periods of low demand to utilize it when the demand is high, ensuring full utilization of the intermittent sources that are available. Hydrogen can be used as a storage medium for intermittent and seasonal renewable technologies, endowing the overall system with greater reliability that would make it better suited to remote stand-alone applications [2].

A test-bed stand-alone RE system based on hydrogen energy storage has been developed and installed in the Technical Thermodynamics Laboratory of the Industrial Engineering School of the University of Extremadura, in Badajoz (Spain). It has been successfully tested for autonomous operation with a control system and power conditioning devices. It comprises a photovoltaic generator, a wind-turbine generator, a battery set, an electrolyzer, a metal-hydride system for hydrogen storage, a fuel cell, and a supervisory control and data acquisition system. In this system, excess energy produced with respect to the load requirement is sent to the electrolyzer for hydrogen production. When the load requirement exceeds the energy produced by the RE sources, the stored hydrogen is fed to a fuel cell to produce electricity. Experimental results clearly indicate that such a stand-alone RE system based on hydrogen production is safe and reliable [3,4].

The experimental installation's geographical data are given in Table 1.

Table 1. Location of the installation.

Latitude	Longitude	Altitude
38° 53' 1.80" N	6° 58' 12.94" W	169 m

Table 2 presents the components and operational characteristics of the wind-solar installation with hydrogen support. The electrolyzer and the fuel cell are of the PEM (Proton Exchange Membrane) type. The hydrogen produced by the electrolyzer is fed directly to a metal hydride bottle. This storage canister is filled with a special metal hydride alloy.

Table 2. Principal devices of the wind-solar installation with hydrogen support.

Component	Characteristics
Photovoltaic generator	Monocrystalline silicon solar module Helios H-45 (45 Wp, 12 V)
Wind generator	Rutland-913 Windcharger (90 W at wind speed of 10 m/s)
Electrolyzer	Type PEM. 10 cells. Hydrogen Works. Hart-250. Maximum pressure: 6 bar. Working temperature: 15-45 °C
Fuel cell	Type PEM. 10 cells. Heliocentrics, 40 W rated power. Working temperature:5-50 °C
Metal hydride bottle	Ovonic. Hydrogen capacity: 600 LN (10 bar).
Battery	Trojan. 85 Ah. 12 V
Electronic load	HP 6063B. 240 W max.
Programmable logic controller	Siemens S7 313 C-2 DP
Touch panel	Siemens. Simatic touch panel TP277 6".