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Analysis of hydrogen production from combined photovoltaics, wind energy and secondary hydroelectricity supply in Brazil

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Abstract

In this work, the technical and economical feasibility for implementing a hypothetical electrolytic hydrogen production plant, powered by electrical energy generated by alternative renewable power sources, wind and solar, and conventional hydroelectricity, was studied mainly trough the analysis of the wind and solar energy potentials for the northeast of Brazil. The hydrogen produced would be exported to countries which do not presently have significant renewable energy sources, but are willing to introduce those sources in their energy system. Hydrogen production was evaluated to be around 56.26×10^6 m^3 H_2/yr at a cost of 10.3 US$/kg.

Keywords: Renewable energy; Hydrogen production; Electrolysis; Hydrogen production cost

1. Introduction

Electric power demand has been increasing in Brazil as well as in the so-called developing countries. Due to this constant increment in energy demand, new supply strategies have been adopted in the short and long terms. Those strategies have to be properly planned in order to grant that the access to energy be more democratic at reasonable social costs and in its most convenient form, respecting the principles of sustainable development. The alternative renewable energy sources and generation systems, such as solar, wind and hydroelectric power plants, meet those principles. Thoroughly thinking, although there are different denominations for those energy power systems, the primary source of energy which makes them available is solar. That is, besides photovoltaic and thermal power generation which consists in a direct utilization of this primary form of energy, wind and hydroelectric systems are also powered by the irradiative and thermal effects of solar energy on our planet.

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Nomenclature

Symbols

f_c	capacity factor
f_d	availability factor
C_{AE}	monthly cost of the electricity supplied by the association of photovoltaic, wind and hydroelectric sources
C_W	monthly wind energy cost
C_{Hyd}	monthly hydropower cost
C_{PV}	monthly cost for the photovoltaic energy
T_T	monthly transmission tariff
T_{Tuc}	energy coming from Tucuruí including transmission tariff
C_{MEA}	monthly energy cost for the association of the power sources
P_{TUC}	power supplied by Tucuruí (MW)
P_W	power from wind generators (MW)
P_{PV}	power from photovoltaics (MW)
t	hydrogen production plant operation time (h month^{-1})
C_{MaxC}	maximum unitary cost for this power supply system (US$ MWh^{-1})
P	power of the electrolysis plant
C_H	cost production of hydrogen (US$ m^{-3})
C_{CC}	capital cost (US$ yr^{-1})
$C_{O\&M}$	operation and maintenance cost (US$ yr^{-1})
C_I	annual cost of the inputs (US$ yr^{-1})
Q_H	annual production of hydrogen (m^3 yr^{-1})
F	capital recovery factor over 1 year
OM	annual operation and maintenance rate
C_{El}	unitary cost of the electrolysis plant (US$ MW^{-1})
d	annual discount rate
n	number of years to recover the investment capital
C_E	annual costs of electricity (US$ yr^{-1})
C_{H_2O}	annual costs of the water (US$ yr^{-1})
t_y	annual plant availability (h yr^{-1})
C_W	volumetric cost of water (US$ m^{-3})
η_{El}	efficiency of the electrolyzer for hydrogen production
E_{min}	minimum theoretical energy necessary to produce 1 m^3 of hydrogen (MWh m^{-3})

Abbreviations

PROINFA	Programa de Incentivo as Fontes Alternativas de Energia Elétrica
KOH	potassium hydroxide
STC	standard test conditions

In 2002, hydroelectric power generation, including hydropower units (HU), in Brazil reached 63.8 GW, which represents about 83% of the total electricity generation. Wind power generation systems account for 22 MW and are distributed throughout Ceará, Pernambuco, Minas Gerais, Santa Catarina and Paraná states. Solar-photovoltaic systems are limited to small power units located in research centers and remote areas, and because of that they are not quantified in the Brazilian energy generation system (Porto, 2002).

Incentive programs, such as PROINFA which is intended to increase wind, biomass and small hydropower unit generation to 3300 MW each, aim to foster the use of alternative renewable energy sources in Brazil in the next decades. Likewise, many other countries have been attempting to introduce alternative renewable power sources in their energy systems, usually motivated by environmental issues and intending to avoid or lessen the impacts caused by conventional forms of electric power generation. For these reasons, those renewable power sources will not be restricted to remote areas, their market niche in the past; they will also have an important role in the energy market.

In Brazil, the generation potential from alternative renewable sources, which is very little explored at the present, would extrapolate the internal demand of energy and originate an energy production surplus. This electric power surplus may represent a new energy market characterized by the possibility of exporting this surplus through hydrogen to other countries which do not have such a significant renewable energy potential and are willing to increase the participation of renewable sources in their energy system mix in order to reduce the use of non-renewable energy.

This paper presents the study of the main parameters involved in the project of a hypothetical electrolytic hydrogen plant fed by alternative and conventional electric power sources such as photovoltaic, wind and hydropower. The hydrogen plant was arbitrarily chosen to be small (30 MW, which is equivalent to power produced by wind turbines in Brazil in 2003). The electric energy produced by those sources would be transmitted through the existing high-voltage network to a single electrolytic hydrogen production plant which, in its turn, would be strategically placed the closest possible to the potential consumer markets such as the United States, Europe and Japan. An analysis indicated that the city of Fortaleza, in Ceará state (CE), would be the best option (Soltermman, 1999).

The potential location for the alternative power units was also studied, pointing that Coremas, PB, would be the best choice for the photovoltaic power unit and Canindé, CE, would be most indicated for the wind power turbines. As for the conventional hydropower unit, Tuc-