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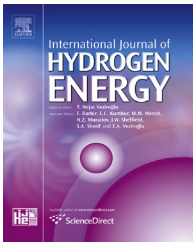

Applying small wind turbines and a photovoltaic system to facilitate electrolysis hydrogen production

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ABSTRACT

This study simulated hydrogen production scenarios for fuel cell electric vehicle (FCEV) hydrogen refueling stations by examining an electrolysis hydrogen production system powered by small wind turbines and a PV system. The simulation model was developed using MATLAB/Simulink to observe the effect of temperature on hydrogen flow and Faraday efficiency in the electrolyzer.

In the simulation, the decentralized hybrid renewable energy system generated power used to produce hydrogen in the electrolyzer at an internal temperature of 40 °C, 60 °C, and 80 °C. The results of the simulation showed that electrolysis hydrogen production efficiency improved under two conditions: (a) when the 12 kW-rated power turbines operated simultaneously with the 18 kW PV system for a total power output of 30 kW; and (b) when the electrolyzer was heated to an operating temperature of 60 °C using the solar thermal collection system. If improvement in per second hydrogen flow can approach 0.1% compared to 40 °C, the system could produce 25 kg of hydrogen in the shortest time, at 49.2 h and I-100 current density.

Introduction

The U.S. National Oceanic and Atmospheric Administration (NOAA) recently announced that September 2015 had the largest departure of global temperatures from the 20th Century monthly average among all 1629 months on record since 1880. Subsequently, the UN announced its schedule to hold the UN Climate Change Conference in Paris. Whether this Conference of Parties 21 (COP21) can successfully achieve a resolution that aim to achieve a legally binding and universal agreement on climate, with the aim of keeping global warming below 1.5 °C between 2030 and 2050. What is clear, however, is that global climate change has arrived and its impact is comprehensive and dramatic. After witnessing the Fukushima nuclear power plant disaster in Japan, Germany decided to gradually phase-out nuclear power and fully develop renewable energy. The plan has already achieved striking results: renewable energy already comprises 29% of all power in Germany and is projected to equal 80% by 2050. Under the

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Nomenclature

A	area of electrode, m^2
A_r	swept area, m^2
B	viscosity, mPa s
C_{elec}	electrolyzer cooling capacity, J °C^{-1}
C_P	rotor power coefficient
F	Faraday's constant, 96,485 kJ (k mol)$^{-1}$
f	Faraday efficiency parameters
G	Gibbs free energy of formation, kJ (k mol)$^{-1}$
I	load current, A
I_L	photovoltaic current, A
I_0	saturation current, A
J	equivalent inertia drive system, kg m^2
M_{H_2}	hydrogen molar mass, kg k mol^{-1}
N_{H_2}	hydrogen molar flow rate, k mol s^{-1}
n_c	number of cells
P_b	storage tank pressure, Pa
P_{bi}	initial storage tank pressure, Pa
R	ideal gas constant, 8.3144621 J(mol K)$^{-1}$
R_s	series resistance, Ω
R	Ohmic resistance parameter
s	overpotential factor, V
T	temperature, °C
T_b	operating temperature, °C
T_F	Coulomb friction, mPa s
V	output voltage, V
V_{act}	activation voltage, V
V_{cell}	total voltage, V
V_{ohm}	Ohmic voltage, V
V_{rev}	reversible voltage, V
V_b	storage tank volume, m^3
V_r	rated wind speed, ms^{-1}
z	number of electron
z_s	system compression factor
η_F	Faraday efficiency, %
ω	wind generator speed, rpm
ρ	air density, 1.225 kg m^{-3}

strong support of the German people, this objective that originally seemed like a mirage is already within sight. The entire world currently strives to research renewable energy technologies that can be used to replace traditional pollution-heavy and high-energy consuming lifestyles to reduce CO_2, making renewable energy research and development an urgent matter [1]. Fuel cells, which use chemical energy conversion, such as hydrogen, methanol, ethanol, formic acid, or methane, to provide higher efficiency, lower emissions, and higher power density than conventional combustion power generation processes, are considered one of the best power source options [2–4]. Therefore, developing fuel cell technology is crucial to the rational development and utilization of natural resources, to environmental protection, to energy security, and to the new energy industry.

Hydrogen can be produced from fossil fuels, water electrolysis, thermal chemical reactions, biomass energy, and photovoltaic effects. Zini and Chavez-Ramirez [5,6] designed a hydrogen energy storage system and simulated results using real data from photovoltaic plants in central Italy and Mexico; results showed that in the future, the system could replace the instability of renewable energy production. Khalilnejad et al. [7] developed a renewable energy model for hydrogen production that simulated maximum hydrogen production by considering minimum production of average excess power. The study found that hybrid power generation systems were at least 26% more effective than any singular system in hydrogen production, with at least 3.8% more unused energy [8].

Guinot and Garcia [9,10] used empirical and semi-empirical models to simulate and compare the usage of intermittent renewable energy and power load. The study established a power management strategy for hybrid solar energy systems with a diesel generator, lithium battery, and hydrogen system, respectively. Results showed that the hybrid solar-hydrogen system is operated by an efficient power management strategy [11], and that the performance degradation of the hydrogen system had a limited impact on the optimal size and economic performance of the system. Finally, system costs were viewed as the most crucial consideration. Castaneda et al. [12] presented three different control strategies designed to satisfy the state of charge (SOC) of the battery, the hydrogen tank, and the battery charge, and considered the operational cost of a battery-fuel cell-electrolysis unit; the results show that the hydrogen production system offered the best energy efficiency results at 42%.

Water electrolysis is crucial in renewable energy-based hydrogen production systems. Two water electrolysis methods are currently used to produce hydrogen. One method uses traditional alkaline electrolytes such as potassium hydroxide (KOH) and potassium chloride (KCl). Kothari et al. [13] used KOH as an electrolyte to measure and compare hydrogen production flow rate (mol s^{-1}) and efficiency for various voltage inputs. The other method substitutes a proton exchange membrane for the alkaline electrolyte, which is more secure, more reliable, and produces purer hydrogen. Among the techniques used to improve the efficiency of water electrolysis hydrogen production, Wang et al. [14] discussed the voltage loss caused by large volumes of bubbles on the electrode generated by hydrogen production at high current densities.

This study developed a modular hybrid wind/photovoltaic decentralized power generation system to produce hydrogen through electrolysis. The main system is a dynamic model development composed of separate units, namely, the Wind Energy Conversion System (WECS), the Photovoltaic Energy Conversion System (PVECS), the electrolysis apparatus, the power electronic interface circuit, and the hydrogen tank. By primarily producing electricity using decentralized renewable energy generation systems, this study caused alkaline water to produce hydrogen in the electrolyzer to refill the 25 kg hydrogen tank and to be used by the Fuel Cell Electric Vehicle (FCEV).

System module development

Electrolyzer

Electrolyzer efficiency is a major working parameter in this study. The better the device design is, the higher the efficiency

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