EuroSun2026

PERFORMANCE ANALYSIS OF AN ALKALINE WATER ELECTROLYZER POWERED BY SOLAR PHOTOVOLTAICS FOR GREEN HYDROGEN PRODUCTION

Summary

Renewable energy, as a backup energy source, is becoming increasingly significant due to growing global environmental and ecological concerns. Among the various renewable energy methods used today is the production of hydrogen through water electrolysis. When coupled with solar photovoltaic (PV), the hydrogen produced has the potential to play a key role as a clean energy carrier for sustainable development. In this work, a mathematical model was developed to predict the electrochemical behavior of the electrolyzer with a particular focus on the cell voltage under varying operating conditions. The model was validated using experimental data, obtained in a 20kW alkaline test rig facility. The average relative error between the modeled and measured values was found to be below 1 % for the cell voltage, indicating good agreement between experimental and modeled values. A sensitivity analysis was also conducted to evaluate the effect of the key parameter on the electrochemical behavior of the electrolyzer.

Keywords: Renewable energy, solar photovoltaics, green hydrogen, alkaline water electrolyzer, mathematical modeling, experimental study, electrochemical behavior.

Field of application for the findings: green hydrogen / Renewable energy systems

Addressed audience: researchers / Engineers

1. Introduction

To mitigate climate change and reduce reliance on fossil fuels, the global transition toward renewable energy has gained significant attention. Green hydrogen, with its high energy density and reduced emissions, is a key solution for decarbonizing hard-to-electricity sectors and replacing gray hydrogen produced from fossil fuels (Van Renssen, 2020). To unlock its potential, hydrogen must be extracted using energy-intensive processes. In this context, water electrolysis has attracted increasing attention as a sustainable method for producing hydrogen, particularly when powered by renewable sources like solar. Among different water electrolyzer technologies, alkaline water electrolysis (AWE) is considered a mature, well-developed, and cost-effective technology suitable for large-scale applications, making it a key enabler in the emerging green hydrogen economy. This work aims to model an alkaline water electrolyzer via Matlab approach. The novelty of this work lies in the combined experimental and modeling approach, in which key performance indicators of the electrolyzer are experimentally determined and validated over an extended operating period (from 10:25 to 18:00), rather than at a single operating point. In addition, the thermal behavior of the system is analyzed through the operating temperature, which provides a better understanding of both the heat generated inside the electrolyzer and the effect of the cooling system. The model equations were developed from empirical electrochemical correlations. Computer simulations of the model developed were carried out and the results generated were analyzed and interpreted to give a deeper insight into the operations of the electrolyzer.

2. Methodology

To produce green hydrogen, direct current (DC) and an aqueous alkaline solution containing sodium hydroxide (20 wt% NaOH) are supplied to the cell stack, where the electrolysis process takes place, generating H_2 at the cathode and O_2 at the anode. The operating point of the electrolyzer is determined by the intersection between the I-V characteristic of the PV array (eq. 1) and that of the AWE (eq. 2). The main objective of this work is to develop a mathematical model capable of predicting the electrochemical behavior of the AWE under realistic operating conditions. In the first stage, experimental tests were conducted on the AWE to characterize its behavior under practical operating conditions. In parallel, experimental data were collected to support the development and validation of the model. In the second stage, a model-based equation was developed and implemented in MATLAB. The electrochemical model computes the cell voltage (V_{cell}) using (eq. 2), the standard reversible voltage equation and the Antoine equation. Finally, the model was validated against the experimental results. A sensitivity analysis was performed then to evaluate how variations in the input parameters influence the output parameters and affect the response of the AWE. In this study, only the cell voltage V_{cell} is modeled and validated against experimental data.

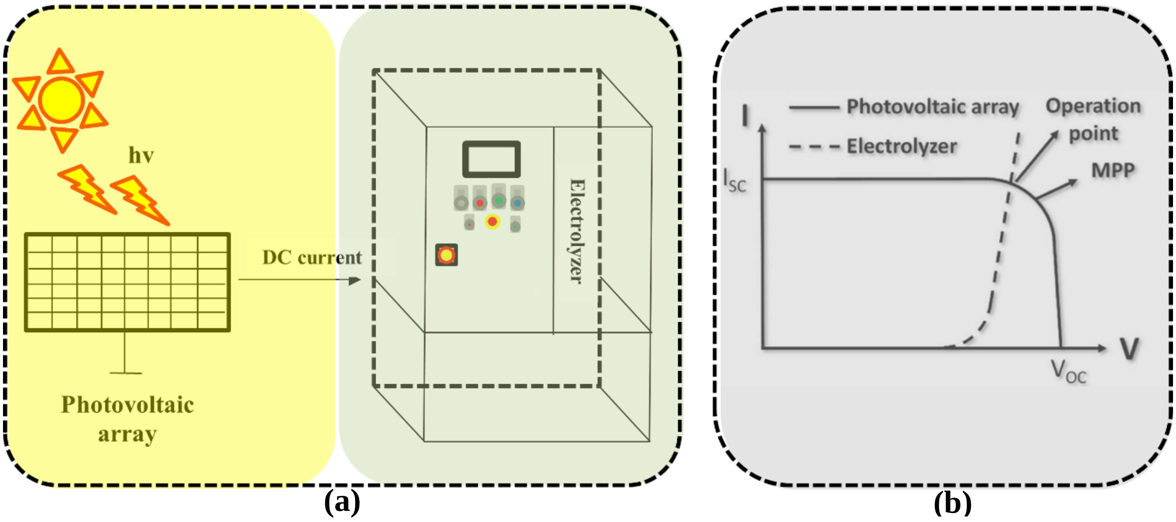

Fig. 1: (a) Scheme of a direct coupling of a photovoltaic array and an electrolyzer, (b) I–V curves of a PV array and an electrolyzer.

$$I_s = N_p I_{ph} - N_p I_o \left[\exp\left(\frac{q(V_s + R_s I_s)}{kTA}\right) - 1\right] - \frac{\left(\left(\frac{N_p}{N_s}\right) V_s + R_s I_s\right)}{R_p} \quad \text{(eq. 1)}$$

Where I_S and V_S represent the output current and voltage of the array, respectively; I_{PH} is the photocurrent generated by light absorption, which depends on irradiance and temperature T; I_O denotes the reverse saturation current of the p–n junction, q is the elementary charge of an electron; A is the ideality factor; K is Boltzmann's constant; and R_S and R_P are the series and parallel resistances, respectively. Tab. 1 contains the coefficients r_1, r_2, s, t_1, t_2 and t_3 used for the modeling.

$$V_{cell} = V_{rev} + [r_1 + r_2 \times T] \times i + s \times log\left[\left(t_1 + \frac{t_2}{T} + \frac{t_3}{T^2}\right) \times i + 1\right] \quad \text{(eq. 2)}$$

Tab. 1: *Coefficients used in this study for modeling the polarization curve* (Ulleberg, 2003).

Models/ equation	Coefficient	Value	Unit
Polarization curve	r_1	$4.45153*10^{-5}$	Ωm^2
	r_2	$6.88874*10^{-9}$	$\Omega m^2/°C$
	s	0.33824	V
	t_1	-0.01539	m^2/A
	t_2	2.00181	$m^2°C/A$
	t_3	15.24178	$m^2°C^2/A$

3. Results

The main results obtained from the experiments and modeling are summarized as follows. The operating temperature (T_{op}) profile exhibits two distinct stages: a rise stage and a stabilization stage (Figure 2 (a)). In the rise stage, the temperature increases gradually from an ambient temperature of 23.74°C to 48.5°C, and then stabilizes between 48.5°C and 52°C with small fluctuations of ±1-2°C. This stabilization occurs when the heat generated inside the cell due to inefficiencies (ohmic losses, overpotentials, etc.) is balanced by the heat dissipated to the environment through convection or the cooling system. Furthermre, Figure 2(a) displays the evolution of current and $\dot{n}_{H2}$ over time. It can be observed that $\dot{n}_{H2}$ is directly proportional to the current (I), confirming Faraday's law, with no significant direct effect of temperature on $\dot{n}_{H2}$. However, temperature can indirectly influence the power consumption by affecting the required current. Figure 2 (b) presents the comparison between the measured and simulated V_{cell}, showing good agreement between both results. Consequently, the proposed model adequately reproduces the behavior of the AWE. To ensure the accuracy and validity of the proposed model, the RMS error for the V_{cell} has been evaluated with an average result of 0.87 %. Finally, Figure 2 (c) shows the influence of temperature on the V_{cell}. An analysis of the results revealed that as the temperature increases, the V_{cell} decreases due to the reduction in both the reversible voltage and ohmic overvoltage (Diéguez et al., 2008; Olivier et al., 2017). According to Figure 2 (c), the V_{cell} was highest at 30°C and lowest at 55°C, with values of 2.34 V and 2.16 V, respectively, at 0.5 A/cm².

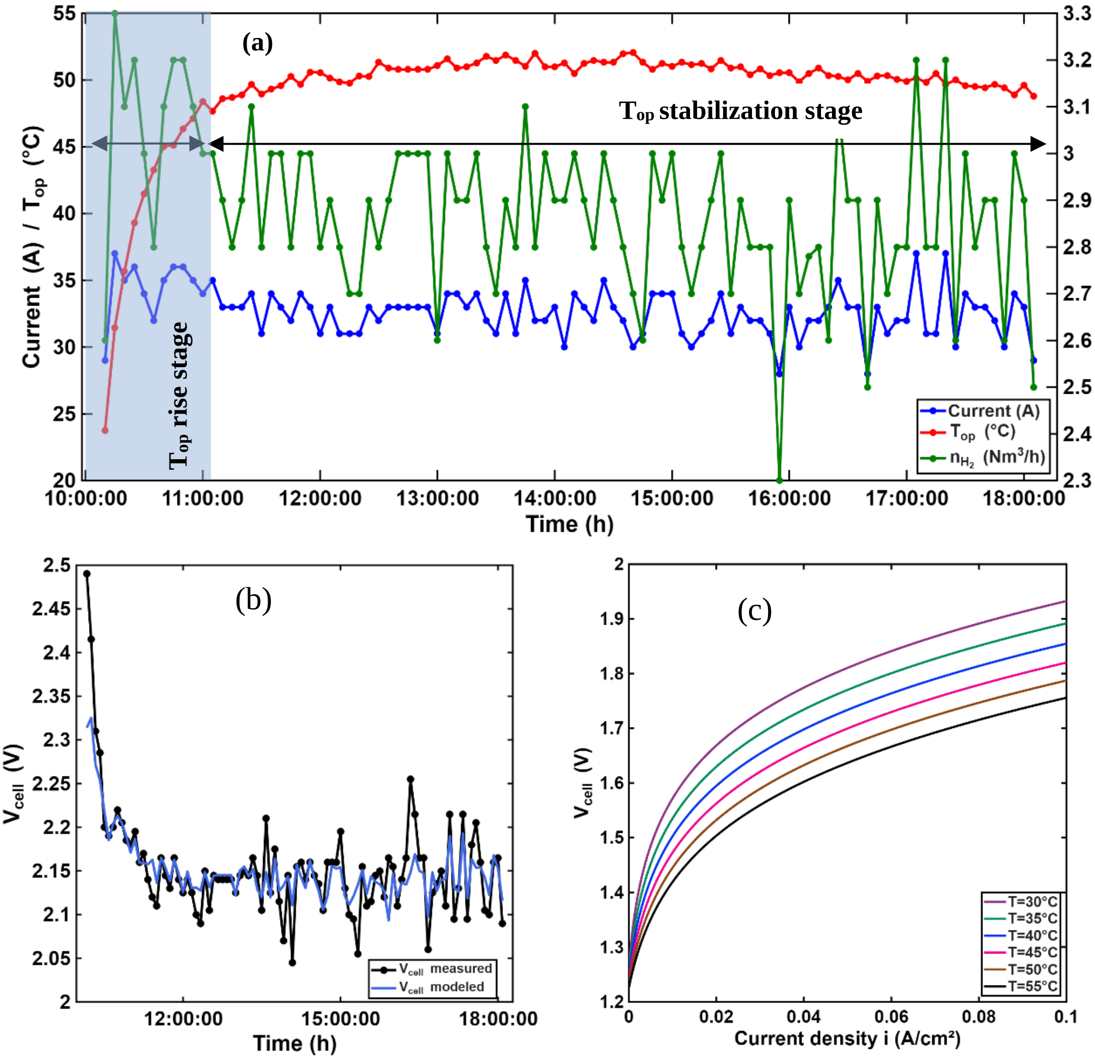

Figure 2: Experimental and numerical results, (a): evolution of current, T_{op}, and $\dot{n}_{H2}$ over time (c): *comparison between simulated and measured cell voltage, and (d): polarization curve at different temperatures.*

4. Conclusion

A semi-empirical mathematical model for an AWE was developed. The model accurately predicts the cell voltage, with deviations below 1% compared to experimental data. The results also indicate that increasing temperature leads to a decrease in cell voltage, highlighting the significant influence of thermal effects on electrolyzer performance. These findings confirm the reliability of the model as a useful tool for system design and optimization. Furthermore, the modeling framework can be extended to evaluate additional performance parameters, such as Faraday efficiency and hydrogen production rate.

5. References

Diéguez, P.M., Ursúa, A., Sanchis, P., Sopena, C., Guelbenzu, E., Gandía, L.M., 2008. Thermal performance of a commercial alkaline water electrolyzer: Experimental study and mathematical modeling. Int. J. Hydrog. Energy 33, 7338–7354. https://doi.org/10.1016/j.ijhydene.2008.09.051

Olivier, P., Bourasseau, C., Bouamama, Pr.B., 2017. Low-temperature electrolysis system modelling: A review. Renew. Sustain. Energy Rev. 78, 280–300. https://doi.org/10.1016/j.rser.2017.03.099

Ulleberg, O., 2003. Modeling of advanced alkaline electrolyzers: a system simulation approach. Int. J. Hydrog. Energy 28, 21–33. https://doi.org/10.1016/S0360-3199(02)00033-2

Van Renssen, S., 2020. The hydrogen solution? Nat. Clim. Change 10, 799–801. https://doi.org/10.1038/s41558-020-0891-0