Optimization of a stand-alone PV system for efficient hydrogen production using an alkaline water electrolyzer

Lopez, Victor Arturo Martinez; Ziar, Hesan; Zeman, Miro; Isabella, Olindo

Publication date
2022

Document Version
Final published version

Published in
Proceedings of WHEC 2022 - 23rd World Hydrogen Energy Conference

Citation (APA)
Lopez, V. A. M., Ziar, H., Zeman, M., & Isabella, O. (2022). Optimization of a stand-alone PV system for efficient hydrogen production using an alkaline water electrolyzer. In I. Dincer, C. O. Colpan, & M. A. Ezan (Eds.), *Proceedings of WHEC 2022 - 23rd World Hydrogen Energy Conference: Bridging Continents by H2* (pp. 1020-1022). (Proceedings of WHEC 2022 - 23rd World Hydrogen Energy Conference: Bridging Continents by H2). International Association for Hydrogen Energy, IAHE.

NATIONAL HYDROGEN ASSOCIATION TURKEY

OntarioTech UNIVERSITY

International Association for Hydrogen Energy

Proceedings of WHEC-2022

Bridging Continents by H_2

WHEC-2022

23rd World Hydrogen Energy Conference

Onsite and Online

June 26-30, 2022

Istanbul Congress Center, Istanbul, Turkey

Editors:

Ibrahim Dincer

Can Ozgur Çolpan

Mehmet Akif Ezan

www.whecistanbul.org

info@whecistanbul.org

SCAN ME

ISBN: 978-625-00-0843-0

#401
OPTIMIZATION OF A STAND-ALONE PV SYSTEM FOR EFFICIENT HYDROGEN PRODUCTION USING AN ALKALINE WATER ELECTROLYZER

[1*] Victor Arturo Martinez Lopez, [2] Hesan Ziar, [3] Miro Zeman, [4] Olindo Isabella
[1, 2, 3, 4] Delft University of Technology, Faculty of Electrical Engineering, Mathematics and Computer Science, Photovoltaic Materials and Devices, Mekelweg 4, 2628CD, Delft, The Netherlands

*Corresponding author e-mail: V.A.MartinezLopez@tudelft.nl

ABSTRACT

We present the analysis of the size and angle configuration of a solar photovoltaic (PV) plant connected to an alkaline electrolyzer without electrical storage nor support from the grid. Our approach is based on using the available energy in the most efficient way. To reach our objective, we allocated the available PV power to the stack and auxiliary components, then determined the produced hydrogen in one year. By defining 4 indicators, we determine that the PV plant should be oversized 1.6 times the rated power of the electrolysis stack. The orientation analysis of the PV modules shows that the optimal angles determined for maximum PV yield are not the same if other indicators are used and many of them are in conflict.

Keywords: Optimization, Energy efficiency, Green hydrogen

INTRODUCTION

Of all the production methods for hydrogen, water electrolysis is still a minority. In The Netherlands, water electrolysis contributed to only 1% of the produced hydrogen during 2021 [1]. If the country were to shift all of its production to electrolysis, a considerable amount of extra electricity is needed. To put things in context, the country needs 3.7 times more electricity than its goal for renewable energy set for 2030. For this reason, it is essential to ensure an energy efficient production of hydrogen. Previous studies have analyzed the optimization of PV-electrolysis systems targeting sizing of batteries, but ignoring the Balance-of-Plant[2]; optimizing grid connected systems [3], or optimizing the PV size for off-grid systems aiming at reducing the cost of hydrogen [4].

Our study contributes to the previous research by defining operation indices that describe the energy use of the electrolysis system. Our analysis leads to an optimization of the PV array. As we omit electric storage, the daytime available energy must be used as efficient as possible. We included the extra power needed to power the pumps, instrumentation and other equipment required to support the production of hydrogen. The PV array must meet the power demand of the electrolyzer and these additional components.

MODELLING METHODOLOGY

We modelled a PV-electrolyzer system to study the effect of plant size (in terms of nameplate power) and module angle configuration on the hydrogen production. We consider a fictitious horizontal PV plant located in Cabauw, The Netherlands. This system receives uniform irradiance and is connected to the electrolyzer by ideal power converters. Hence, we considered that the modules are always operating at maximum power point (MPP). All the generated power (P_{pv}) is consumed by the electrolyzer (P_{ele}) and Balance-of-Plant (P_{BoP}) (Eq. (1)). PV power that would violate the operating limits of the electrolyzer is curtailed.

$$P_{pv} = P_{ele} + P_{BoP} \tag{1}$$

The electrolyzer considered is a 100 kW, alkaline type and 186 cells (n_{cells}) in series. The stack voltage (V_{ele}) is modelled as a function of the applied current density (i) using Eq. (2) [5]. The operating limits lie within 20% of nominal current and 100% of nominal power. We assumed a constant operating temperature of 60 °C, considering that the power needed to keep this condition is absorbed by the Balance-of-Plant.

$$V_{ele} = n_{cells}(1.29 + 4.0468 \cdot i + 0.1803\, log(2.2709 \cdot i + 1)) \tag{2}$$

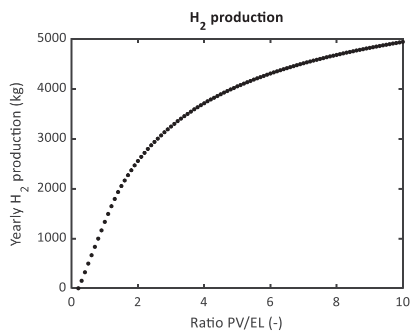
To support the operation of the electrolyzer, auxiliary components (pumps, power electronics) are included as Balance-of-Plant. These components consume power that is a percentage of the power demanded by the stack as in Eq. (3) [6].

$$P_{BoP} = 0.19276 \cdot P_{ele}^{0.249} \tag{3}$$

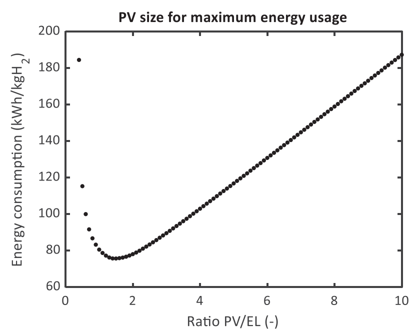
The performance of the system is measured using 4 indicators: (i) total produced hydrogen (kgH_2), (ii) system energy usage per kilogram hydrogen produced (kWh/kgH_2), (iii) wasted energy (kWh) and (iv) the utilization factor, defined as a ratio of the monthly energy used by the stack to the energy used if it was operated at nominal power during the same period.
The irradiance data was obtained from the Royal Meteorological Institute of the Netherlands (KNMI) and corresponds to the measurements of 2013 with a resolution of one minute.

RESULTS AND DISCUSSION

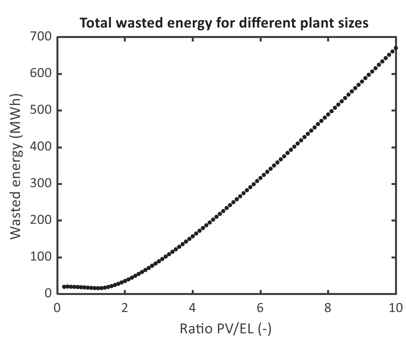
We first analyzed the oversizing of the PV-electrolyzer system. We kept the electrolyzer nominal power fixed while changing the PV nameplate capacity (kW) as a fraction of the electrolyzer's power. As seen in Figure 1, downsizing the electrolyzer (i.e., increasing the PV plant peak power) results in an improvement of all indices. The hydrogen production (Figure 1 (a)) benefits the most from an increased PV plant, in part due to a higher utilization of the electrolyzer (Figure 1 (d)). However, there is a limit in the PV plant size at which the energy is best utilized. This limit corresponds to a PV plant rated power that exceeds by 1.6 times the nominal power of the electrolyzer (Figure 1 (b)). The minimum wasted energy is achieved with a PV size that is 1.2 times larger in power than the electrolyzer (Figure 1 (c)).



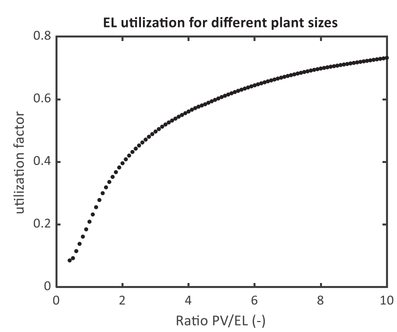
(a)



(b)



(c)



(d)

Figure 1. Analysis of PV rated power with respect to the electrolyzer nominal power. The horizontal axis shows a ratio of the two powers. Different indicators are analyzed. (a) hydrogen production, (b) the system efficiency expressed as a measure of the energy needed to produce 1 kg of hydrogen; (c) the energy that cannot be used for exceeding or not being enough to power up the process and (d) the amount of time the electrolyzer operates at nominal power .

We chose the ratio PV/electrolyzer that minimizes the utilization of energy (Figure 1 (b)) and studied the effect of different module orientations (azimuth and tilt) on the 4 indicators. Figure 2 shows the optimal module angles for each indicator. From the figure, it becomes clear that the indicators compete. In particular, setting the array at an optimal angle for minimizing the energy use can potentially reduce the produced hydrogen, but results also in lower wasted energy.

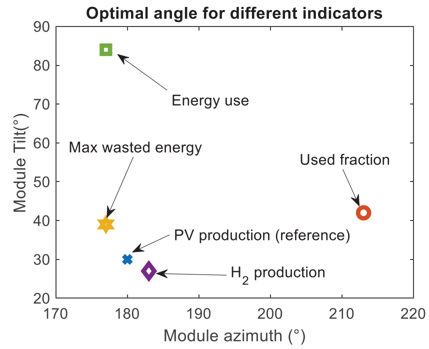


Figure 2. Optimal angles of the different indicators. The 'x' is the optimal angle for maximum PV production at the site and is included as a reference. Note that none of the indicators coincides with this configuration.

Even when increasing the PV size leads to an improved hydrogen production, the analysis of wasted energy imposes a limit on the oversize of the system. Note that this indicator never drops to zero even for very small PV systems as low power levels are not enough to start the electrolyzer, which remains off and hence curtailment is unavoidable. At an oversize ratio (PV power/electrolyzer rated power) of 1.2 the wasted energy is minimized. Interestingly, this is not the point for highest efficiency (oversize ratio of 1.6). At low power, the auxiliary components demand more energy, making the process more inefficient. The most efficient point occurs then when the correctly allocated to produce hydrogen, instead of supporting the Balance-of-Plant, at a cost of more energy spilled.

CONCLUSIONS

We presented an analysis and method for sizing a PV system connected to an alkaline electrolyzer and its auxiliary components. Our approach gives priority to a best utilization of the available energy from the Sun, trying to reduce the amount of unused energy. We found that spilling is unavoidable without storage. Further, minimizing the wasted energy can be detrimental for a high-efficiency process mainly due to the Balance of Plant. We found an optimal ratio of PV peak power to rated power of electrolyzer equal to 1.6.
We concluded a module orientation analysis concluding that the PV system should not be oriented aiming at maximum PV production but to a specific target. The selection of this target needs to be selected carefully as the module orientations are different for each one.

REFERENCES

1. https://www.energieinnederland.nl/ Accessed on:17-06-2021.
2. Gutiérrez-Martín, F., L. Amodio, and M. Pagano 2020 Hydrogen production by water electrolysis and off-grid solar PV. International Journal of Hydrogen Energy.
3. Karacavus, B. and K. Aydın 2020 Hydrogen production and storage analysis of a system by using TRNSYS. International Journal of Hydrogen Energy. 45: 34608-34619.
4. Yates, J., et al. 2020 Techno-economic Analysis of Hydrogen Electrolysis from Off-Grid Stand-Alone Photovoltaics Incorporating Uncertainty Analysis. Cell Reports Physical Science. 1: 100209.
5. Ulleberg, O. 2003 Modeling of advanced alkaline electrolyzers: a system simulation approach. International Journal of Hydrogen Energy. 28: 21-33.
6. Fragiacomo, P. and M. Genovese 2019 Modeling and energy demand analysis of a scalable green hydrogen production system. International Journal of Hydrogen Energy. 44: 30237-30255.