Study on Integration of Solar Power Generation in Hydroxyoxigen (HHO) Gas Production

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Abstract. The research aims to conduct an analysis of the capacity, type, and position of the solar panel against the current and voltage, Optimize the HHO gas production process with electrolysis integrated with the solar panel against the amount of gas produced, and conduct an analysis of the integration of Solar Power Plants with HHO gas generators. The research shows that the amount of solar irradiation ranges from 0.079 - 0.123 kW/M2. The higher the degree of inclination, the smaller the solar irradiation. The efficiency of the solar panel ranges from 0.01 - 0.02%. The higher the degree of inclination, the smaller the efficiency of the solar panel. HHO gas production rate between 0.114 – 0.268 liter per minute. The hydrogen content in HHO gas is 12%.

1 Introduction

Green energy is the idea of using technology from new renewable energy sources to fight climate change and lessen its adverse effects. The development of green energy requires taking into account the energy supply's availability as a result of social and economic factors. In order to solve this issue, technology from new renewable energy sources is essential. According to this viewpoint, industrialized nations' strategies are currently focused on boosting the usage of new renewable energy sources. There will be repercussions for the implementation of new renewable energy technology if it is adopted [1]

An important problem that must be faced is the generation of electricity from renewable energy which comes from solar power plants which are very dependent on sunlight, and this causes fluctuations in electricity production which results in an unstable electricity supply. Energy security is generally achieved when there is a balance between demand and energy availability at all times. Energy storage systems are very significant in overcoming fluctuations in the electricity generation system based on renewable energy. Hydrogen is considered one of the main technologies that enables the storage of renewable energy systems in the future on a large scale and is environmentally friendly which can then be combined with other supporting technologies [2].

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Hydrogen can be produced from various raw materials with many different processing technologies. Hydrogen is still produced using fossil-based energy, which is 96% of the world's hydrogen production. Steam Methane Reforming is one of the production routes for hydrogen using natural gas. Other thermochemical processes can also produce hydrogen through other routes ranging from coal, oil, biomass fuels, and waste. These approaches cannot be separated from greenhouse gases [3].

The Power-to-Gas concept based on water electrolysis energy using electrical energy obtained from new renewable energy sources (solar, wind, geothermal, hydro, etc.) is an approach that is considered the most environmentally friendly. This method is interesting to study further, because its use is still relatively low at around 4%, but it is estimated that it will expand to 22% in 2050 [4]. Various renewable energy systems are used for hydrogen production using electrolysis, the method that still dominates is electrolysis using sunlight energy. For renewable energy systems that utilize wind and solar power, the variety of meteorological conditions from sunlight is imperative in utilizing both energies. The execution of the use of wind and solar energy is highly dependent on the climate conditions in the targeted area. The photovoltaic system is highly dependent on climate conditions, at night the photovoltaic system will not produce power. There is difficulty in storing the power generated by the photovoltaic system. The photovoltaic system can be combined with several other systems such as electrolyzers, hydrogen stockpiling, and fuel cell systems [4-8]. HHO gas has been used for alternative energy for several purposes. El-Kassaby et al. [9] used HHO for gasoline engines. Wang et al. [10] combined the HHO gas in the boiler for electricity generation, combined with coal and oil. Al-Dawody et al. [11] used HHO gas to enhance efficacy and reduce emissions from diesel engines. Gad et al. [12] studied the impact of HHO gas on spark ignition engines. Babu et al. [13] studied the influences of its introduction to CI engines along with diesel-biodiesel blends at varying injection pressures. The research aims to conduct an analysis of the capacity, type, and position of the solar panel against the current and voltage, Optimize the HHO gas production process with electrolysis integrated with the solar panel against the amount of gas produced, and conduct an analysis of the integration of Solar Power Plants with HHO generators.

2 Materials and Methods

2.1 Materials

Solar panel type PV type ODA400-36-MH was obtained from Ningbo Osda Solar. Batteray 45 A was obtained from GS Batteray. KOH was obtained from Merck.

2.2 Solar Panel System

The Solar panels were arranged with supports that can be adjusted for tilt angle. Solar panels are installed in places that are directly exposed to sunlight. The electricity generated is measured every hour using a multimeter. The arrangement of solar panels can be seen in Figure 1. The solar panel was located at the rooftop of post post-graduated building Diponegoro University Semarang.

2.3 HHO Gas Production and Optimization

KOH 1 M solution was put into the water electrolyzer. The electrolyzer was using SS316L+TITANIUM electrodes. Connect the positive and negative electrodes to the battery.

Turn on the battery and determine the desired current. Measure the HHO gas produced at various currents using volumetric glass.

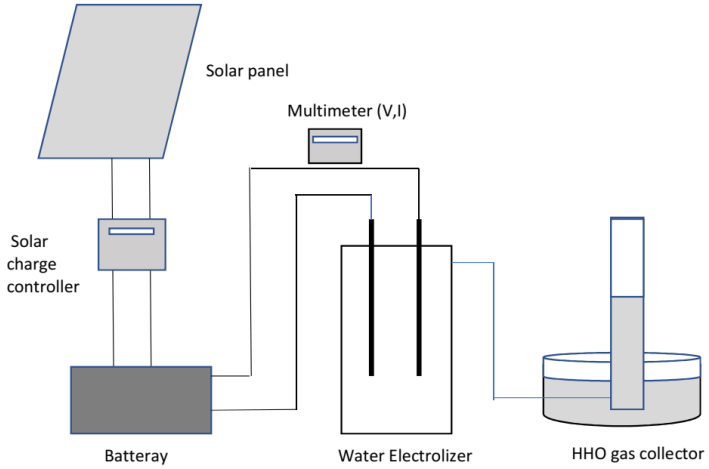

Figure 1. The solar panel – HHO gas production system

The HHO gas optimization experimental design was carried out using factorial design level 3 with the process variables of electric current (X1) and KOH concentration (X2). The experimental design is shown in Table 1 [1].

Table 1 Design of Experimental HHO Production.

Variables	**Level**		
	Lower (-1)	Center (0)	Upper (+1)
Current (A), X1	6	8	10
Concentration (mol/L), X2	0.5	1	1.5

Run	**X1**	**X2**
1	-1	-1
2	0	-1
3	+1	-1
4	-1	0
5	0	0
6	+1	0
7	-1	+1
8	0	+1
9	+1	+1

The effect of variables was analyzed using analysis of variance (ANOVA) for single effect and interaction effect. The relation of single and interaction variables is represented by a quadratic equation (Equation 1).

$$Q = \alpha 1 + \alpha 2.\, X1 + \alpha 3.\, X2 + \alpha 4.\, X1.X2 + \alpha 5\, X1^2 + \alpha 6.\, X2^2 \quad (1)$$

2.4 HHO Gas Analysis

The HHO gas produced was analyzed using the Gas Chromatography-Mass Spectrometry (GC-MS) of Shimadzu (GCMS-QP2010 SE).

3 Result and Discussion

3.1 Potential Solar Irradiation

Potential solar irradiation is an important factor in designing an effective and efficient Solar Power Plant. Solar irradiation received by a location greatly affects the capacity and performance of the designed solar panels system. In this study, the use of solar power meter measurement data was carried out to obtain accurate information regarding climate parameters and solar irradiation at the research location. This data is useful in modeling and simulating solar power plant design, to provide an overview of the potential energy generated from sunlight at the research location, thus supporting optimal technical decisions in the development of renewable energy. Table 2 shows the output of solar irradiation of solar panels.

Table 2. Potential Output Power Results of Solar Irradiation Measurements

Slope (º)	Potential output power (kW/day)
0	0.028
45	0.025
90	0.024
135	0.018

Based on the average daily power data generated from solar panels at various slopes, the average current at various slopes can be calculated and displayed in Table 3.

Table 3. Average of current at various slopes of solar panel

Slope	Power, W	Voltage, volt	Current, A	
0	123	12	10.25	10
45	110	12	9.17	8
90	106	12	8.83	
135	79	12	6.58	6

3.2 Optimization of HHO Gas Production from Electrolysis

The electrolysis process of water with an acid or base catalyst will produce high-octane hydrogen and oxygen gas (hydroxygen gas (HHO)), so it can be used as fuel. The total reaction of water electrolysis is the decomposition of water into hydrogen and oxygen. The half-cell reaction depends on the type of electrolyte used. For the electrolysis reaction using a base catalyst, the following are:

Cathode : $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

Anode : $2OH^- \rightarrow ½\ O_2 + H2O + 2e^-$

Total : $H_2O \rightarrow H_2 + ½\ O_2$

The hydrogen and oxygen gases produced from this reaction will form bubbles on the electrodes and can be collected into HHO gas. Based on the research results, the range of HHO gas production was obtained between 0.114 - 0.268 LPM (Figure 2). In general, the production of HHO gas produced is influenced by electric current (X1) and KOH concentration (X2). At the same current strength, the higher the KOH gas concentration, the higher the HHO gas production rate. Meanwhile, at the same concentration, the higher the current strength, the higher the HHO gas production rate.

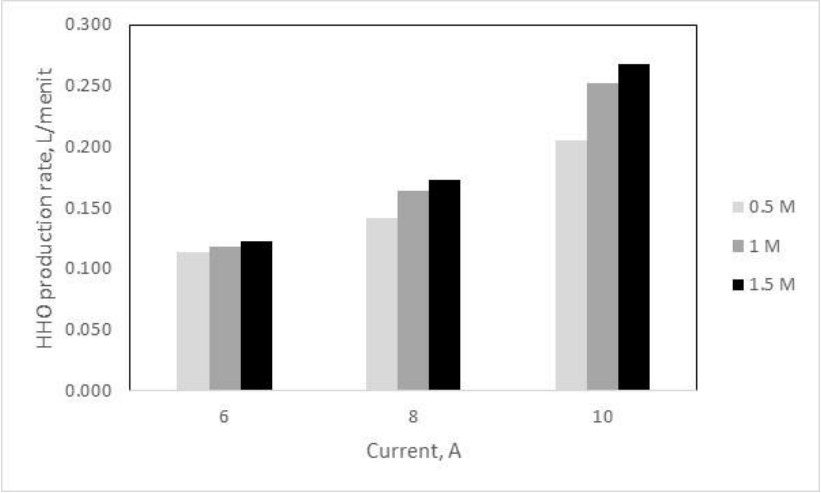

Figure 2. The HHO gas production rate at various variables

El Soly et al. [14] reported that in the production of HHO gas using dry, wet, and hybrid cells, the maximum produced HHO for dry, wet, and hybrid cells were 1.250, 1.376, and 1.360 LPM, respectively at 20% NaOH concentration uses the current of 60 A. Mousa et al. [15] produced HHO gas using a water electrolyzer 0.207 – 0.399 LPM with a KOH concentration of 0.05 – 0.5 M at a voltage of 10.5 – 13 volt.

Based on analysis of variance (ANOVA), it can be seen that the variables (single and interaction) that have a significant effect (p-value < 0,05) on HHO gas flowrate are electric current (X1), interaction of electric current and KOH concentration (X1.X2), and quadratic of electric current (X1^2). The complete ANOVA is shown in Table 4.

Table 4 Analysis of variance

Variable	coefficient	p-value	Assignment
intercept	0.291483	0.024122	
X1	-0.06524	0.029356	s
X2	-0.01355	0.758449	n.s.
X1.X2	0.013416	0.018727	s
X1^2	0.005172	0.014786	s
X2^2	-0.02981	0.165048	n.s

s = significant, n.s. = not significant

Based on the results of the ANOVA shown in Table 4, the correlation of single and interaction of variables can represented in Equation 2.

$$Q = 0.291\ 5 - 0.06524\ X1 - 0.01355\ X2 + 0.0134\ X1.X2 + 0.005172\ X1\text{^}2 - 0.0298\ X2\text{^}2 \quad (2)$$

Where Q is the HHO gas production flow rate (LPM), X1 is the electric current (A) and X2 is the KOH concentration (M). The ANOVA shows that multiple R and R^2 values are 0.998 and 0.996 respectively. The R^2 value of 0.996 indicates that the equation is valid. This shows that electric current has a very significant effect on the HHO gas production flow rate, and KOH concentration has a significant effect on the HHO gas production flow rate. If an electric current (X1) is expressed in power (X1'), The effect of variables can be seen in Table 5 and Equation 3. Where power (W) is eclectic current (I) multiplied by voltage (V).

Table 5. Analysis of variance with X1'

Variable	coefficient	p-value	Assignment
intercept	0.29148324	0.02412159	
X1'	-0.0054366	0.02935602	s
X2	-0.0135499	0.75844929	n.s.
X1'.X2	0.00111799	0.01872662	s
X1'^2	3.5919E-05	0.01478637	s
X2^2	-0.0298119	0.16504823	n.s

s = significant, n.s. = not significant

$$Q = 0.291\ 5 - 0.00453\ X1' - 0.01355\ X2 + 0.00111\ X1'.X2 + 0.0000359\ X1'^2 - 0.0298\ X2^2 \quad (3)$$

The mechanism of the electrolysis process can be seen in Figure 3. At the cathode, with the presence of an electric current, H_2O will be ionized into H_2 gas and OH- ions. The hydrogen gas produced is then collected in a gas storage chamber. The production of hydrogen gas is influenced by the electrical power used. At the anode, OH- will form oxygen (O_2) and water (H_2O). The oxygen gas produced is collected in a gas storage chamber. Conventional alkali electrolysis has an efficiency of around 70%. Taking into account the use of higher heating values (since inefficiencies through heat can be redirected back into the system to create steam needed by the catalyst), the average working efficiency for PEM electrolysis is about 80%. This is expected to increase to 82 - 86%. The theoretical efficiency of PEM electrolyzers is estimated to be up to 94%.

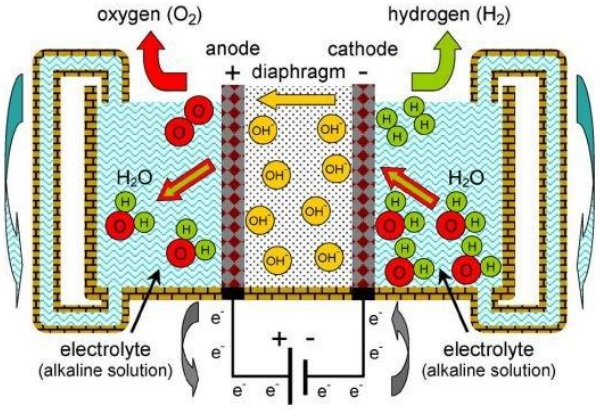

Figure 3. Electrolysis process mechanism

The main content of HHO gas is hydrogen and oxygen. The results of the analysis of HHO gas from electrolysis with a base catalyst using GC-MS (gas chromatography-mass spectroscopy) can be seen in Table 6. The GC-MS spectrum of HHO gas from electrolysis can be seen in Figure 4. Based on Table 6, it can be seen that the hydrogen content in HHO

gas is 12%. The hydrogen content of only 12% is because the gas produced is a mixture of oxygen and hydrogen.

Table 6. Content of HHO gas from electrolysis

No	Component	Content, % mol
1	Hydrogen (H_2)	12,226
2	Oxygen (O_2)	31,871
3	Argon (Ar)	19,813
4	Nitrogen (N_2)	36,090

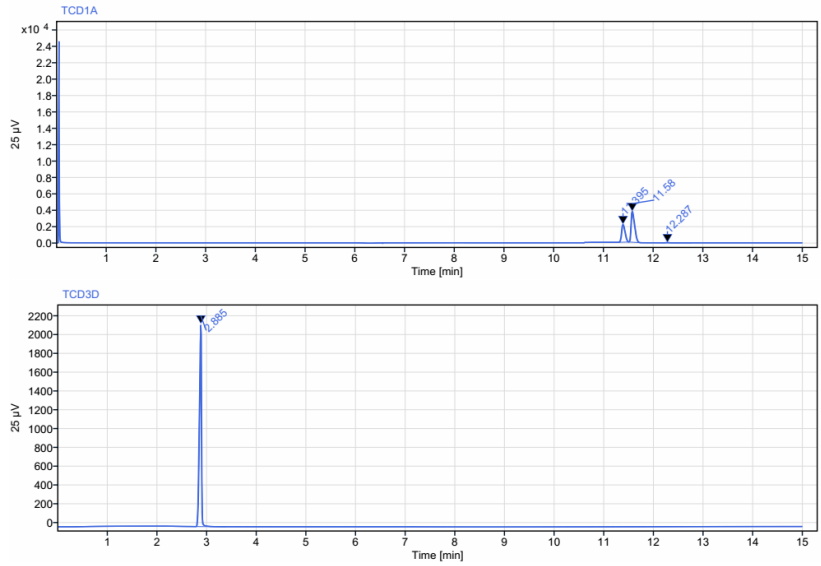

Figure 4. Spectrum of GC-MS of HHO

4 Conclusion

The research shows that the amount of solar irradiation ranges from 0.079 - 0.123 kW/M^2. The higher the degree of inclination, the smaller the solar irradiation. The higher the degree of inclination, the smaller the efficiency of the solar panel. HHO gas production rate between 0.114 – 0.268 liter per minute. This shows that electric current has a very significant effect on the HHO gas production flow rate, and KOH concentration has a significant effect on the HHO gas production flow rate. The hydrogen content in HHO gas is 12%.

References

1. D. D. A. de Fátima Palhares, L. G. M. Vieira, and J. J. R. Damasceno. Hydrogen production by a low-cost electrolyzer developed through the combination of alkaline water electrolysis and solar energy use. Int. J. Hydrogen Energy, **43**(9), 4265–4275 (2018). https://doi.org/10.1016/j.ijhydene.2018.01.051
2. A. Ben Othman, K. Belkilani, and M. Besbes. Global solar radiation on tilted surfaces in Tunisia: Measurement, estimation and gained energy assessments. Energy Reports, **4**, 101–109 (2018). https://doi.org/10.1016/j.egyr.2017.10.003

3. M. D. Cabezas, J. I. Franco, and H. J. Fasoli. Optimization of self-regulated hydrogen production from photovoltaic energy. Int. J. Hydrogen Energy, **45**(17), 10391–10397 (2020). https://doi.org/10.1016/j.ijhydene.2018.10.203
4. R. Bhattacharyya, A. Misra, and K. C. Sandeep. Photovoltaic solar energy conversion for hydrogen production by alkaline water electrolysis: Conceptual design and analysis. Energy Convers. Manag., **133**, 1–13 (2017). https://doi.org/10.1016/j.enconman.2016.11.057
5. S. Dahbi, R. Aboutni, A. Aziz, N. Benazzi, M. Elhafyani, and K. Kassmi. Optimised hydrogen production by a photovoltaic-electrolysis system DC/DC converter and water flow controller. Int. J. Hydrogen Energy, **41**(45), 20858–20866 (2016). https://doi.org/10.1016/j.ijhydene.2016.05.111
6. S. Menia, H. Tebibel, F. Lassouane, A. Khellaf, and I. Nouicer. Hydrogen production by methanol aqueous electrolysis using photovoltaic energy: Algerian potential. Int. J. Hydrogen Energy, **42**(13), 8661–8669 (2017). https://doi.org/10.1016/j.ijhydene.2016.11.178
7. M. Chandrasekar, P. Gopal, C. Ramesh Kumar, and V. Edwin Geo. Effect of solar photovoltaic and various photovoltaic air thermal systems on hydrogen generation by water electrolysis. Int. J. Hydrogen Energy, **47**(5), 3211–3223 (2022). https://doi.org/10.1016/j.ijhydene.2021.04.205
8. R. Shahraki Shahdabadi, M. Zamen, and S. V. Hosseini. Adaptive design for the connection of multicell HHO generator with solar photovoltaic panels. Int. J. Hydrogen Energy, **48**(86), 33422–33433 (2023). https://doi.org/10.1016/j.ijhydene.2023.05.035
9. M. M. El-Kassaby, Y. A. Eldrainy, M. E. Khidr, and K. I. Khidr. Effect of hydroxy (HHO) gas addition on gasoline engine performance and emissions. Alexandria Eng. J., **55**(1), 243–251 (2016). https://doi.org/10.1016/j.aej.2015.10.016
10. C. N. Wang, M. T. Chou, H. P. Hsu, J. W. Wang, and S. Selvaraj. The efficiency improvement by combining HHO gas, coal and oil in boiler for electricity generation. Energies (Basel), **10**(2) (2017). https://doi.org/10.3390/en10020251
11. M. F. Al-Dawody, et al. Using oxy-hydrogen gas to enhance efficacy and reduce emissions of diesel engine. Ain Shams Eng. J., **14**(12) (2023). https://doi.org/10.1016/j.asej.2023.102217
12. M. S. Gad, A. S. El-Shafay, Ü. Ağbulut, and H. Panchal. Impact of produced oxyhydrogen gas (HHO) from dry cell electrolyzer on spark ignition engine characteristics. Int. J. Hydrogen Energy, **49**, 553–563 (2024). https://doi.org/10.1016/j.ijhydene.2023.08.210
13. J. M. Babu, et al. Production of HHO gas in the water-electrolysis unit and the influences of its introduction to CI engine along with diesel-biodiesel blends at varying injection pressures. Int. J. Hydrogen Energy, **52**, 865–885 (2024). https://doi.org/10.1016/j.ijhydene.2023.06.078
14. A. K. El Soly, M. S. Gad, and M. A. El Kady. Experimental comparison of oxyhydrogen production rate using different designs of electrolyzers. Int. J. Hydrogen Energy, **48**(93), 36254–36270 (2023). https://doi.org/10.1016/j.ijhydene.2023.06.022
15. A. M. Mousa, H. A. A. Sayed, K. A. M. Ali, N. S. Elkaoud, and W. A. E. Mahmoud. Energy-conversion efficiency for producing oxy-hydrogen gas using a simple generator based on water electrolysis. Sci. Rep., **14**(1) (2024). https://doi.org/10.1038/s41598-024-73534-1