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Renewable Energy Conversion with hybrid Solar Cell and Fuel Cell

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Abstract— The greater the electrical energy consumption by growth in industrial and residential areas. Potential for solar energy 4.5 KW/m^2/day can be converted into electrical energy with a solar cell, biofuel energy can be converted into electrical energy with a fuel cell. solar cell and fuel cell can be used for power generation hybrid renewable energy. Research experiment with designing hybrid renewable energy power plants. Research variable; a) the independent variable; variation of the load ,10 watt, 15 watt, 25 watt, 35 watt, 40 watt; b). The dependent variable: the performance of renewable energy power plants; c) Control variables: capacity 200Wp solar cell and fuel cell 12 watt. The results of the research performance of renewable energy power plants to the electrical energy produced by solar cell range 146,80 - 168,92 watt. Average per day to produce electricity of 168.92 watts x 6 hours of irradiation = 1013.54 Wh. While the fuel cell average of 9.43 watts used to supply electrical energy when the solar cell does not produce electricity. The electrical energy stored in the battery can be turned 125 watt load for 8 hours.

Keywords— renewable energy, energy conversion, solar cell, fuel cell

INTRODUCTION

Indonesia is one of the countries with the potential of renewable energy. renewable energy resources are not utilized optimally. The advantages of renewable energy is the source of energy is quickly recovered in a natural, ongoing process. Renewable energy produced from sources of energy that naturally would not be depleted if managed properly.

The use of renewable energy can replace the use of fossil-based energy (coal, petroleum, and natural gas) and nuclear. The use of renewable energy can reduce environmental pollution and damage to the environment. Some of the renewable energy potential in indonesia used to be converted into electrical energy is the energy of the Sun and the energy hydrogen.

Solar energy is energy in the form of heat and light that is emitted from the Sun. solar energy emitted into the Earth's surface 1000 watt permeter square surface of the Earth. The potential of solar energy in Indonesia has a very long 6 to 8 hours per day, while the average long very ideal for producing electrical energy with solar panels is 4 to 5 hours per day, so that the potential of the electric energy of 4.8 Kwh/m2. Today. Solar energy has not yet exploited optimally utilize new about 10 MWp. One of the utilization of solar energy is by utilizing the technology solar cell or photovoltaic cells to convert sunlight into electrical energy.

Hydrogen energy is the most abundant element of 75% of the total mass of the elements of the universe. The hydrogen compound is relatively rare and is rarely found naturally on Earth. Hydrogen is produced industrially from hydrocarbon compounds such as methane, water through the process of electrolysis and biofuels are produced from the fermentation of the biomass plant, which has a high sugar content (such as sorghum and sugar cane) and plants which have a high content of vegetable oils (such as distance, algae, and palm oil).

a. The principle of solar cell

Solar cell made of a semiconductor material with two layers of semiconductors, semiconductor layer is positive and negative. Solar cell capture the rays of the Sun in the form of small particles, the photon energy of the Sun. The energy of the photons that are absorbed by the negative layer of solar cells at present is sufficient, then the electrons will be freed from the negative heading into positive layer, so that the potential difference arises between the two poles of a solar cell and a flow of electrons (electrical energy). the working principle of a solar cell is illustrated Figure 1.

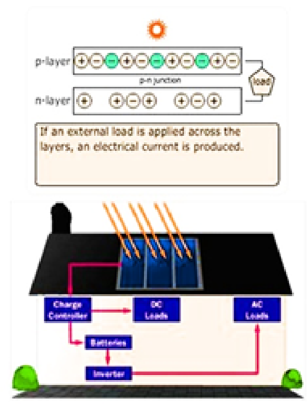

Figure 1. Illustration of the working principles of the solar cell

The energy emitted by the wavelength λ and frequency photons V defined by the equation:

$$E = h.c / \lambda \quad (1)$$

h : Plancks is constant (6.62 x 10-34 J.s)
c : The speed of light in vacuum (3.00x108 m/s).

The equation shows that the photon is a particle of energy with a specific wavelength and frequency. Solar cells produce DC voltage of 0.5 to 1 volt, short-circuit currents in the milliampere per cm^2 scale. Large solar cell voltage and current can be increased by arranging in series solar cell comprising 28-36 cells. as shown in Figure 2.

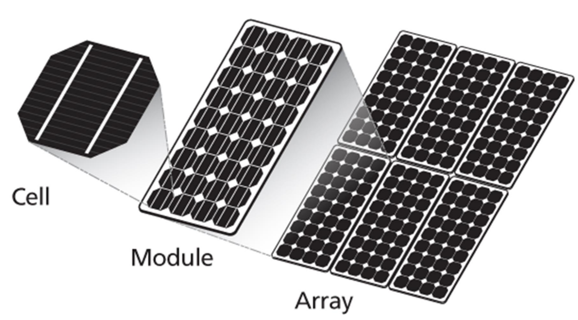

Figure 2. Solar cell module

b. Solar Cells Performance

The performance of the solar cell seen ouput power generated electricity. Solar cell under short circuit conditions, the maximum current or short circuit current (Isc) is produced, while the open circuit condition no current can flow so that the maximum tergangannya, called the open-circuit voltage (Voc). The point on the I-V curves that produce current and maximum voltage is called maximum power point. Maximum power occurs when the maximum Isc and V, as shown in Figure 3.

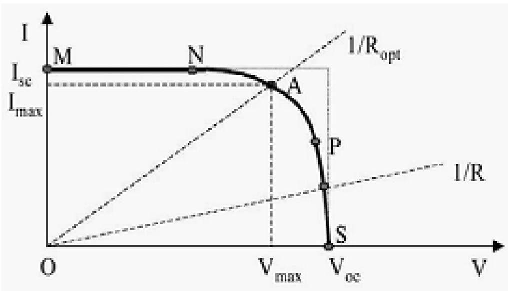

Figure 3. I- V characteristic curve in the solar cell

The performance of the solar cell is determined intersitas sunlight, the tilt angle of the solar cell and solar cell surface temperature, surface temperature increase solar cell can reduce the performance of the solar cell, as shown in figure 4.

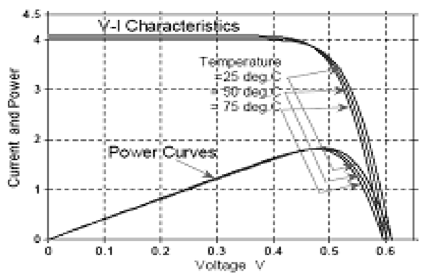

Figure 4. The characteristic curves I-V to changes in temperature

Changes in the surface of the solar cell irradiation affects the performance of the solar cell. Decrease in electrical current and voltage solar cell occurs when sunlight on the surface of the solar cell decreased, as shown in figure 5.

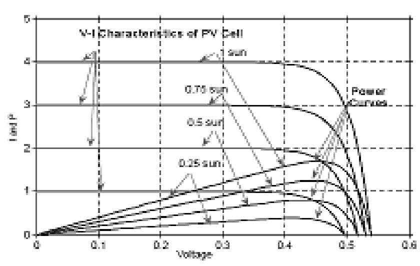

Figure 5. I-V characteristic curves to change the irradiation

Equivalent of a solar cell scheme illustrates the voltage-current characteristics of the dark and the state of irradiation, as shown in figure 6.

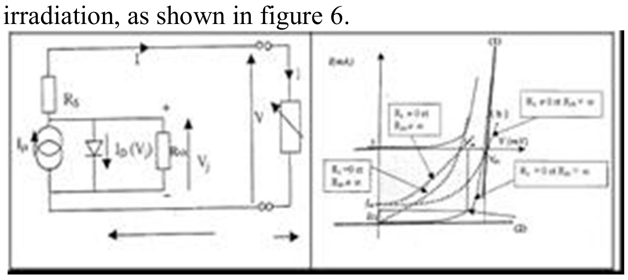

Figure 6. Schematic equivalent of a solar cell

The characteristics of the current - voltage (IC) connection P-N can be derived equations,

$$I = I_{ph} - I_d - \frac{V + R_s I}{R_{sh}} \tag{2}$$

$$I_d = I_D + I_R = I_{oD}\left(\exp\frac{qV_s}{k_B T} - 1\right) + I_{oR}\left(\exp\frac{qV_s}{2k_B T} - 1\right) \tag{3}$$

$$I = I_{ph} - I_0\left[\exp\left(\frac{qV + R_s I}{nk_B T}\right) - 1\right] - \frac{V + R_s I}{R_{sh}} \tag{4}$$

$$I = I_{ph} - I_0\left[\exp\left(\frac{qV}{nk_B T}\right) - 1\right] \tag{5}$$

I_0 : the saturation flow diode .

n: not ideal diode (n = 1 for an ideal diode).

For open circuit (I = 0), then the Voc values calculated by the equation;

$$V_{oc} = n\left(\frac{k_B T}{q}\right)\ln\left(\frac{I_{ph}}{I_0} + 1\right) \approx n\left(\frac{k_B T}{q}\right)\ln\left(\frac{I_{ph}}{I_0}\right) \tag{6}$$

The conversion efficiency (η) is defined as the ratio between the maximum electrical power and solar power absorbed by the solar cell with FF form factor can be expressed by this parameter optimal efficiency and Vco Icc. Icc current when the circuit is short-circuited (V = 0) is a parameter that describes the capacity of photovoltaic solar cells capture photons produce free charge carriers. While the open circuit voltage Vco (i = 0) describe the mechanisms of recombination solar cell. FF form factor can be expressed in the equation.

$$FF = FI\left(1 - \frac{V_{co}}{R_{sh} I_{cc}} - \frac{I_{cc} R_s}{V_{co}} - \frac{R_s}{R_{sh}}\right) \tag{7}$$

$$FI = \frac{I_m V_m}{I_{cc} V_{co}} = \frac{V_m\left(I_{cc} - I_0\left(\exp\frac{qV_m}{nkT} - 1\right)\right)}{V_{co} I_0\left(\exp\frac{qV_{co}}{nkT} - 1\right)} \tag{8}$$

FI : diode ideality factor

If zo = qVco/nkT dan zm = qVm/nkT, FI can be expressed

$$FI = \frac{z_m}{z_o}\,\frac{\exp z_o - \exp z_m}{\exp z_o - 1} \tag{9}$$

ideal conditions by taking Rs = 0, and Rsh = ∞, so FF = FI. zo form factor, as shown in Figure 7.

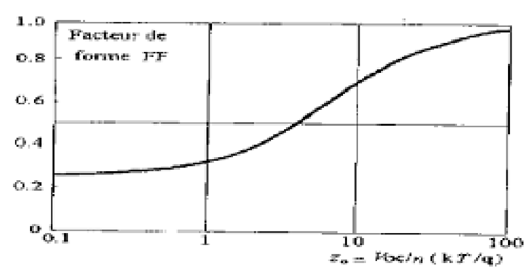

Figure 7. The form factor FF as a function zo

c. Solar Cell Efficiency

Electric power generated by the solar cell can be calculated by multiplying the electric current and the voltage produced by the solar cell.

$$P_{out} = V_{oc}\ x\ I_{sc} \tag{10}$$

by;

P_{out} = solar cell power (watts)

V_{oc} = open circuit voltage (volt)

I_{sc} = current flowing sircuit (ampere)

Solar cell efficiency is the ratio of solar energy that can be converted into electrical energy. Commercial solar cell efficiencies have averaged 15-20%. Ideal solar cell efficiency can be calculated by the equation;

$$\eta = \frac{V_m I_m}{P_{surya}} = \frac{FF x V_{CO} x I_{CO}}{P_{surya}} \tag{11}$$

d. Fuel Cell System

Fuel cells use a chemical reaction to generate electrical energy. The process is the reverse of electrolysis. In electrolysis, an electric current is used to decompose water into of hydrogen and oxygen. Fuel cell energy conversion is usually more efficient than other types of energy converters. Efiensi energy conversion can be achieved up to 60-80%. Another advantage is the fuel cell can supply energy in a long time. the fuel cell can be continuously filled fuel (hydrogen) and oxygen from outside sources. Fuel cell is an environmentally friendly energy source because it does not generate pollutants and can be used continuously for the supply of hydrogen derived from natural resources that can be updated.

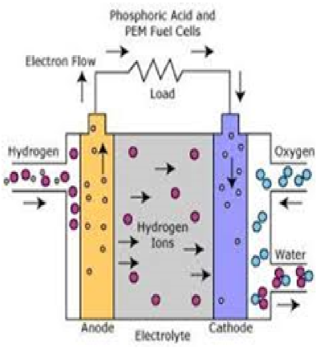

Figure 8. The working principle of the fuel cell

e. Fuel cell voltage

Standard voltage of the fuel cell can be calculated by the equation

$$E^0 = \frac{-\Delta G}{nF} \quad (12)$$

$$E_o = \frac{(\Delta G \text{ product} - \Delta G \text{ reactant})}{2.F} \quad (13)$$

With,
E_0 : standard fuel cell voltage (Volt)
n : number of electrons in the reaction
F : Faraday constant (96 485 coulombs/mole of electrons)

$$E^0 = \frac{-\Delta G}{nF} = \frac{237{,}340 \text{ J mol}^{-1}}{2 \text{ x } 96{,}485 \text{ C mol}^{-1}} = 1{,}23\,Volt \quad (14)$$

f. Fuel Cell Efficiency

The theoretical maximum efficiency of a fuel cell is the ratio between free energy (ΔG) with enthalpy of hydrogen gas (ΔH), assuming all converted all gibbs free energy into electrical energy.

$$\eta = \frac{\Delta G}{\Delta H} = \frac{237{,}34}{286{,}02} = 83\,\% \quad (15)$$

The actual fuel cell efficiency is defined as the ratio between the electrical energy produced to the hydrogen gas is consumed, which can be connecting directly with a voltage

$$\eta_{HHV} = \frac{V_c}{1{,}428} \quad (16)$$

Natural thermal stresses of HHV hydrogen is 1,428 and the natural thermal stresses LHV of hydrogen with a value of 1.254.

$$\eta_{LHN} = \frac{V}{1{,}254} \quad (17)$$

$$\eta_{fc} = \frac{P_{output}}{\dot{m}_{H_2}.LHV_{H_2}} \quad (18)$$

with,

η_{fc} = Effisiensi *fuel cell* (%)

P_{output} = power output *fuel cell* (Watt)

$\dot{m}_{H_2}$ = Hydrogen mass flow rate (Kg/s)

LHV_{H_2} = *Lower Heating value* hydrogen (KJ/Kg)

Power output is expressed as :

$$I = i.\ A \quad (19)$$

with,
i = the electrical current density (A/cm^2)
A = active cell area (cm^2)

The value of the voltage efficiency can be searched by comparing the theoretical voltage with a maximum voltage

$$\eta_v = \frac{E_t}{E_m} \quad (20)$$

with,

E_t : Theoretical voltage (Volt)

E_m The maximum voltage (Volt)

Fuel efficiency can be calculated by comparison of ionized hydrogen gas into electrons and protons to the amount of hydrogen gas supplied to the fuel cell.

$$\eta_{fuel} = \frac{m_{H_2 \text{react}}}{m_{H_2 \text{supplied}}} \quad (21)$$

with,

η_{fuel} : Utility hydrogen gas (%)

$m_{H_2\,react} = \frac{I.MW_{H_2}}{2F}$ (Kg/s)

$m_{H_2\,\sup plied}$ = Hydrogen gas is supplied to the fuel cell stack (kg/s)

The incorporation of solar cell systems and fuel cell can be used as a hybrid electricity generation systems, as shown in Figure 9.

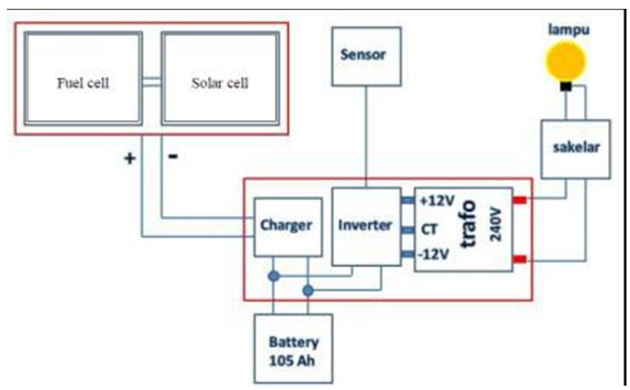

Figure 9. The hybrid power generation system

METHOD

This research is an experimental research with large-scale power generation hybrid system based household fuel cell and solar cell, so the the research variable consisted of three variables, namely;

a. The independent variables, the independent variable is the load used, ie 25 watt, 50 watt, 75 watt, 100 watt, 125 watt.
b. The dependent variable, the dependent variable is the performance of power generation hybrid system based on fuel cell and solar cell, the voltage, current and power generated electricity.
c. Control variables, the angle of the solar cell 250, exposure time 08:00 to 16:00 pm, hit the gas of 0.50 bar of hydrogen gas, oxygen gas pressure bar 0:50. measuring the intensity of sun per 30 minutes.

The research instrument power generation hybrid system based on fuel cell and solar cell, as Figure 10.

Figure 10. The research instrument power generation system hybrid

Methods of data collection is to record the results of electric current and voltage of the solar cell and the voltage and electric current produced fuel cell. Procedure record electric current production data using data loger with Exel format. Furthermore, the surface of the solar cell is exposed to sunlight for 8 a.m. to 16:00 pm, is recording the intensity of the sun every 30 minutes and given the load on the hybrid system with load variations.

Data analysis using descriptive analysis techniques of quantitative-qualitative. Quantitative data will be analyzed by percentage and displayed in a graph to determine the difference in performance (power) produced the hybrid system, while the qualitative data will be described in the form of words or phrases separated by category for the conclusion.

RESULTS AND DISCUSSION

The results of the research data of electrical energy generated by the solar cell with the hybrid system is presented in Table 1.

Table 1. Power plant hybrid solar cell and fuel cell

Time (haur)	solar cell power	Fuel cell power
08:00	146,80	9,52
08:30	147,86	8,65
09:00	151,15	9,43
09:30	156,13	8,80
10:00	156,30	9,62
10:30	160,16	9,56
11:00	159,51	9,52
11:30	164,82	9,43
12:00	162,65	9,35
12:30	168,92	8,70
13:00	166,85	9,49
13:30	168,35	9,36
14:00	161,36	8,76
14:30	160,40	8,82
15:00	148,61	8,64
15:30	135,82	8,76
16:00	120,03	9,43

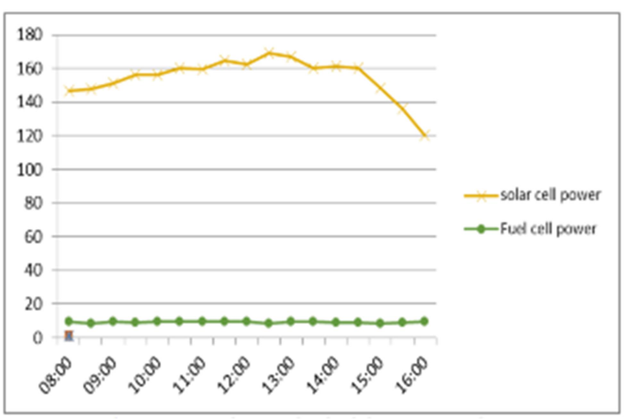

Figure 9. Charts hybrid power plant.

Power is the result of multiplying the electric current and voltage of the solar cell. Hybrid power generation system produced by the installation of two units of 200 Wp solar cell that are arranged parallel electric power generated maximum 168.92 watt and minimum 120.03 watts, while the fuel cell electrical power of 12 watts as a backup energy hybrid systems with a range of 8.64 - 9.52 watts.

CONCLUSION

The electrical energy produced by the solar cell electric power has increased due to the increased intensity of sunlight on the surface of the solar cell with maximum power 168.92 watts and minimum 120.03 watt solar cell, system can not produce electricity at night or when weather conditions do not exist sunlight. The electrical energy produced by the fuel cell is stable on average by 9.52 watts that can be used to supply electrical energy needs at night or during rainy or overcast conditions with a hybrid system. The electrical energy produced by the solar cell system on average 168.924 watts x 6 hours = 1013.544 watts can be used to meet the energy needs of daily electricity for 8 hours with load of 125 watts, and the shortage of electrical energy can be supplied from the fuel cell with hybrid system model.

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