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Low Sun Spectrum on Simulation of a Thin Film Photovoltaic, Heat Absorber and Thermoelectric Generator System

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Abstract

The research presents the simulation results with Matlab on combining of a type of thin film photovoltaic module (a-Si), a copper plate heat absorber with thermoelectric generators (TEG) utilizing the standard low-sun spectrum AM1.5G at 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1 Sun as a source of radiation. Amorphous silicon is a type of thin-film solar cell that is more suitable for indoor use, so that by using a source of low-intensity light radiation from the sun will still generate electrical energy conversion. Spectrum splitting is used as a cold mirror which reflects the spectrum of light to the a-Si module in the form of photon energy, while transmitting to the TEG module the spectrum of near-infrared light radiation in the form of heat. On the hot side of the TEG, a copper plate was placed to accommodate the heat from light radiation to increase convection heat transfer and temperature differences between hot and cold side of the TEG. The simulation results show that the highest efficiency of a-Si module is 3.46% achieved at the lowest spectrum of 0.05 Sun, vice versa TEG is at the highest spectrum at 0.1 Sun and 10.05% its efficiency. This low sun spectrum will be a milestone in the utilization of bulb radiation energy in general domestic needs.

Keywords: thin-film, low-sun spectrum, cold mirror splitter

1. Introduction

The characterizations of hybrid of a photovoltaic (PV) module that require photon energy with a thermoelectric generator (TEG) module at the standard of AM1.5G solar energy radiation source are of concern to researchers to study them so that the PV-TEG electrical energy conversion needs are optimally achieved. The way that is often done is to place the TEG module under the surface of the PV which functions as a cooler as well as receiving the excess photon energy received by the PV surface. This PV and TEG position can be called a cascade PV and TEG hybrid configuration [1-3]. The weakness of this configuration requires a DC electrical energy source on the TEG. Next, the cascade PV-TEG model does not show the splitting of the wavelength spectrum of radiation received by the two modules according to their electrical energy conversion requirements. The solution is to split the wavelength spectrum of the light from the spectrum beam splitter, so that the PV module with TEG is not stick together anymore. Kraemer et al., [4] with solar spectrum splitter and Tritt et al., [5] with wavelength segregation initiated a review of the concept of spectrum splitting through simulations that utilize AM1.5G spectrum. Some researchers continue this concept [6-9] by using a standard spectrum. Ju et al. [6] conducted a simulation that split the solar spectrum of a hot mirror type, Jadin et al., [7] with hybrid system modeling, unfortunately did not explain the type of spectrum splitter used. Elsarrag et al., [8] investigated the splitting of the solar spectrum with cold mirror in simulations and experiments. Bierman et al., [9] with hybrid PV and thermal engine modeling using the same principle as PV-TEG. Recently, Hariyanto et al., [10] also did modeling with hot mirror as a beam spliiter spectrum of the AM1.5D wavelength spectrum of light. In fact, the spectrum standard used has not yet applied artificial light whose spectrum is close to characteristic the sun, namely light bulbs [11]. The type of light bulb referred to by Doolittle [11] such as halogen, mercury and xenon.

Research with an experimental 50 Watt Halogen light bulb source was experimentally conducted by Piarah et al., [12] who characterized and compared the use of hot and cold mirror spectrum splitters in hybrid of polycrystalline mini PV module with a single in the Bismuth Telluride module type. The results show that hybrid output power is better by using cold mirror (40% cold mirror > hot mirror). Unfortunately, spectral irradians only range from 0 to 0.06 W/m²/nm, so the output power produced is still very low compared to the specifications of the PV and TEG modules used. Even though the spectral irradians of the sun are in the range of 0 to close to 2 W/m²/nm [13]. Therefore, to reduce errors, costs and time efficiency in PV-TEG hybrid experiments at low intensity, this study was simulated on the AM1.5G light standard at 0.05, 0.06, 0.07, 0.08, 0.09, 0.09 and 0.1 Sun with a type spectrum splitter cold mirror that aims to see the characteristics of low sun intensity light. The low intensity of sunlight is a simulation approach to the light spectrum of a bulb that is used indoors for PV need [14]. Later on, the results of the simulation will become a milestone in the utilization of bulb radiation energy in general domestic needs that not only function as room lighting but also as a source of radiation that can be converted back into electrical energy with the help of PV and TEG technology.

2. Procedures

The simulation of PV-TEG hybrid can be seen in Figure 1. This hybrid utilizes the spectral input of the solar energy standard AM1.5G with low intensity below 0.1 Sun which approaches the spectrum of the bulb in indoor lights as in Figure 2. Irradiances are concentrated with a thin Fresnel lens (Fl) form of conical grooves with dimensions of 5.0 x 5.0 inches, effective size 4.0 inches, focal length 5.0 inches, but in its application this focal point distance will be adjusted to the dimensions of the spectrum splitter that receives lights transmission from Fl to obtain optimal spectrum [15]. Complete lens specifications are shown in Table 1.

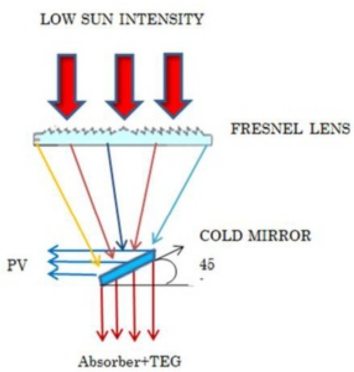

Fig. 1. Hybrid of PV, absorber and TEG

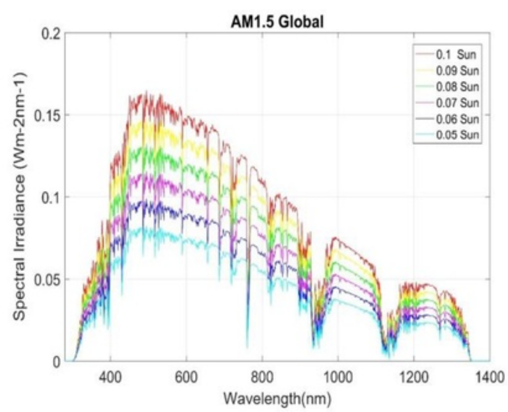

Fig. 2. Spectral irradiance under 0.1 Sun of AM1.5G

Table 1. The spesification of Fresnel lens [15]

Dimensional Tolerance		Substrate	Acrylic
(inches)	±0.05	Thickness Tolerance (%)	±40
Coating	Uncoated	Operating temp. (°C)	80 (Maximum)
Index of Refraction n_d:	1.49	Wavelength Range (nm)	400-1100 nm
Transmission (%)	92 (400-1100nm)		

When referring to the table above, Fresnel lens thickness is so thin that loses is less likely to occur during absorption of the light spectrum. The possibility is only reflected back, so that the ability to transmit light absorbed is a maximum of 92%. The 92% will be passed down to the spectrum splitter, in this case a Cold Mirror (CM) is used. Furthermore, the percentage will be divided in two ways, some are reflected in the PV modules in the wavelength spectrum between 400-690 nm by 95% and some are transmitted to the TEG module by 90% in the range of 700-1150 nm. However, before being received by the TEG hot side, the beam of light radiation is accommodated first by the absorber plate of copper before being transmitted by convection to the TEG. It aims to gather lights into heat for TEG material requirements..

The CM dimension can be seen in Fig. 3 with a size of 101 x 127 mm at a thickness tolerance of +0.0 and -0.2 mm, a thickness of 3.3 mm which is positioned at an angle of 45° below Fl. The dimension of the CM adjusts the beam of light that is transmitted by Fl. This is one of the causes of the results of the research of Piarah et al., [12] where the total radiation transmitted by Fl is not fully absorbed optimally by CM because it only has dimensions of 50 x 50 mm, so that in this simulation the dimensions are enlarged [15].

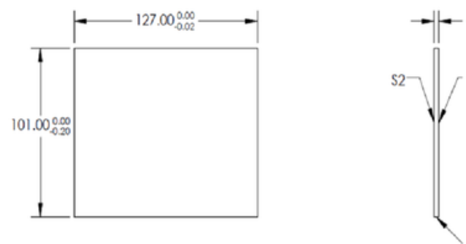

Fig. 3. Cold Mirror [15]

The reflected light beam is directed to the thin film solar cell with the specifications in Table 2 and the TEG module in Table 3.

Table 2. The spesification of Flexible Film Amorphous Silicon PV [16]

Parameter	Value
Peak Power	1 W
Voltage	6 V
Current	0.16 A
Working temperature	-15°C - 60°C

Table 3. The spesification of Thermoelectric Generator (Bi_2Te_3)

Parameter	Value
Voltage open circuit	4.8 V
Current	0.66 A
Resistance	2.4 Ω
Hot side temperature	100°C
Dimensions	40x40x3.4 mm

3. Results and Discussion

Table 4 shows the results of the low sun spectrum simulation after passing through the Fresnel lens and the spectrum transmitted to the TEG module and reflected to the PV by Cold Mirror. It is seen that the total spectral power reflected is greater (169.05 W/m^2) in the form of photon energy compared to that transmitted to the TEG module (126.90 W/m^2) in the form of heat energy. The transmitted light spectrum is accommodated first by the copper plate as a heat absorber to increase the conversion of light to heat and by convection heat transfer to the hot side of the TEG module.

Tabel 4. Irradiances of AM1.5G on low Sun spectrum

Spectrum AM.1.5G	Full spectrm 250-1500nm (W/m^2)	Reflection 400-700nm to PV (W/m^2)	Transmission 700-1150nm to copper plate+TEG (W/m^2)
0.1	89.79	37.57	28.20
0.09	80.82	33.81	25.38
0.08	71.84	30.05	22.56
0.07	62.86	26.30	19.74
0.06	53.88	22.54	16.92
0.05	44.90	18.78	14.10

Module of PV

It appears that the spectral irradiance at 0.05 Sun, the smallest power input generates the highest efficiency, 3.46% more than 0.04 compare with in the 0.07 Sun irradiance (Table 5). This shows that although the spectral irradiance and the small power in the wavelength spectrum of 400-700 nm, the efficiency is still high. The power generated is still far greater than the power in the study of Piarah et al., [12]. This is due to the simulated assumption that there is no radiation energy loses other than following the FL and CM transmission specifications.

Tabel 5. Efficiency of PV Module on low Sun spectrum under 0.1 Sun AM1.5G

Spectrum AM1.5 G	Reflection 400-700 nm to PV (W/m^2)	Current (A)	Voltage (V)	Power (W)	A_{pv}	P_{in}	η_{PV} (%)
0.1	37.57	0.006	4.25	0.03	0.02	0.75	3.33
0.09	33.81	0.005	4.24	0.02	0.02	0.68	3.11
0.08	30.05	0.005	4.23	0.02	0.02	0.60	3.33
0.07	26.30	0.004	4.22	0.02	0.02	0.53	3.42
0.06	22.54	0.004	4.22	0.02	0.02	0.45	3.33
0.05	18.78	0.003	4.21	0.01	0.02	0.38	3.46

In Figure 4 shows the simulation results using the 0.1 AM1.5G spectrum input which has passed the Fl and CM of 37.5672 W/m^2. The maximum output power obtained is 0.023 W, with a voltage of 4.098 V and a current of 0.005 A.

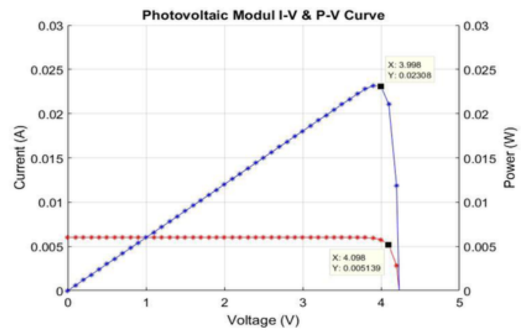

Fig. 4. Simulation of PV in I=f(V) and P=f(V)

Module of TEG

The simulation results in Table 6 on the TEG module as a result of the lights transmission of low sun spectrum after CM depicts the temperature changes on the hot side TEG from 70 to 120°C to a 10°C with a constant temperature on the cold side. Optimum power is achieved at a 80°C delta temperature between the hot and cold side of the TEG module. This large temperature ratio indicates that the copper plate absorbs light into heat well before being transferred by convection to the TEG hot side. As a result, TEG module efficiency also displays an increase in trend similar to its output power (Fig. 5).

Table 6. Simulation of TEG module on low Sun spectrum under 0.1 Sun AM1.5G

T_H(°C)	T_C(°C)	Current (A)	Voltage (V)	Power (W)
70	40	0.355	1.238	0.110
80	40	0.474	1.654	0.196
90	40	0.592	2.068	0.307
100	40	0.711	2.481	0.442
110	40	0.830	2.895	0.602
120	40	0.948	3.308	0.787

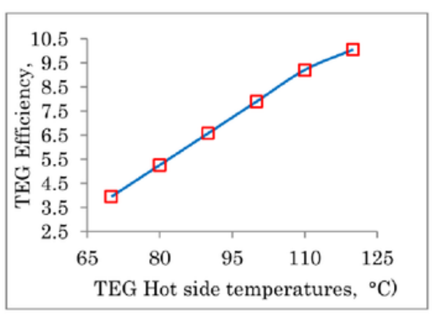

Fig. 5. Efficiency of TEG module

In Fig. 6 presents the simulation results on temperature of a TEG hot side, T_H = 70°C and and the cold side of the module, T_C = 40°C. The maximum output power obtained is 0.1107 W, with a voltage of 1.241 V and a current of 0.354 A.

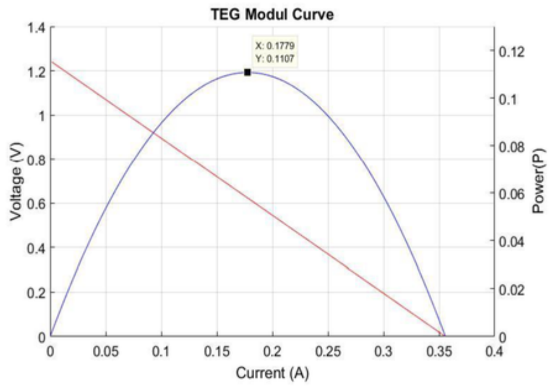

Fig. 6. Simulation result of T_H = 70⁰C and T_C = 40⁰C on TEG module.

Spectrum AM1.5 G	η_{PV-TEG} (%)
0.1	13.38
0.09	12.31
0.08	11.22
0.07	10.00
0.06	8.59
0.05	7.41

Fig. 6. Efficiency of PV-TEG hybrid

In short, the highest efficiency achieved at 0.1 Sun low sun spectrum input of 13.38%. This high value is the contribution of the simulation on TEG as a result of the effectiveness of copper heat absorbent, because the highest efficiency of the PV module is actually obtained in the lowest spectrum of 0.05 Sun.

4. Conclusion

It can be concluded that even in the low Sun spectrum, the photo energy produced is sufficient to generate electrical energy or output power in the PV module. Likewise, the output power generated by the TEG module increases with the addition of a heat collection plate. This is in line with the results of the study of Ju et al., [6], Only they did not display the type of light spectrum splitter in their PV-TEG hybrid.

Acknowledgment

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