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The Characterization of a Thermoelectric Generator Type TEC1-12706 Hybridized on 50 W Polycrystalline PV

Iskandar[1], Arif Rahman Hakim[2], Mustofa[3], Rustan Hatib[4], Yuli Asmi Rahman[5], Zuryati Djafar[6], Wahyu Haryadi Piarah[7]
[1,2,3,4]Department of Mechanical Engineering, Universitas Tadulako, Palu 9418, Indonesia
[5]Department of Electrical Engineering, Universitas Tadulako, Palu 94148, Indonesia
[6,7]Department of Mechanical Engineering, Universitas Hasanuddin, Gowa 92171, Indonesia

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ABSTRACT

The capability of solar energy to produce electricity using Thermoelectric Generators (TEG) and Photovoltaic (PV) technology is significant. Therefore, it is important to understand how the technology works. This study aims to characterize the electrical generation of 12 TEG modules type TEC1-12706 hybridized with 2 PV panels. One PV panel is left without a TEG module as a comparison. Meanwhile, on the cold side of the TEG attached to the PV, a heatsink with 3 fins is placed. The left and right fins are air allowed to flow naturally, while the middle fin flows with cold water fluid through a 0.01 m diameter water hose with 2 flow rates; 0.02 and 0.05 m/s. The study showed that the fluid flow rate 0.02 presented a better TEG performance effect than 0.05 m / s at an irradiance of 450 W/m^2. Different things are shown by PV solar panels, where the power generation and efficiency are better in TEG at a flow rate of 0.05 m/s compared to 0.02 m/s for the same irradiance. Overall, the performance of PV-TEG is better at a TEG cooling fluid flow rate of 0.05 m/s.

Corresponding Author:

Mustofa
Department of Mechanical Engineering, Universitas Tadulako, Palu 94148, Indonesia
Email: mustofauntad@gmail.com

1. INTRODUCTION

The study of electrical energy conversion is always interesting if it uses renewable energy as its source, such as solar energy. The abundant, non-polluting and available solar energy potential can be used as energy input for solar panel technology and thermoelectric generator (TEG) modules to generate electrical energy. Photon light emitted to the surface of the PV semiconductor will be converted into electrical energy. In contrast, solar thermal energy transmitted to the surface of the panel will affect the temperature difference on both sides of the TEG as the Seebeck effect is attached to the bottom surface of the PV, thus generating a difference in electrical voltage at both poles of the TEG. The electrical energy output of PV and TEG becomes a broad topic for researchers if combined into PV-TEG. Although the form of energy output is the same, the performance characteristics of the two technologies are different. Many researchers focus on the characteristics of PV cooled with various cooling modes, such as PCM [1-3] and thermoelectric [4-6].

Both PV and TEG use photon and thermal energy sources from the sun and other energy sources including light bulbs. However, light bulbs that have a spectrum similar to solar energy are only Halogen, Xenon, and Mercury as proposed by Doolittle [7]. This encourages researchers to test other

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types of bulbs including LEDs [8-12]. Although these types of bulbs have the visible light wavelength spectrum (300-700 nm) needed by PV and the near-infrared spectrum between 700 and 900 nm for TEG needs, the ability of visible light waves in bulbs is relatively low to release covalent bonds of electrons in the valence band to the conduction band in semiconductor materials which produces very small electric currents [9]. Modification of PV and TEG materials is needed to increase their output power if they continue to use these bulbs.

The main reason for combining PV and TEG is to maintain the PV surface temperature below the critical temperature between 60 till 80°C, both experimentally [13-17] and numerically [18,19]. Increasing the PV surface temperature beyond the critical limit will reduce its performance [20]. Therefore, to achieve this effort, a good understanding of the characteristics and performance of not only the PV panel but also the TEG module is required. Siregar [21] characterized the TEC1-12706 type thermoelectric. Unfortunately, the characterization was limited to knowing the open circuit voltage (V_{oc}) of two thermoelectric modules connected in series based on the temperature difference between the two sides of the module, without describing the P-V and I-V characterization in detail. Jaziri et al., [22] provided complete information about the fabrication technology and its implementation which can be used as a benchmark to see the performance of the Peltier module based on its operating conditions.

Based on the above research gap phenomenon, this study aims to characterize the output power and performance of TEG attached to the bottom surface of PV solar panels separately, so that the effects of photon light and solar thermal energy on the PV-TEG system can be widely seen.

2. RESEARCH METHOD

Figure 1 shows the flow diagram of the TEG characteristic testing on PV compared to PV without TEG. There are 3 stages carried out starting from the experimental setup, temperature monitoring with the IoT platform using ThingSpeak application combined with digital multimeters for current and voltage. The last stage is data analysis and conclusion.

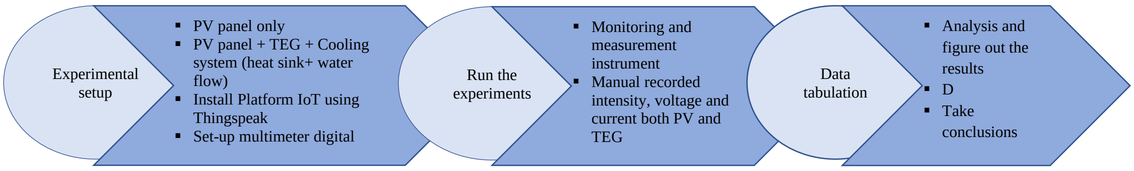

Figure 1. Experimental flow-chart

2.1. TEG and PV module specifications

In general, the main materials used in producing TEG modules are Bi2Te3, $PbSe_{0.5}Te_{0.5}$, $Bi_{0.3}Sb_{1.7}Te_3$, and Zn_4Sb_3, as well as AIN [23]. Our research selected 12 TEG modules based on Bismuth Telluride (Bi2Te3) TEC1-12706 with an operating temperature of -30 to 70°C in white. For PV, three panels of 50 W polycrystalline were used as seen in Figure 2. Two TEG combined PV panels and one PV panel without TEG combined as a comparison. The specifications of the PV used are as in Table 1.

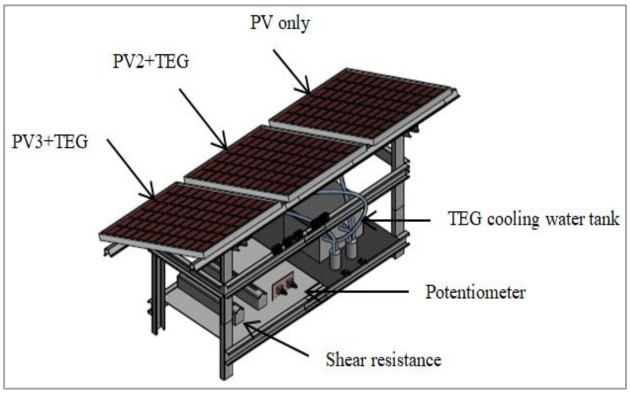

Figure 2. Experimental set-up

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Table 1. Specification of PV Polycrystalline 50 W

Rate maximum power (P_{max})	5.0 Wp
Voltage at maximum power (V_{mp})	17.6 V
Current at maximum power (I_{mp})	2.86 A
Open circuit voltage (V_{oc})	21 V
Short circuit current (I_{sc})	3.2 A
Maximum system voltage	1000 V

Twelve TEG modules are connected in series and form a circle configuration as shown in Figure 3. The cold side of the module is attached to an aluminum heat sink that has three fins, where the left and right paths are permitted to have natural airflow, while the middle fin flows with cold water fluid with a flow rate of 0.02 m/s at PV2 and 0.05 m/s at PV3 which aims to maintain the constant temperature of the cold side of the TEG, as well as to obtain a greater temperature difference with the hot side. The greater the temperature difference on both sides of the module, the better its performance [23-25].

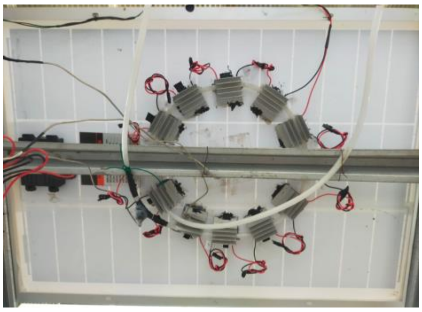

Figure 3. Configuration of 12 TEG modules on the bottom surface of the PV

2.2. Monitoring and measurement instrument

During testing, sensors powered by IoT technology with the Thingspeak application were used to measure the upper and lower surface temperatures of the PV and the cold side temperature of the TEG, which can be monitored live at https://monitoring-pv-mustofa.blogspot.com. The Pasco SF-9569A Digital Voltmeter and Ampere Meter are used to measure the output voltage and current of the PV and TEG, and the Solar Power Meter SM206-SOLAR is for sunlight irradiance. Furthermore, to obtain the characteristics of power (P) - voltage (V) and current (I) - V on the PV, the YOKOGAWA 2791 shear resistor is used with a nominal resistance of 4.7Ω/10Ω, while the 10Ω potentiometer is used as a load on the TEG circuit module.

3. RESULTS AND DISCUSSION

3.1. PV1 characterization

To examine the characteristics of the solar panel, the test was carried out on two irradiance points; a minimum of around 445 W/m^2 and a maximum irradiance of minimum of about 1200 W/m^2 at the time of observation. Figure 4 shows the I-V characteristics of PV1 without TEG at minimum and maximum irradiance. For the PV, the efficiency value is determined as the fraction of incident power that is converted to electricity and is defined as.

$$POC_{SC_{max}} \quad (1)$$

$$\eta_{PV} = \frac{V_{OC} I_{SC} FF}{P_{in}} \quad (2)$$

$$P_{in} = AG \quad (3)$$

V_{OC} is the open-circuit voltage, I_{SC} is the short-circuit current, FF is the fill factor, A is the area of PV (0.41 m^2) and G is the solar irradiance (W/m^2). In this test, PV-TEG characterization was carried out using three shear resistors on the PV and two potentiometers for the TEG.

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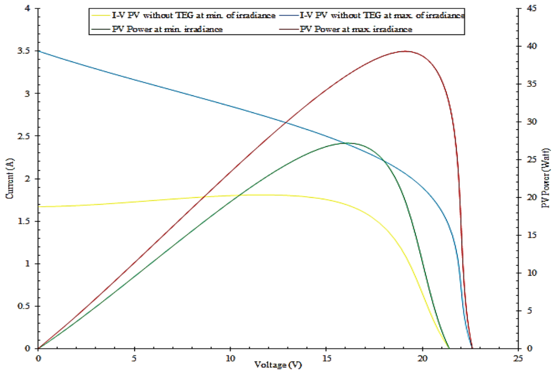

Figure 4. I-V and P-V characteristics of PV without TEG

Figure 4 shows the parameters for determining the results as in Table 2. It can be seen that 14.91% is at the minimum irradiance of 445 W/m^2 and 7.99% is at the maximum irradiance of 1200 W/m^2.

Table 2. Characteristic parameters of PV without TEG for two irradiance points

PV1 without TEG at minimum irradiance of 445 W/m^2				
V_{OC} (V)	I_{SC} (A)	P (W)	FF	η_{PV} (%)
21.4	0	0	0.76	14.91
16.1	1.69	27.21		
0	1.67	0		
PV1 without TEG at maximum irradiance of 1200 W/m^2				
22.6	0	0	0.49	7.99
19.1	2.06	39.35		
0	3.5	0		

3.2. PV2 characterization

The I-V characteristics of PV2 combined with TEG decreased in power at the beginning of the observation but increased by 4.67 Watts during the day compared to PV1 (Figure 2). Similarly, the solar panel performance value increased by 0.96% at maximum irradiance, as shown in Table 3. This suggests that attaching the TEG module to PV has begun to take effect.

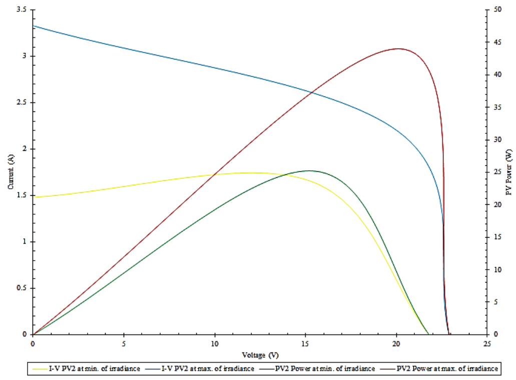

Figure 5. I-V and P-V characteristics of PV2 with TEG1

Table 3. Characteristic parameters of PV2 with TEG1 (TEG cooling fluid flow rate 0.02 m/s)

PV2 combined with TEG at minimum irradiance of 445 W/m^2				
V_{OC} (V)	I_{SC} (A)	P (W)	FF	η_{PV} (%)
21.8	0	0	0.78	13.83
15.2	1.66	25.232		
0	1.48	0		
PV2 combined with TEG at maximum irradiance of 1200 W/m^2				
22.9	0	0	0.58	8.95
20.1	2.19	44.02		
0	3.33	0		

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3.3. PV3 characterization

Unlike the 2 PVs above, PV3 in Figure 6 and Table 4 shows the effect of the TEG combination on PV in terms of increasing actual power and efficiency when compared to PV without a waste heat absorption module. Power and efficiency characteristics increase simultaneously in PV. In PV without TEG from 27.21 W to 28.181 W in PV with TEG and from PV efficiency of 14.91% to 15.54% under the same conditions at minimum irradiance. Meanwhile, in the maximum irradiance conditions, the power increases from 39.35 W to 45.70 W and from 7.99% to 9.29%. One of the factors is that the flow rate of the cooling fluid on the cold side of the TEG significantly increases the ΔT of the TEG module and the PV surface.

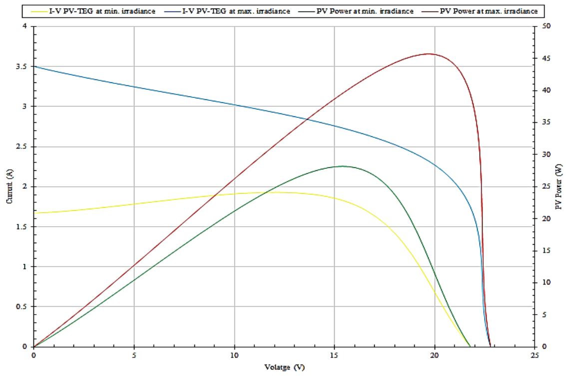

Figure 6. I-V and P-V characteristics of PV3 with TEG2

Table 4. Characteristic parameters of PV3 with TEG2 (TEG cooling fluid flow rate 0.05 m/s)

PV3 combined with TEG at minimum irradiance of 445 W/m²				
V_{OC} (V)	I_{SC} (A)	P (W)	FF	η_{PV} (%)
21.8	0	0	0.78	15.45
15.4	1.83	28.182		
0	1.67	0		
PV3 combined with TEG at maximum irradiance of 1200 W/m²				
22.	0	0	0.57	9.29
19.7	2.32	45.70		
0	3.5	0		

The figure and table above indicate that the efficiency and power of PV hybridized with TEG module circular configuration are better at a cooling fluid flow rate of 0.05 m/s compared to 0.02 m/s and with PV without TEG. This is also seen in the electrical power of the type of PV hybridized with a rectangular TEG module configuration [24]. One of the parameters that cause this to happen is the difference in PV surface temperature, where the upper surface temperature of PV2+TEG1 water cooling rate 0.02 m/s is higher than PV3+TEG2 with TEG water cooling rate 0.05 m/s (43.75°C> 40.75°C at minimum irradiance and 60.125°C>47°C at maximum irradiance). Therefore, the combination of TEG modules and their cooling types provides good recommendations for improving the performance of the PV-TEG system.

3.4. TEG1 and TEG2 characterization

The characteristics of TEG1 are different from PV2 even though they both produce electrical energy. The formulation used to calculate the efficiency of the TEG module is based on the maximum conversion efficiency that could be expressed in the function of the Carnot efficiency ($(T_h-T_c)/T_h$) and the dimensionless figure of merit factor of the materials used as [26] with a ZT value of 0.7 or 1 for the type of TEG material used in this study [22][27].

$$\eta \frac{T_h-T_c}{T_h} \frac{(\sqrt{1+ZT}-1)}{\sqrt{1+ZT}+{}^{T_c}/_{T_h}}{}_{TEG1max} \quad (4)$$

Where T_h and T_c are TEG hot side and cold side temperatures, simultaneously. Using equation (4) based on test data, the value of $\eta TEG1_{max}$ at PV2 is 8.7% at ΔT 6°C. Furthermore, Figure 7 shows the general characteristics of the TEG module, where moderate increase in electric power accompanies the sharp decrease in TEG electric current. The increase in power continues until the maximum power

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point and decreases sharply after the peak until the voltage approaches the maximum. The figure also shows the magnitude of the equivalent power with the magnitude of the temperature difference between the two sides of the module. At ΔT 8°C, the TEG1 power is 0.006 W compared to 0.003 W at ΔT 6°C.

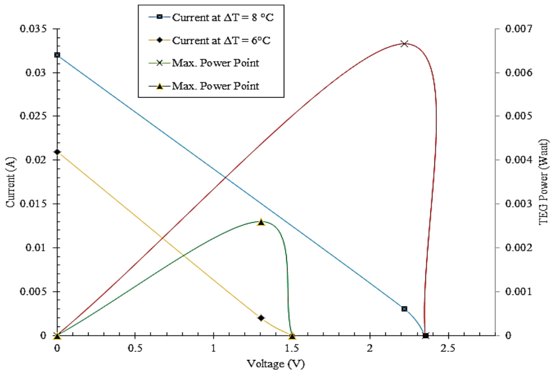

Figure 7. I-V and P-V characteristics of TEG1 attached to PV2

In contrast, Figure 8 shows the difference in characterization of TEG2 on PV3 with TEG1 on PV2. The output power of TEG2 increased by 0.0033 W/m^2 or more than 50% compared to the generated power on TEG1 in maximum solar thermal radiation (1200 W/m^2). Interestingly, at the beginning of the observation, the output power of TEG1 was actually greater than TEG2 (0.0026 > 0.0013 W). This is likely due to the rate of water cooling on the cold side of the TEG which began to have an effect when the sun's intensity increased.

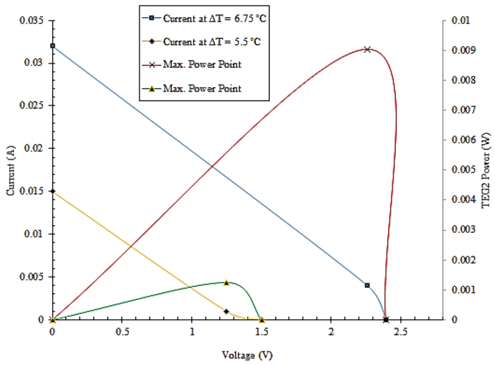

Figure 8. I-V and P-V characteristics of TEG2 attached to PV3

Regarding the module's performance, TEG1 is better than TEG2 (8.07>6.71%) at minimum irradiance. The same thing happens at maximum irradiance (10.09>8.09%). The characteristics of TEG that occurred in this study are akin to the research results conducted by Piarah *et al.*, [9], the difference lies in the thermal energy source used from a Halogen bulb with a power of only about 1 μW. In this research, the characteristics of TEG are visible where the increase in electrical voltage (V) is accompanied by a sharp decrease in current (I), while the output power increases to a peak point and decreases thereafter. Unlike TEG, the characteristics of PV show that the position of the electrical current tends to be flat when the voltage and electrical power increase. The decrease in current occurs when it reaches the maximum power point (MPP).

4. CONCLUSION

The characterization analysis of the thermoelectric generator type TEC1-12706 made from Bismuth Telluride (Bi2Te3) shows that the I-V and P-V generation are increasingly different from PV. The number and configuration of TEG modules attached to the bottom surface of the PV also have a major influence on PV performance. The more TEG modules with even circulation of cooling fluid on the cold side of the module, the better the effect on PV performance. This research also proves that using the Thingspeak platform as an IoT application is very accurate in helping to provide temperature data for the PV-TEG hybrid system.

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