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Study on performance characteristics of thermoelectric generator string

N A Mahardiono^{1*}, T Haiyunnisa¹, R W Firmansyah¹, I Purnama¹

Technical Implementation Unit for Instrumentation Development (UPT BPI)
Indonesia Institute of Science (LIPI) Bandung 40135, Indonesia

*nova001@lipi.go.id

Abstract. A thermoelectric generator (TEG) converts thermal energy directly into electrical energy. The principle work of this device is known as a Seebeck Effect. The TEG can be used effectively to harvest low thermal energy to power a low power Wireless Sensor Node (WSN). As the same as solar cells, the TEG connection can be a distributed string either in parallel or in series. However, the performance of the TEG string due to the inhomogeneity temperature gradient in each TEG is still not well investigated. This paper presents the effect of the inhomogeneity temperature gradient on the performance characteristics of the TEG string. The test is carried out using a Thermoelectric Cooler (TEC) as a thermal source on the TEG string. The experimental result is provided to verify the performance of the TEG in various cases of this inhomogeneity temperature gradient.

1. Introduction

Currently, the demand for electrical energy is rapidly increased and will increase in the upcoming years. The high demand of energy and increasing fossil fuels depletion generates the requirement for using renewable energy resource [1]. There are 2 types of electrical energy resources. First, electrical energy is generated by utilizing water, steam, gas, wind and nuclear [2]. Second, electrical energy is generated by utilizing heat energy.

The thermal energy can be generated by solar thermal or a thermal that is released by objects such as combustion heat in industries or motor vehicles. Several studies have been conducted to obtain electrical energy from thermal resources. Dejan Milenic and his colleagues did the design of geothermal energy sources by utilizing ground water using the principle of heat exchanger [3].

The thermal energy resources widely used by humans is solar thermal. The sun is the largest source of thermal energy that can be utilized. The thermal energy released by the sun does not feel significant because of the distance of the sun away from the earth. However, in certain condition, the thermal that is released in the highest temperature of sunlight can be utilized and turned into a very useful energy resource for human life.

Solar thermal energy generation is carried out by using the thermoelectric principle which directly convert heat into electrical energy called Thermoelectric Generator (TEG). The electricity which is generated by thermoelectric is obtained by temperature difference on the hot and cold side of TEG material through the Seebeck effect and can be seen by analyzing TEG characteristics and performances that are adjusted to the actual environmental conditions.

Some of the characteristics and performance analysis of TEG by directly convert solar thermal energy have been performed by Jeyashree et al [4]. Jeyashree et al analyzed the TEG performance with



different environmental conditions. TEG performance analysis with solar thermal energy can be simulated by using Peltier effect of Thermoelectric Cooler (TEC). Some experiments have been carried out to obtain these characteristics and performances, such as Casano by obtaining the temperature difference of TEC using water as a cooler to produce the output voltage from TEG [5]. Wei-Hsin Chen et al. [6] conducted an analysis by observing temperature differences by water flow on the cold side of the TEG. Hun Sik Han et al. [7] placed a heater on the hot side and placed TEC on the cold side of TEG. This paper presents the testing of the characteristics and performances for TEG to determine temperature difference gradients to generate the output voltage and power. The test is carried out by artificial solar thermal energy using TEC on the hot side and heatsink component with water bath on the cold side of TEG module. The heat transfer from TEC to TEG is a simulation of the solar thermal energy.

2. Thermoelectric Generator

The Thermoelectric Generator (TEG) works like heat exchanger. TEG function is to convert the difference in temperatures between two bodies into electrical current by the Seebeck effect [8]. The Seebeck effect is a function of Ohm's law in which the electromotive force from the temperature difference generates the summation of the electric field and the electromotive force.

$$J = \sigma(E + E_{emf}) \quad (1)$$

where J , σ , E , and E_{emf} are the current density, conductivity, local electric field, and electromotive force, respectively. The electromotive force in the Seebeck effect is the product of the Seebeck coefficient ($S_{seebeck}$) and the temperature (T) gradient [8],

$$E_{emf} = -S_{seebeck} \cdot \nabla T \quad (2)$$

TEGs are solid state heat engines. There are consists of two primary junctions, known as p - and n -type semiconductor materials that is arranged as shown in the figure 1, forming two legs that are joined at one junction by a metal conductor. Materials a and b are now respectively substituted with the p and n -type semiconductors. The p -type semiconductor has a positive Seebeck coefficient α_p , whereas for the n -type semiconductor, the Seebeck coefficient α_n is negative. The overall Seebeck coefficient is defined as below [9]:

$$\alpha_{pn} = \alpha_p - \alpha_n \quad (3)$$

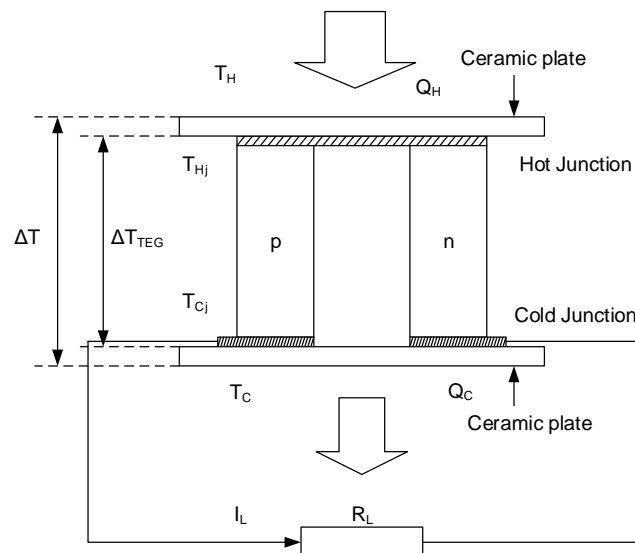


Figure 1. Basic structure of semiconductor thermoelectric couple

The Peltier effect is one of phenomenon which is the opposite of the Seebeck effect. The Peltier effect, occurs when current flows through the junction as shown in the figure 2. Depending on the direction of current flow, heat is either absorbed or dissipated at connection [10]. The rate of the heat, i.e., the power that is exchanged at junction H due to the Peltier effect is

$$Q_H = \alpha_{ab} T_H I \quad (4)$$

where T_H is the absolute temperature of the junction. Assuming a positive sign of I for a current flowing in conductor α from the hot to the cold junction, the signs of Q_H and Q_C are considered positive for a heat flow that enters and leaves the thermoelectric element, respectively [9].

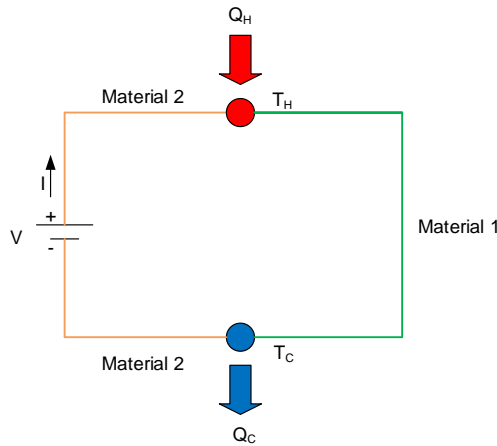


Figure 2. Thermoelectric couple circuit

3. Experimental Setup and Method

The design of the Thermoelectric Generator (TEG) test equipment consists of several TEG modules with internal resistance (R_I) of 5Ω on each TEG, Thermoelectric Cooler (TEC) that is connected to the Pulse Width Modulation (PWM) circuit, heat sinks on the TEG cold surface, several temperature sensors that is connected to the data logger, variable resistor and water bath as shown schematic diagram in the figure 3.

To generate the proposed temperature differences, the hot side is connected to TEC. The output temperature control of TEC is effected by PWM with AC power electronic circuit. The cooling system uses heatsink and water underneath the heatsink. Each hot and cold side of TEG is measured by type K thermocouple to determine the temperature gradient.

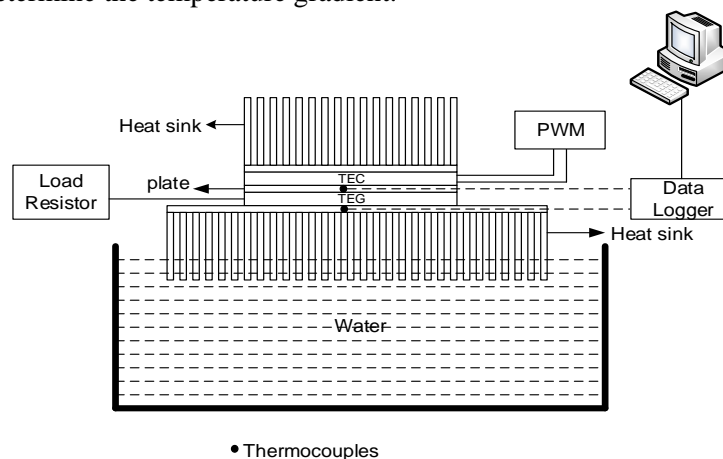


Figure 3. Schematic diagram measurement

The single TEG testing is previously carried out to determine the output voltage. Characterization measurements are only carried out at one TEG by assuming the other TEG generates the equal results. The resistor is applied in circuits to measure the electric current that is generated until the output power in a single TEG can be measured.

The TEG string testing method is carried out by making a series of eight TEGs connected to a resistor. There are two methods that is applied to determine the performance characteristics of TEG string. The first method is to give the same of the temperature differences (ΔT) for each TEG and the second method is to give the different of the temperature differences (ΔT) as an anomaly for the other 2 TEG modules with load resistance (R_L). The schematic of testing a series of eight TEG modules can be shown in the figure 4.

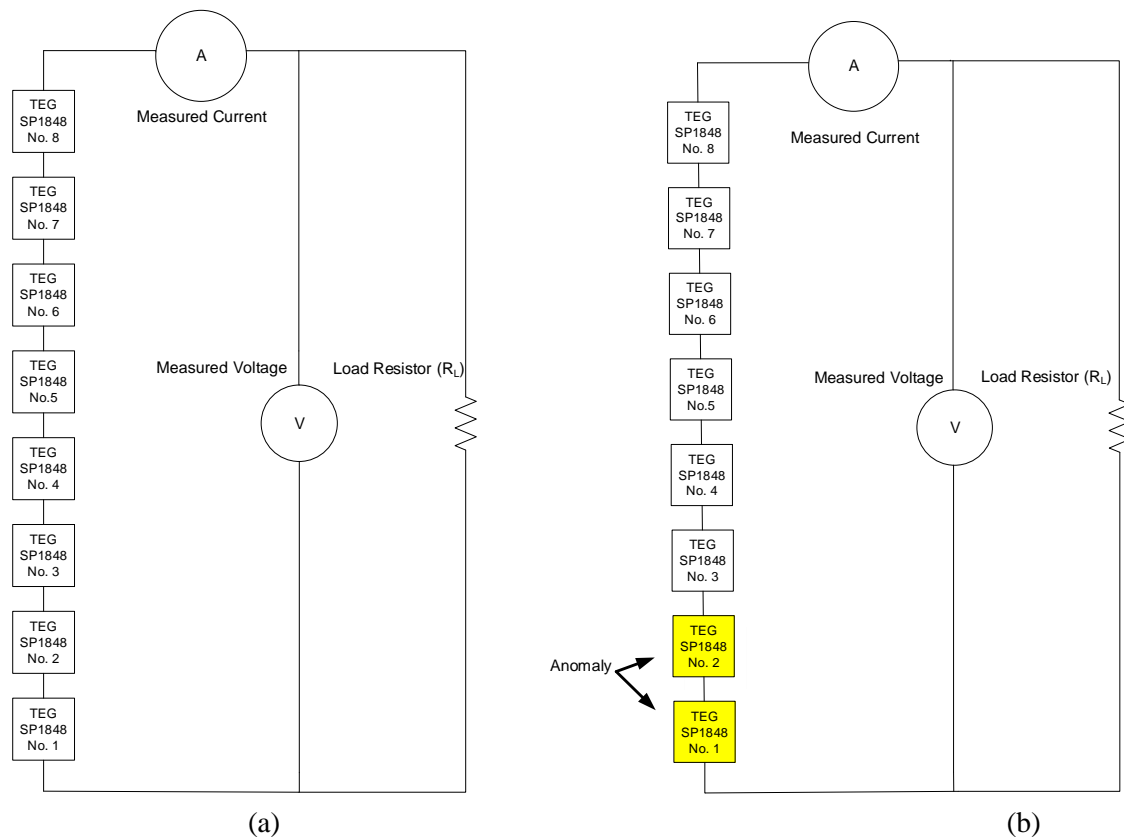


Figure 4. TEG series circuit (a) without anomaly (b) with anomaly

4. Result and Discussion

The first test in this study is the characterization of a single TEG. This is carried out to determine the performance of the TEG that will be used on the TEG string. Before testing, an internal resistance is measured in a single TEG. Based on measurement results, the resistance in one TEG is 5 ohms. Therefore, in a single TEG test a resistance of 5 ohms is given in a closed-circuit. This is performed to determine the power produced by a single TEG. Based on the test, the voltage rises linearly due to the increase of temperature differences as shown in the figure 5. Furthermore, by giving resistance of 5 ohms the output power can be calculated, where the greatest output power is 45.25 mW at ΔT of 46 °C. It appears that the greater ΔT causes the greater output voltage and power. This occurs due to the Seebeck effect on the TEG structure which consists of a composition of n-type elements (material with excess electrons) and p-type (material with lack of electrons) where heat enters on one side and come out from the other side resulting in a voltage passing through thermoelectric connection. If heat enters on one side and has a higher temperature, the electrons have enough energy to move orbits to produce a greater output voltage. It produces the resulting output voltage and power become proportional to the temperature gradient.

In the second test, eight sets of TEG are arranged in series with a resistance of 5 ohms in a closed-circuit. There are two different treatments in the TEG string characterization test. In the first test the

same temperature differences is applied to the eight TEGs. This is performed to determine the output voltage and power by eight TEGs that are arranged in series as shown in the figure 6. Based on the tests, the overall output voltage is different when it is manually calculated in each of TEG output voltage. However, the output voltage and power are still linear to the increase in ΔT and propotional to the temperature gradient.

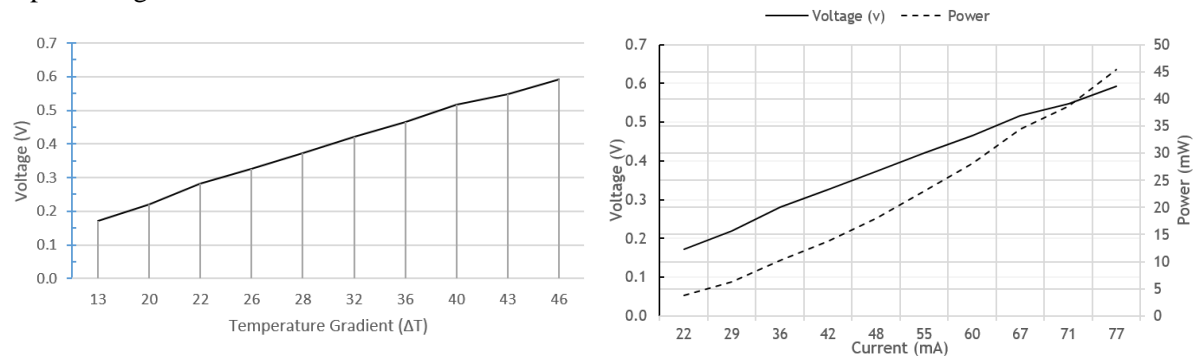


Figure 5. Graph of the correlation between output voltage and output power in single TEG testing

The next test is to give an anomaly to the TEG string. In the figure 4 (b), the testing of the characteristics two TEGs (marked in yellow) at a temperature differences (ΔT) of 10 °C produces an output power of 1.49 mW for each TEG. Similarly, in the other six TEGs with a temperature differences (ΔT) of 35 °C produces an output power of 20.72 mW for each TEG. Because the circuit is series, in calculation, the overall output power is 127.3 mW. The next test is to measure directly the whole series of eight TEGs with two TEGs anomaly produces an overall output power of 112.9 mW. The overall output power by measuring the output power at each TEG is equal to the overall output power of eight series of TEGs when two TEGs are anomaly. Therefore, the two TEGs anomaly in eight TEGs series circuit does not affect the overall output power that is produced in the measurement of each TEG.

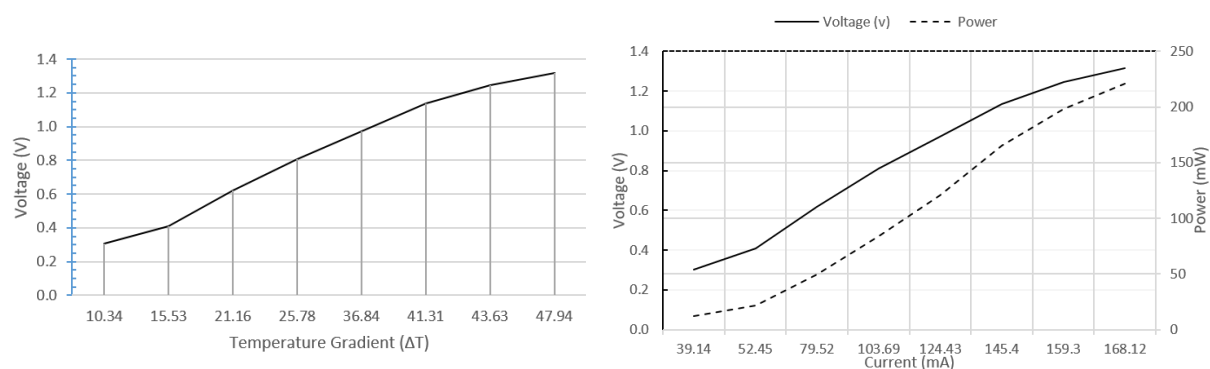


Figure 6. Graph of the correlation between output voltage and output power in string TEG testing

5. Conclusion

In this paper, study on the performance characteristics of Thermoelectric Generator string is presented. It is validated by experimental hardware. This paper is shown that temperature differences affect the output voltage generated by TEG. Characteristics testing using the same temperature gradient (ΔT) at each TEG generates greater output power when ΔT is greater. Appropriate design on hot and cold surfaces of TEG produces an electric power source that can be utilized. However, in multi-TEG testing, if there are anomaly, TEGs that functions are anomaly does not affect other TEGs. It can be proven from the results of experiments and power calculations from each TEG. This is different in solar cell modules where the intensity of sunlight is blocked then it will affect the output power produced.

Acknowledgement

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