Proceedings of the 2nd Faculty of Industrial Technology International Congress
International Conference
Bandung, Indonesia, January 28-30, 2020
ISBN 978-623-7525-37-0

Feasibility Study of Thermoelectric Generator Configuration in Electricity Generation

W. Priharti*, M. Ramdhani, F.R.J. Putra, A. Khansalya
School of Electrical Engineering, Telkom University, Bandung - INDONESIA
* Corresponding author e-mail: wpriharti@telkomuniversity.ac.id

Abstract

Thermoelectric generator (TEG) is a device that can directly convert heat into electrical energy based on temperature gradient. Higher temperature gradient produces higher generated energy. This study aims to analyse three different configurations of TEG in order to obtain an optimum temperature gradient. The configurations were (a) TEG only, (b) TEG attached to heat sink and (c) TEG attached to heat sink and enclosed by ceramic. TEG attached to heat sink was found to be the best configuration with the highest generated voltage and power of 0.35 V and 11.33 mW respectively. Using this configuration to store the energy, the increase of 19% capacity of 3.7 V 200 mAh LiPo battery was obtain within 300 minutes.

Keywords: Waste heat, electricity generation, thermoelectric generator, thermoelectricity.

1. Introduction

The traditional energy which sources from fossil fuels such as petroleum and coal remain a major source of electricity today. However, these sources are currently depleting and have caused several pollution problems. Thus, in the recent years, the alternative and renewable energy has become more attractive for electricity generation due to advantages towards clean environment and sustainability issues (Johar, 2017).

Various renewable energy sources such as solar, wind, hydro energy and biomass can be used to generate electricity in a large scale. Apart from that, there are a lot of research activities in the lower-level electricity generation using different physics phenomenon such as pressure (Liu et al., 2018), vibration (Wei et al., 2017), radio frequency (RF) (Aparicio et al., 2016) and thermal energy (Moreno et al., 2016).

The conversion of thermal energy into electrical energy can be generated by a device called Thermoelectric Generator (TEG). This device utilizes the thermoelectric effect known as Seebeck effect that was first discovered in 1821 by Thomas Johann Seebeck (Enescu, 2019). The effect occurs when a temperature difference across the surface of two conductors producing a voltage V between its open ends. One side of the conductors has the hot temperature T_h and another side has the cold temperature T_c (where $T_h > T_c$). The value of the voltage is proportional to the temperature difference between the two surfaces that can be written as:

$$V = \alpha \, (T_h - T_c) \tag{1}$$

where V is the voltage across the thermoelectric module, α is the Seebeck coefficient, T_h is the temperature at the hot side, and T_c is the temperature at the cold side.

A TEG consists of an array of p and n semiconductors, connected electrically in series and thermally in parallel. These conductors are connected electrically in series to increase the operating voltage and connected thermally in parallel to increase the thermal conductivity. The main characteristics of TEG is the absence of mechanical moving part, small in size, fully scalable, long lived and silent (Ahiska and Mamur, 2014). Recent studies also reported the increasing use of TEG in utilizing waste heat such as in industrial plants, automobile engines, stoves and many others (Zaman et al., 2017, Pohekar et al., 2018). Although the heat produced from waste heat is relatively small, TEG is believed to be an ideal solution in low power applications that have limited electrical grid access and require low maintenance (Dell et al., 2019).

The TEG efficiency η strongly depends on the temperature gradient between the hot and cold side ΔT of the TEG, the thermoelectric figure-of-merit Z_T, and the TEG design (cross-sectional area, length and shape) (Ali et al., 2013). The temperature gradient can be obtained by manipulating the condition of TEG surrounding, for example using cooler to maintain the cold side temperature, enveloping the TEG with an insulator and so on.

This study aims to find the recommended configuration of TEG module to obtain significant temperature gradient. Three configurations will be used and a constant heat will be given. For each case, the performance of TEG will be evaluated.

2. Method

The TEG used in this system was Tegpro TE-MOD-22W7V-56. This TEG could give a maximum of 21.7 Watt output power with 7.2 VDC output voltage. The based material of this TEG was Bismuth Telluride (Bi2Te3) with a dimension of (56 × 56 × 5) mm3. This TEG can operate continuously at 330°C and intermittently up to 400°C. The highly conductive graphite sheets was layered on both sides of the ceramic plates to provide low thermal resistance.

The diagram block of this system is shown in Fig.1. In this figure, the TEG was indicated by asterisk. It means that this study analysed the performance of TEG in three different configurations: (1) basic configuration of TEG (TEG only), (2) TEG attached to heat sink, (3) TEG attached to heat sink and enclosed by ceramic. The figure of these configuration are respectively shown in Fig.2 (a), (b) and (c). The heat sink was attached at the cold side of TEG and used as a passive cooler in order to dissipate heat. All of these configurations were carried out in an open circuit condition (without load).

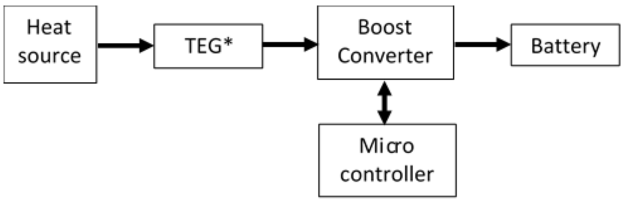

Fig. 1: The block diagram of the system. The asterisk symbol in TEG indicated that the experiment was carried out with three different configurations

A heater with a rating of 12V 3A was used to generate heat source on the hot side. A heater was used due to the easiness in controlling the produce heat for a laboratory environment. The TEG was exposed to a constant heat of 100°C for 60 minutes. The experiment was carried out in a room temperature of 25°C.

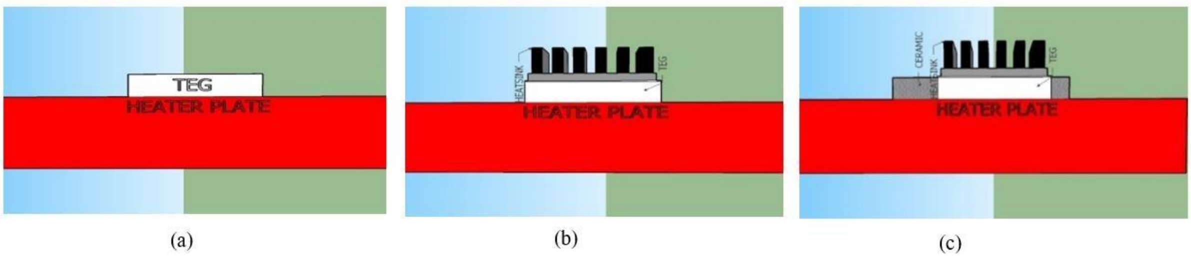

Fig. 2: Three different configuration of TEG used in the study: (a) basic configuration of TEG (TEG only), (b) TEG attached to heat sink, (c) TEG attached to heat sink and enclosed by ceramic

The performance of each configurations was analyzed and the best configuration were selected. The selected configuration was then used to analyses the power storage performance of the TEG. LiPo battery with a rating of 3.7 V 200 mAh (voltage range 3.1 – 4.1 V) was used as the storage. A DC-DC boost converter CE8301 was also used to stabilize and to step-up the output voltage before being storage in the battery. An Arduino Uno ATMEGA328 with 5 V operating voltage was used as the microcontroller to control the operation.

3. **Result and Discussion**

Fig.3 illustrates the variation of voltage and temperature gradient obtained from the heating of TEG for 60 minutes. V_1, V_2 and V_3 indicated the output voltage for configuration: 1) basic configuration of TEG (TEG only), (2) TEG attached to heat sink, (3) TEG attached to heat sink enclosed by ceramic respectively. The same naming will be used throughout this paper for all parameter being studied, i.e. ΔT_1, ΔT_2, ΔT_3, P_1, P_2, P_3 and so on.

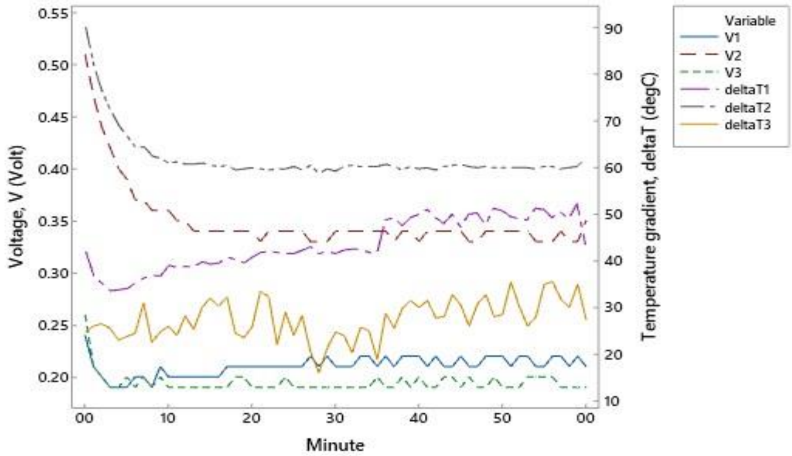

Fig. 3: The relationship between temperature gradient and the voltage generated by TEG

From this figure, it can be clearly seen that the voltage V generated by TEG is exactly proportional to the temperature gradient ΔT between the hot side and the cold side of the TEG. The highest output voltage (=0.51 V) obtain by configuration (2) with a highest temperature gradient (=90.19°C). It can also be observed that this highest output voltage was occurred within the first minute and continue to decrease until it reached an almost constant temperature gradient and output voltage. The fact that this phenomenon occured seem to indicate that the best performance (the highest output voltage) can be obtained by TEG when the system have the largest temperature gradient. This clearly followed the V and ΔT relationship between given by equation (1).

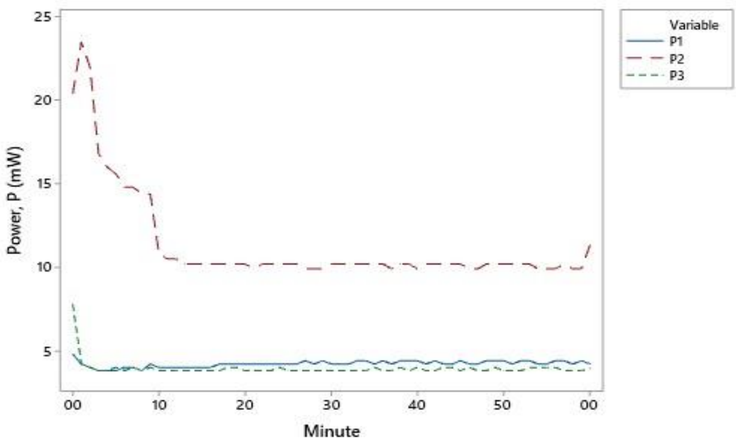

Fig. 4: The output power generated by TEG for three configurations

The output power generated by TEG for three configurations (P_1, P_2 and P_3) is shown in Fig.4. The power P was calculated from the equation of voltage V times current I ($P = V I$). For each configuration, an almost constant current of 0.02 – 0.03 Ampere (20 – 30 mA) was produced. The highest generated power was recorded by configuration (2), followed by configuration (1) and (3). In configuration (2) where heat sink was attached to the cold side of TEG, the temperature gradient seems to be larger since the heat sink could act as the passive cooler.

However, the same phenomenon was not occurred in configuration (3) that was also attached with heat sink but with enclosed ceramic. The ceramic that originally planned as the additional cooler was actually trapped heat in the TEG. This trapped heat not only increase the temperature on the hot side but also on the cold side of the TEG. The results of this eventually yielding a lower temperature gradient thus lower generated power. The make the performance analysis of the tree configuration of TEG easier, the mean value of voltage, current and power generated by each configuration are concluded in Table 1.

Table 1: The mean value of voltage, current and power generated by TEG using three different configurations

Parameter	**(1)[a]**	**(2)[b]**	**(3)[c]**
Voltage (V)	0.21	0.35	0.19
Current (A)	0.02	0.03	0.02
Power (mW)	4.21	11.33	3.93

[a] Basic configuration of TEG (TEG only); [b] TEG attached to heat sink; [c] TEG attached to heat sink and enclosed by ceramic

Table 1 is clearly shown the best performance of TEG with number (2) configurati0n i.e TEG attached to heat sink with a generated voltage and power of 0.35 V and 11.33 mW respectively. Using the best configuration, an effort to store the generated power using a 3.7 V 200 mAh LiPo battery with a DC-DC boost converter was attempted. It was found that the initial voltage of the battery at minute 0 was 3.16 V (6% capacity) and the charging was started at minute 7 with an increase of 0.02 V (as shown in Fig. 5). The voltage was gradually increase and reach a voltage of 3.36 V (25% capacity) at minute 300. From this test, it was found that the stored power of a single TEG is low with only 19% increase of battery capacity within 300 minutes (5 hours). Several TEG connected in series and parallel could be used to maximise the generated voltage as well as the generated current.

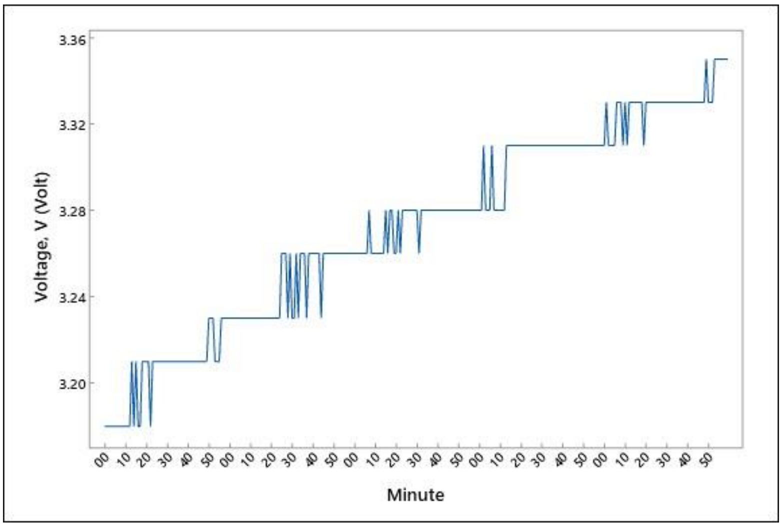

Fig. 5: The increase of TEG generated voltage stored in the battery

4. Conclusion

Feasibility study on the generation of electricity from heat was carried out using a single TEG. Three configurations of TEG were used and the configuration that given the best performance was selected i.e. TEG attached to heat sink. This configuration was used to store the power generated by TEG and the increase of 19% capacity of 3.7 V 200 mAh LiPo battery was obtain within 300 minutes. The used of several TEG connected in series and parallel are proposed in the next study to maximize the generated voltage and current.

5. Nomenclature

I	Current	A	T	Temperature	°C
V	Voltage	V	α	Seebeck's coefficient	V/°C
P	Power	W	ΔT	Temperature gradient	°C

6. Acknowledgements

The authors wish to thank Direktorat Penelitian dan Pengabdian Masyarakat (PPM) Telkom University for the financial support to attend this conference.

7. References

Ahıska, R and Mamur, H. 2014. A Review: Thermoelectric Generators In Renewable Energy. International Journal Of Renewable Energy Research, 4, 128-136.

Ali, H., Sahin, A.Z. and Yilbas, B.S. 2014. Thermodynamic Analysis of A Thermoelectric Power Generator Inrelation to Geometric Configuration Device Pins. Energy Conversion and Management, 78, 634-640.

Aparicio, M.P., Bakkali, A. Sebastian, T., Sogorb, V. and Bou, A. 2016. Radio Frequency Energy Harvesting - Sources and Techniques, 155-169. http://dx.doi.org/10.5772/61722.

Dell, R., Petralia, M.T., Pokharel, A. and Unnthorsson, R. 2019. Thermoelectric Generator Using Passive Cooling, 1-37. http://dx.doi.org/10.5772/intechopen.85559

Enescu, D. 2019. Thermoelectric Energy Harvesting: Basic Principles and Applications, 1-37. http://dx.doi.org/10.5772/ intechopen.83495.

Johar, M. A. 2017. Feasibility Study of Thermal Electric Generator Configurations as Renewable Energy Sources. Journal of Physics: Conference Series, 914, 123-135.

Liu, H., Zhong, C., Lee, S.W. and Lin, L. 2018. A Comprehensive Review on Piezoelectric Energy Harvesting Technology: Materials, Mechanisms, and Applications. Applied Physics Reviews. https://doi.org/10.1063/1.5074184.

Moreno, R.J., Grbovic, D. and Pollman, A. 2016. Harvesting Waste Thermal Energy From Military Systems. Proc. of the ASME 2018 Power and Energy Conference, 1-6, June 2016.

Pohekar, P., Alaspure, P., Punase, P. and Tikhe, S.G. 2018. Automotive Waste Heat Harvesting for Electricity Generation using Thermoelectric Generator A Review. International Research Journal of Engineering and Technology, 5, 477-481.

Wei, C. and Jing, X. 2017. A Comprehensive Review on Vibration Energy Harvesting: Modelling and Realization, Renewable and Sustainable Energy Reviews, 74, 1-18.

Zaman, H. Shourov, C., Mahmood, A. and Siddique, N.A. 2017. Conversion of Wasted Heat Energy into Electrical Energy Using TEG. IEEE, 1-5.