REKAYASA 18 (1) (2020): 24-29

REKAYASA
Jurnal Penerapan Teknologi dan Pembelajaran

https://journal.unnes.ac.id/nju/index.php/rekayasa

Thermoelectric Generator Module as An Alternative Source of Electrical Energy in Rural Areas

Artoto Arkundato[1], Misto[2], Gaguk Jatisukamto[3], Wenny Maulina[4], Khalif Ardian Syah[5]

[1,2,4]Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Jember
[3]Department of Mechanical Engineering, Faculty of Engineering, Universitas Jember
[5]Department of Electrical Engineering, Faculty of Engineering, University Jember

Email: a.arkundato@unej.ac.id[1]

DOI: http://dx.doi.org/10.15294/rekayasa.v8i1.23691
Received : March 2020; Accepted: June 2020; Published: July 2020

Abstract

It has been done a research to design a heat-to-electric converter as an alternative electrical energy source based on the thermoelectric generator devices that can convert the heat into the DC electricity. This research aims to determine the optimal operating temperature range to produce the thermoelectric generator's output voltage as the desired conversion module. The developed conversion module uses the Seebeck effect by applying four thermoelectric generators arranged in an electrical circuit series. The electric current in thermoelectric generator occurs under the Seebeck effect due to the temperature difference between the two metal chips in the thermoelectric generator module. Candles were used as a heat source of thermoelectric generator module, while water is used for cooling. The results showed that the application of thermoelectric generator technology had produced an electrical voltage of about 5 volts. The thermoelectric generator's operating temperature around 100 ºC, and the temperature of the water cooling medium was maintained at around 30 ºC so that there is a correlation with a temperature difference of about 70 ºC between the two sides of the thermoelectric generator chips. The electrical voltage that occurs could be used as a source of electrical energy for any purposes.

Keywords: thermoelectric generator; seebeck effect; heat-electric conversion; different temperature

INTRODUCTION

One of the most important energy sources needed for supporting human daily needs is electrical energy. However, this energy is sometimes challenging to obtain, especially in rural areas. Remote rural areas and mountains are often unspoiled by electricity so that some activities are hampered because communication via cell phones requires electricity to turn on, for example. Electrical difficulties must be resolved immediately because without electricity, progress will be hampered, and residents and visitors cannot carry out activities and communicate.

Energy from general energy sources, namely solar power, wind, sea wave can be converted into electrical energy. We can convert heat energy from many sources (fire, solar, etc) to electrical energy by using thermoelectric energy technology, taking advantage of the Seebeck effect. This effect explains the direct conversion of temperature gradients (temperature differences) into electrical energy by using the thermoelectric generator device at the thermoelectric element's junction. This highly reliable energy converter can generate electricity in applications where electrical source is lost. Besides, thermoelectric energy devices are quite efficient as they convert waste heat in micro-scale applications. Potential thermoelectric generator applications as an applied energy technology are already being used in medical devices, sensors, buildings, and consumer electronics for low-power applications, incredibly remote areas.

Suger Kidul village, district of Jelbuk, city of Jember, is a remote village inhabited by a blacksmith whose products consist of several tools such as hoes, machetes, etc. Blacksmiths use quenching and heating processes in doing their jobs (Arkundato et al., 2019). In this process, the charcoal's heat is used to soften the steel before being hammered. The heat generated in this process reaches 1000 °C and more.

Based on the previous observations in a blacksmith's work area, not all of the heat generated from burning charcoal in a furnace can be used for efficient work. Only a certain amount of heat can be used up by forged steel. Large be enough heat from the fire is wasted into the environment. This was possible because the stove design is an open stove type. This open stove design is cheap and easy to manufacture. As a result, heat tools are wasted during the manufacturing process, even though a blacksmith should be able to generate electricity from the waste heat by using a thermoelectric generator (TEG) applied technology.

Based on the above background, many workers use fire to do work, but residents also need an alternative source of electrical energy in Sugerkidul Jelbuk Village. Residents can develop a converter of heat energy into electrical energy as an applied technology based on TEG from wasted heat or not hitting heat targets.

The specific method that can be applied through the Seebeck effect has generated electricity through the TEG component based on the difference in temperature generated between the two sides of the TEG chip. The optimum value must be sought for this temperature difference to obtain the output voltage for the conversion module to be designed. A significant problem and a solution must be sought to determine the temperature at which the designed device can generate sufficient voltage for storage and later use. Suppose the operating module temperature is too high. In that case, the TEG component can be damaged, on the other hand, if it is too low, the resulting power output voltage is too small, and the tool becomes inefficient.

A heat to electricity conversion modules modified by understanding the basic principles of TEG-based conversion design. The mechanical design can be module dimensions or module models. If the module's placement is not correct, it will not result in maximum conversion, even if it can produce electrical energy. A researcher have worked on the use of stove-powered TEG at a temperature difference of 148°C, which can supply clean and warm air (625 W) and electricity 8.25 W at 5 V (Zheng et al., 2018).

Heat energy can also be taken from the motor's exhaust temperature at stable condition at a particular voltage using the TEG application test (Shena et al., 2019). In other event, the exhaust temperature is used for automotive generator systems by restoring exhaust gas energy flow using 24 commercial thermoelectric modules (Ziolkowski, 2017). TEG Small Modular with 2 Peltier Bi_2Te_3 (Bismuth Telluride) modules is also created to produce 3.01 Volts with a temperature difference of 22.7 °C to produce 0.091 Watt of power (Mahmud et al., 2017). Thermoelectric generator prototypes can also use aluminum heat sinks, and thermo-electric cooler ICs (Peltier devices) used as generators (David, 2017).

In this research, the idea is to generate stored energy used in various applications such as the power and recharge mobile devices. It requires creativity in designing the heat to electricity conversion module based on the TEG electronic device. The heat used as the primary energy source is converted from the candle flame, but it can also be from charcoal or bio briquettes. The Seebeck effect is the resulting open-circuit voltage between two points on a conductor where a uniform temperature difference of 1K. This movement produces a more negative charge in the colder part than the warmer part, thereby generating an electric potential. If this pair is connected via an electric circuit, it will produce a DC power plant. However, the resulting voltage is relatively small in micro volt units (10^{-6}). Parallel connected systems increase the maximum output current. Increasing the voltage can be done by connecting the series to increase the voltage (Wang et al., 2013). In both systems, the output current and voltage are in a linear relationship. A sufficiently large and stable temperature difference must be maintained to produce the desired output voltage. The TEG is applied in Suger kidul village, Jelbuk sub-district, Jember district, East Java province by creating a simple module of application technology for electricity generation and applying it.

METHOD

Research procedures to carry out this research are design, manufacture, and testing of modules, testing, and implementation of module design.

Design and manufacture of conversion modules

The manufacture of the conversion module could be separated into two module designs, namely mechanical and electrical. The appliance's mechanical design was related to the shape of the furnace or the module's heat source chamber, the placement of the thermoelectric generator (which can absorb heat well to generate electricity), and the cooling system of the thermoelectric generator. Electrical design was an electronic circuit so that the module could conduct electricity as desired. The Conversion module's mechanical design was shown in Figure 1 for converting 4 TEG modules that use temperature differences in cold water storage and hot rooms.

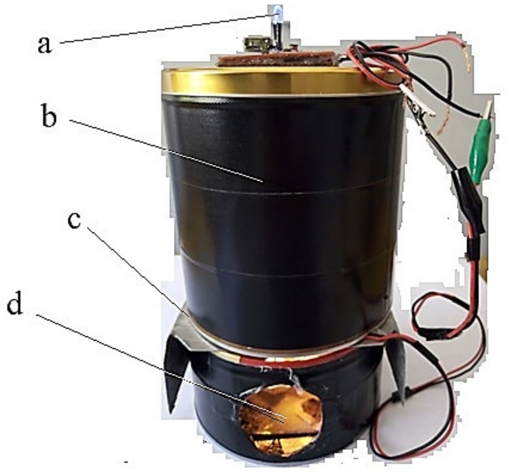

Figure 1. Mechanical design of the conversion module, a. LED, b. Cooling water storage, c TEG components, d. Heater chamber

In this conversion module, 4 TEG components were arranged in series, as shown in Figure 2, which were placed between (sandwiched and attached) to the water cooling room and the heating room. The amount of TEG required could be adjusted as needed. The materials used are four pieces of TEG type SP1848. Using aluminum plates 1-2 mm thick (where the TEG will be attached), LEDs, power bank, water cans for storing cooling water, cans for heating rooms, electrical cables, silicon for security, cables, PCBs, USB modules, heat sources in the form of candles, power cables, and coolers.

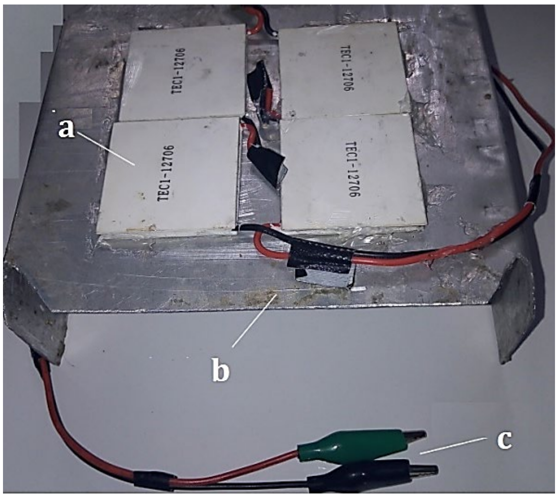

Figure 2. Series circuit electrical design a. TEG, b. Aluminum plate, c. Electrical output cable

Testing

In this research, it must be found at what temperature the conversion module can produce sufficient voltage to be stored to indicate the converted electric current's presence. An LED light will light up when there is a DC electric current. The electric current resulting from heat conversion is then stored in the power bank. To determine the relationship between the generated voltage and the temperature on the TEG chip's hot side, an Infrared laser thermometer (Figure 3) is used to measure high temperatures, even up to 1500 ºC. Measurement of the output voltage using a digital voltmeter, as shown in Figure 4.

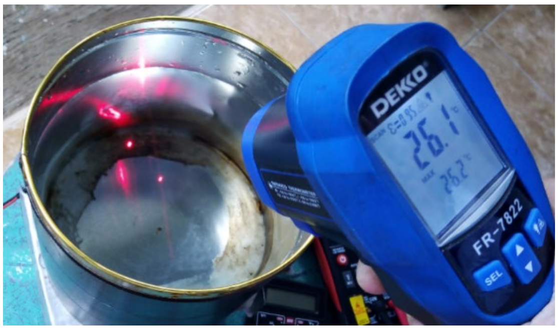

Figure 3. Temperature measurement using the infrared laser on the cold side of the TEG

Figure 4. Measurement of the TEG output voltage

Implementation of Module Design

The aluminum plate with a thickness, area, and a specific shape is adapted to the cooling container used to accommodate 4 TEG, as in Figure 5, which holds heat from a heat source (wax) and is spread evenly on the hot side of the TEG chip (the side without product serial number). The aluminum plate on the side that is not TEG affixed will be positioned facing heat or receiving heat from the heat source. On the TEG chip (cold side, there is a product serial number) that does not stick to the aluminum plate, it will stick directly to the cooling water storage. Between the two sides of the TEG should not be in direct contact with heat conduction, for that the side was isolated with silicon paste. When the hot side of the TEG receives heat, there must be a sufficient temperature difference for heat conversion to electricity based on the Seebeck effect. This temperature difference range can see the specifications of the TEG components purchased/provided. In this module, the temperature difference of 50 - 70 °C has generated quite good electricity. This temperature difference must be kept constant and within the tolerance range according to the recommended specifications so that the components are not damaged and can generate electricity continuously. If the cooling water is too hot, to maintain temperature stability, immediately replace it with new cold water.

If the water starts to get warm or hot enough, the LED indicator light will appear to dim until then die when the temperature is too hot. In this case, it means that the temperature difference ΔT is too small or even zero so that the Seebeck effect, which generates an electric current, does not occur again.

The melting point of aluminum is around 660.32 °C, and the maximum temperature of TEG is also noteworthy. Therefore, the temperature of the aluminum chips adhering to the TEG's hot side is not exceeding the maximum recommended limit.

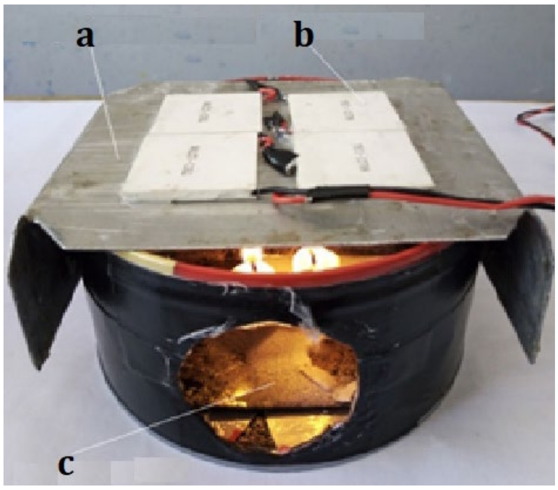

Figure 5. Series of TEG and heating room a. Aluminum Plate, b. TEG, and c. Heater chamber

The volume of cooling water required is adjusted to the needs. It is urgent to keep the temperature difference constant to produce the output voltage at an absolute value. The main thing is not the coolant volume or the type of coolant, but the main thing is maintaining the temperature difference between the two sides of the TEG chip. The resulting voltage should be greater than 4.5 V. Furthermore, the electricity from the temperature difference conversion is stored in the power bank. For that, we need a USB module, as in Figure 6.

Figure 6. USB module for power bank connection

Table 1. The relationship between temperature and output voltage

No.	Temperatur (^oC) TEG			Output voltage (± 0.02 volt)
	hot side (± 0.9 ºC)	cold side (± 0.9 ºC)	ΔT	
1	44.7	29.0	18.00	2.84
2	64.4	29.2	35.20	2.87
3	77.5	30.1	47.40	4.39
4	86.7	30.6	56.10	4.60
5	102.5	31.6	70.90	5.50

RESULT AND DISCUSSION

In the TEG study with a module that uses different cooling water temperatures and wax heating results, observations have been made. The output voltage data is taken along with the temperature shown in Table 1. The resulting heat temperature reaches 102.5 ^oC while the lowest temperature is 29 ^oC, but the hot side rises, then the cold side rises too. In the pair, the maximum temperature and voltage were 102.5, with the cold side temperature of 31.6 ^oC. The voltage reached around 4 V occurs at a temperature of 77.5 ^oC. At a temperature difference of 56 ºC to 71 ºC, the conversion module could supply an electrical voltage between 4.6 to 5.5 volts. Therefore, the prototype conversion module can be operated at a TEG hot-side temperature of around 100 ºC with water cooling media, which is maintained at a temperature of about 30 ºC to be able to produce an electric voltage of about 5 (even more) volts at a temperature difference of about 70 ºC. A heating source formed a burning candle with a temperature difference of 68 ^oC. They resulted in a voltage 4V and 2A with one candle (Palanisamy and Kumar, 2017).

The electricity from the temperature difference conversion is stored in a power bank, so a USB module is required. This is similar to the schematic design for a harvesting system using energy from a thermoelectric generator bank. This energy is generated from the TEG module to charge the battery (power) bank using constant current and constant voltage charging (Dalala et al., 2019). The energy generated used to power cellular devices, especially cell phones, has made use of the design of TEG, uses the temperature difference that exists among the TEG interfaces. The temperature different can be implemented by using a burning candle to reach more than 85 ^oC and produce a minimum temperature difference of 50 ^oC and produce a minimum voltage of 4.5 volts.

CONCLUSION

The TEG conversion module that uses cooling water and candle flame as a heating source can be operated at a TEG hot-side temperature of around 100 ºC with water cooling media maintained at around 30ºC to produce an electric voltage of about 5 volts with a temperature difference of about 70 ºC on both sides. The performance of this conversion module can be used comprehensively to charge a power bank. It can be used to power communication devices (cell phones) by converting candles› temperature and cooling water.

ACKNOWLEDGEMENT

Gratitude goes to DRPM DIKTI of the Republic of Indonesia and the University of Jember for the 2019 PKM Community Service Grant. Thanks were also given to Mr. Abdullah, a blacksmith craftsman in Suger kidul village, Jelbuk sub-district, Jember Regency, for his availability as a training ground for community service activities.

REFERENCES

Arkundato, A., Misto, M., Paramu, H., Jatisukamto, G., & Sugihartono, I. (2019). Heating and Quenching Procedure on The Making of Traditional Blacksmith Steel With High Quality. *Spektra: Jurnal Fisika dan Aplikasinya*, 4(1), 39-50.

David, A. P. J. (2017). Thermoelectric generator: mobile device charger. In *8th CEBU International Conference on "Recent Trends in Engineering and Technology* (pp. 7-11).

Dalala, Z. M., Hamdan, Z. S., Al-Taani, H., Al-Addous, M., & Albatayneh, A. (2019). Battery Charging Application with Thermoelectric Generators as Energy Harvesters. *The Academic Research Community publication, 3*(1), 248-259.

Magwili, G. V., Bulaong, M. L. D., Macose, A. M. P., & Rodriguez, P. S. B. (2018, December). Thermos design and assembly for conversion of heat to electrical energy based from the principle of seebeck effect using thermoelectric generator and temperature difference of liquids. In *AIP Conference Proceedings* (Vol. 2045, No. 1, p. 020057). AIP Publishing LLC.

Mahmud, K. H., Yudistirani, S. A., & Ramadhan, A. I. (2017). Analysis of power characteristics of model thermoelectric generator (TEG) small modular. *International Journal of Scientific & Technology Research, 6*(4), 161-167.

Palanisamy, R. & Kumar, S. S. (2017). Thermoelectric Fan and Ice Chest Powered by Candle. *International Journal of Mechanical Engineering and Technology. 8*(3), 400–408.

Shen, Z. G., Tian, L. L., & Liu, X. (2019). Automotive exhaust thermoelectric generators: Current status, challenges and future prospects. *Energy Conversion and Management, 195*, 1138-1173.

Wang, Y. T., Liu, W., Fan, A. W., & Li, P. (2013). Performance comparison between series-connected and parallel-connected thermoelectric generator systems. In *Applied Mechanics and Materials* (Vol. 325, pp. 327-331). Trans Tech Publications Ltd.

Zheng, Y., Hu, J., Li, G., Zhu, L., & Guo, W. (2018). Testing and Optimizing a Stove-Powered *Thermoelectric Generator with Fan Cooling. Materials, 11*(6), 966.

Ziolkowski, A. (2017). Automotive Thermoelectric Generator impact on the efficiency of a drive system with a combustion engine. In *MATEC Web of Conferences* (Vol. 118, p. 00024). EDP Sciences.