Analysis Of Power Characteristics Of Model Thermoelectric Generator (TEG) Small Modular

Kisman H. Mahmud, Sri Anastasia Yudistirani, Anwar Ilmar Ramadhan

Abstract: Thermoelectrically Generator (TEG) can generate electricity from the temperature difference between hot and cold, at the junction thermoelectric module with two different semiconductor materials, there will be a flow of current through the junction so as to produce a voltage. This principle uses the Seebeck effect thermoelectric generator as a base. By using these principles, this research was conducted to determine the potential of the electric energy of the two peltier modules which would be an alternative source for mobile charger using heat from source of methylated. The focus in this research is the testing of the model TEG (Thermoelectric Generator) Small Modular to generate power with a variety of different materials of 4, namely: Bi_2Te_3 (Bismuth Telluride), PbTe-Bite, CMO and CMO Cascade-32-62S-32-62S [Calcium Mangan oxide], to use the cold side heat sink and a fan to simulate heat aluminum plate attached to the hot side of the TEG modules with heat source of methylated. Test results on the TEG Small Modular Model for mobile charger output voltage obtained from 2 pieces Bi_2Te_3 module (Bismuth Telluride) Peltier strung together a series of 3.01 Volt, with ΔT of 22.7 ° C which produce power of 0.091 Watt.

Index Terms: Thermoelectric generators, TEG Material, Thermoelectric Cooling, Semiconductor, Experimental

1 INTRODUCTION

In 2020 an estimated energy needs will increase by around 40% from current needs. Thermoelectrically technology is a major alternative source of energy in addressing the needs. Thermoelectrically can produce heat or cold. Thin shape, measuring 4 x 4 cm with a thickness of only 4 mm. Thermoelectrically generally wrapped by a thin ceramic rods containing bismuth telluride therein when fed a DC voltage of 12 volts to one side will be hot, while the other side gets cold. To be able to work optimally should be at thermoelectrically 5-7 Ampere. How it works thermoelectrically, by making the heat on one side, then on the other hand, the heat will be absorbed until cold. Temperature difference between the hot and cold sides can reach 65 ° C. Thermoelectrically code printed on it, there are numbers 12 706, which means that the input voltage of 12 volts, the current optimal requested 6 amperes [1-2]. One obstacle facing Indonesia today is the imbalance between the power consumption requirements of customers compared with PLN's ability to provide electrical energy. So also on the issue of the depletion of oil reserves. As we know that fuel to produce electric energy sources derived from fossil energy sources such as coal and other fossil fuels. Fossil energy sources alone can be discharged at any time if the user is done continuously. To resolve the matter, PLN conduct electrical energy savings to consumers by seeking alternative energy sources to improve the efficiency of existing energy sources. In everyday life are common sources of thermal energy that is derived from various sources. The heat source can be derived from the Sun, fuel, food, friction, candles, gas stoves and others.

- *Kisman H. Mahmud, Sri Anastasia Yudistirani, Anwar Ilmar Ramadhan*
- *Department of Informatics Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta*
- *Department of Chemical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta*
- *Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta*
- *Email: anwar.ilmar@umj.ac.id*

Thermoelectric generation is a module that can generate electricity by harnessing the thermal energy source. Thermoelectric plants are environmentally friendly because it does not cause pollution [3-5]. Waste heat engine Toyota 4k types Based on the results of the eighth series of thermoelectric modules produced electric voltage 6.6 [Volt Ampere] with one electric current but having applied for electrolysis, the voltage to 2.5 [V] with an electric current of 0.1. The electric power applied to 6.6 watts and after application in electrolysis becomes 0.22 [W]. The use of fuel in 50 minutes without fuel electrolysis is 910 milliliters. Means within 50 minutes by using electrolysis we can save fuel 130 milliliter [6]. The experimental study conducted to test this prototype utilizing the waste heat energy from the condenser, the power supply voltage output by 3.14 [V] obtained from the input of heat energy that goes into an air duct with an average temperature of 34 [°C]. Then the heat energy flowing on the airways interact with thermoelectric modules, so that the temperature remains cool, then by the fan. The obstacles in the thermoelectric of 60 [Ω]. In the experimental apparatus at 0.16 [W] obtained [4]. The experimental research to obtain characterization of thermoelectric generator with twelve thermoelectric modules mounted around the sides of the heater generate power output of thermoelectric plants is about 8 [W]. Waste heat source was simulated using the heater / heater that varied the voltage, which is 110 [V] and 220 [V]. The test results showed that with twelve partier elements arranged in series with the heater voltage 220 [V], can produce a maximum output power 8.11 [W] with an average temperature difference of 42.82 [°C] [7]. In this research will be testing the model Thermoelectric Generator (TEG) mini helpless. Testing was done by varying the composition of different peltier, the series and parallel. Waste heat source was simulated using the heater that varied the voltage.

2 LITERATURE STUDY

2.1 Thermoelectric Effect

There are three main effects occurring in the thermocouple circuit that Seebeck, Peltier and Thomson. Seebeck effect describes the voltage or electrical force (electromotive force / EMF) caused by the temperature difference (gradient) along the wire. Changes in the EMF material in connection with the change in temperature is called the Seebeck coefficient or thermoelectric sensitivity. This coefficient nonliniar usually a function of temperature. Peltier effect explains the temperature difference generated by EMF and is the inverse of the Seebeck effect. Meanwhile, Thomson effects associated with reversible thermal gradients and EMF in a homogeneous conductor.

2.2 Seebeck Effect

Seebeck effect is the change directly from the difference in temperature to the power and takes the name of the German physicist - Estonia, Thomas Johann Seebeck, who in 1821 discovered that a compass needle would be deflected by the closed loop formed by the combination of two metals in two places, the temperature difference between junctions. This is due to the response of different metals - depending on the temperature difference, causing loop currents and magnetic fields. Seebeck did not realize there are electric currents involved, then he calls this phenomenon the thermomagnetic effects. The Danish physicist Hans Christian Orsted correct errors and coined the term thermoelectric. The voltage produced by this effect in the order of μV / K. One example of a combination of copper and nickel has a Seebeck coefficient of 41 μV / K at room temperature. The voltage generated at Seebeck phenomenon proportional to the temperature difference between the two junctions. The greater the temperature difference, the greater the voltage between junction. From this phenomenon, we can determine the Seebeck coefficient, equation (1):

$$S = -\frac{\Delta V}{\Delta T} = -\frac{Vhot - Vcold}{Thot - Tcold} \qquad (1)$$

S = Seebeck Coefficient
ΔV = Difference Voltage
ΔT = Difference Temperature
V_{hot} = the voltage at the hot junction
V_{cold} = the voltage at the cold junction
T_{hot} = the temperature at the hot junction
T_{cold} = the temperature at the cold junction

2.3 Peltier Effect

The discovery of the Seebeck inspires Jean Charles Peltier to see the opposite of the phenomenon. He is an electric discharge on two pieces of metal that are glued in a circuit. When electric current is applied, heat absorption occurs at the junction of the two metals and the release of heat on the other connection. Release and heat absorption are mutually turned so the current direction is reversed. The discovery occurred in 1934 which was then known as the Peltier effect, as shown in Figure 1.

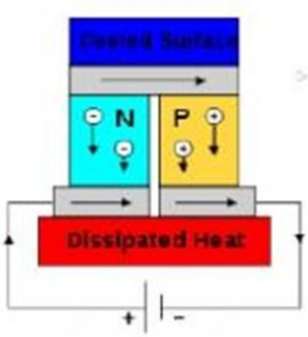

Figure 1. *Schematic illustration of the Peltier effect [8]*

Peltier effect heat generated in each metal calculated per unit of time with the equation (2):

$$Q = (\Pi_A - \Pi_B)\, I \qquad (2)$$

Where: Π_A (Π_B) is the Peltier coefficient of conductor A (B), and I is the electric current from A to B. The heat generated in the joint is not only determined by the Peltier effect, but is also influenced by the effects of Joule heating and thermal gradients. Peltier coefficients represent how much heat is generated per unit charge.

2.3 Module Termoelectric

Thermoelectric Modules (also called Seebeck generator) is a tool that can convert heat (the temperature difference) into electrical energy directly. Efficiencies range between 5-8%. Its construction consists of pairs of p-type semiconductor material and n-type thermocouples formed that has a shape like a sandwich between two thin ceramic wafers. This module can be used to produce heat and cold on each side if the electric current is used. Initially the device is designed to use bimetallic connection and great in size. In development at this time, the device is designed to use the p-n connection made of Bi2Te3 (Bismuth Telluride), lead telluride (PbTe), calcium manganese oxide, or a combination another, depending on the temperature, as shown in Figure 2.

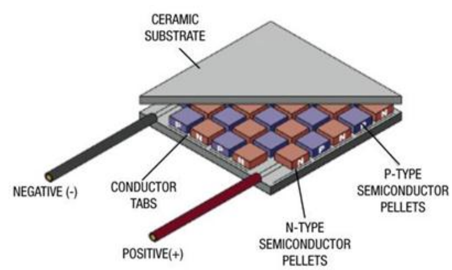

Figure 2. *Construction thermoelectric modules [9]*

Thermoelectric generator can be used for various purposes, among others:

a. Power generation (power generation). Some power plants are already using a method known as cogeneration where in addition to the electric power generated, the thermoelectric heat generated during this process is converted into electrical energy so that the heat produced is not wasted in vain and the energy generated power plants become more great, as well as energy efficiency becomes higher.
b. On space exploration missions such as space probes, including a robotic Mars rover, thermoelectric generators used as power plants where the heat gained comes from radioactive elements.
c. Automotive thermoelectric generators, vehicle exhaust waste heat can be converted into electrical energy and is used to improve fuel efficiency in vehicles.
d. Thermionic converter. The power plant with a thermionic works by converting heat energy into electrical energy using thermionic emission.

In addition to the above uses, there are many uses of a thermoelectric generator. Nowadays, many companies began researching the use of thermoelectric generators to utilize waste heat from industrial processes. But in development at this time, there are still shortcomings in the use of thermoelectric generators such as high output resistance and thermal characteristics of the material. Good thermoelectric materials should have the following characteristics:

a. High electrical conductivity to minimize joule heating (rising temperature of the barriers to electric current flowing through).
b. Seebeck coefficient which is great for the maximum change from heat to electric power or electric power to the cooling performance.
c. The low thermal conductivity to prevent the conduction of heat through the material.

All three of these properties are usually combined into a single parameter that measures the overall performance of a thermoelectric device that is "figure -of - merit" or ZT. Figure - of - merit of thermoelectric defined in equation (3):

$$Z = \frac{\alpha^2 \sigma}{\lambda} \qquad (3)$$

Where:

α : Coefficient *Seebeck* of material [V/K]
σ : Electrical conductivity of material [A/Vm]
λ : Heat conductivity of material [W/m.K]

Because Z has units per degree of temperature, more useful dimension figure - of - merit can be defined as Z * T, where T is the average - average working temperature. This important parameter determining the maximum efficiency of power changes or maximum cooling coefficient of performance for thermoelectric devices. Preliminary research of thermoelectric materials in the 1950s and 1960s - early produce Bi2Te3 (Bismuth Telluride), Lead Telluride (PbTe) and alloy Silicon - Germanium (SiGe) as a material with a figure - of - merit the best in three slightly different temperature ranges. Bi2Te3 (Bismuth Telluride), and mixtures thereof have been used extensively in applications of thermoelectric cooling and some low power applications and has a useful temperature range from 180 K to 450 K. PbTe and SiGe material has been used extensively in power plant applications temperatures high, especially power generation spacecraft and has a useful temperature range of each - each from 500 K to 900 K and 800 K to 1300 K [Figure 3].

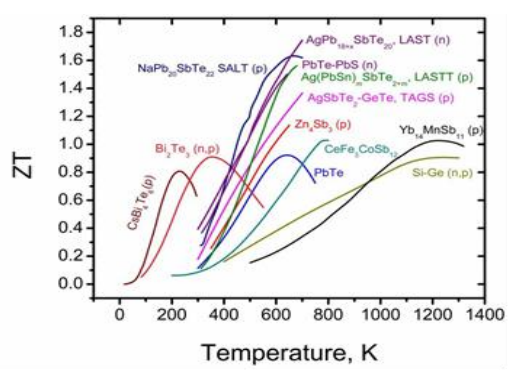

Figure 3. *Graph of ZT value of the variation of thermoelectric materials [10]*

It is important to note that all the thermoelectric device is highly dependent on temperature, temperature gradient is not only work, but also tilapia absolute temperature. Thermoelectric devices can be used to generate electrical energy direct current (DC) when the temperature difference. However, currently available thermoelectric materials have ZT <1 and the efficiency of the device to generate electrical energy rarely exceed 5%. This limits the performance of thermoelectric generators for applications where the requirements for remote operation, test stand, there are no moving parts and no noise has exceeded aspects worse than the expensive cost and low conversion efficiency. This tends to limit the application of thermoelectric technology for small cooling systems, low power, or special cooling or power applications. These systems generally require power or a small flow of heat energy. Maximum efficiency of thermoelectric devices in power plants is determined by equation (4):

$$\eta_{max} = \left[\frac{T_h - T_c}{T_h}\right]\left[\frac{\sqrt[2]{1+Z*T}-1}{\sqrt[2]{1+Z*T+1}}\right] \qquad (4)$$

Where:

Z^* = Z optimal value of the pair type - type or p - n in thermoelectric devices
T_h = The temperature of the hot side
T_c = The temperature of the cold side
T = Average value and

This relationship is shown in Figure 4 to give an idea of the magnitude of the efficiency in relation to the variation ZT and the temperature difference. The first part of the equation (4) indicates that the maximum efficiency of thermoelectric associated with T_h and T_c same as Carnot efficiency.

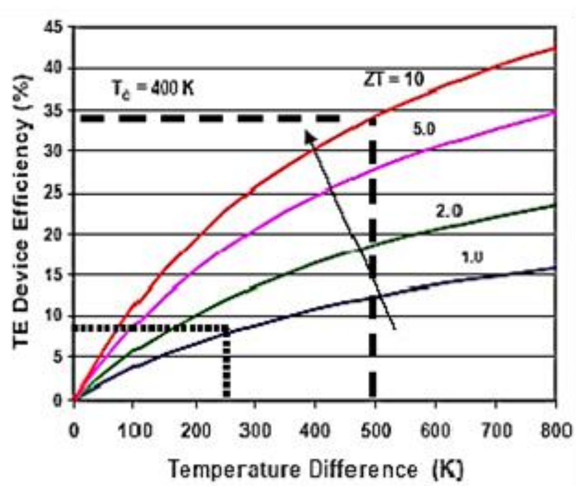

Figure 4. *Efficiency as a function of the temperature difference [10]*

3 Research Method

3.1. Design of Thermoelectric Generator (TEG)

Making design uses software Computer Aided Design (CAD) Code, as the initial drafting of design on each component the model TEG (thermoelectric generators), as shown in Figure 5 and Figure 6.

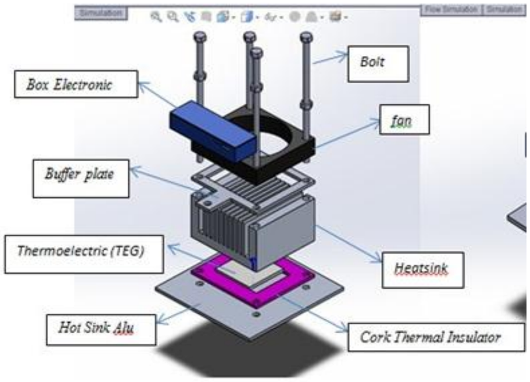

Figure 5. *Design of Prototype Components TEG device [11]*

Things need to be done first to design the model thermoelectric generator (TEG) as mini generating electricity, among other things: designing a heat sink, design fan, make Design TEG Module, Design Cork Thermal Insulator, and make hot sink Aluminum plate, Design buffer plate, Design Box electronic, making bolts and nuts as a binder. Each respective component must have the right size and diameter to avoid mistakes in the design process. To find out how large dimensions, the size of which will be used in the initial process of designing, then used CAD software to design components.

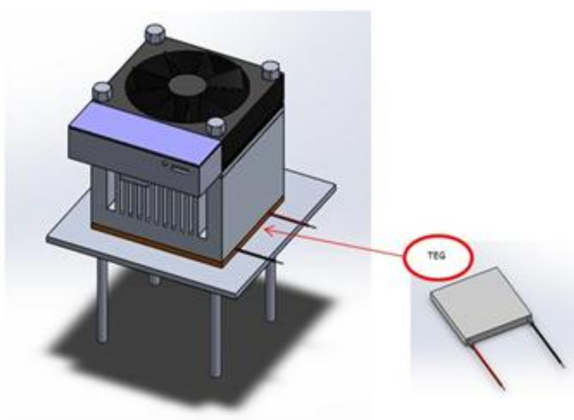

Figure 6. *Prototype Design TEG device*

Once the design TEG completed, then the simulation process on the TEG to know what kind of material what is good for power generation in this study, and then made design prototype TEG, to medium heat selected from materials aluminum sourced from heating source of methylated and cold side her thermoelectric heat sink paired so that the temperature stays cool. Then the electricity at thermoelectric voltage output measured using a multitier, and to know temperature using digital thermo or infrared thermometer.

4 RESULTS AND DISCUSSION

4.1. Results of Simulation Model Thermoelectric Generator (TEG) Small Modular

Simulation by using a CAD Code was to determine the thermal material after obtaining temperature by reference to the value of the cold side (T_c) and the hot side (T_h) on the thermoelectric module on the material can be seen in Figures 7 and 8.

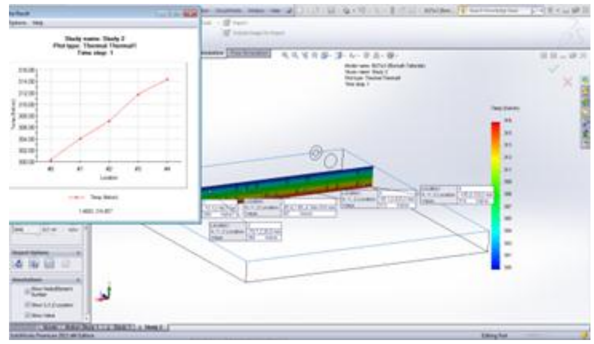

Figure 7. *TEG thermal simulation results*

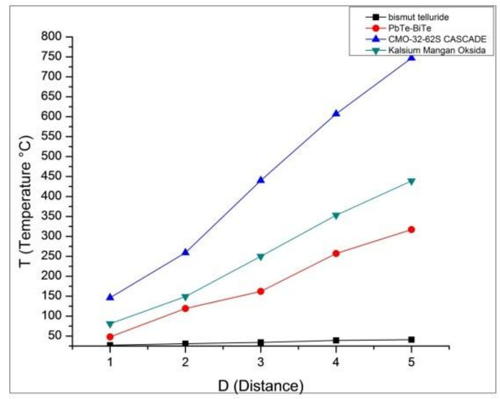

Figure 8. *Thermal simulation results TEG material for 4 different materials*

In Figure 7-8 above shows that the material has resistance values in thermal between 50 to 800 (°C) is the type of material CMO-CASCADE better used to create electricity generators mini is by the resilience of the thermal reaches 747 (°C), and for material (Calcium Mangan oxide) CMO-32-62S thermal resilience reaches 439 (°C), while its thermal resilience Pbte-Bite material reaches 317 (°C) and the fourth is Bi2Te3 (Bismuth Telluride) having its thermal resistance under 100 (°C) at 41 (°C). To determine the ability thermoelectric as generating electrical power that can be applied to lighting, in this research built prototype TEG device as a thermoelectric power plant testing. Figure 9 shows the prototype TEG made of heat sink fan as his refrigerator and plate aluminum measuring 110×110×3 mm^3 as a medium heat on the hot side of the module TEG then output wires of TEG module is connected to the terminal and connect to the LED lights to determine if it's working or not.

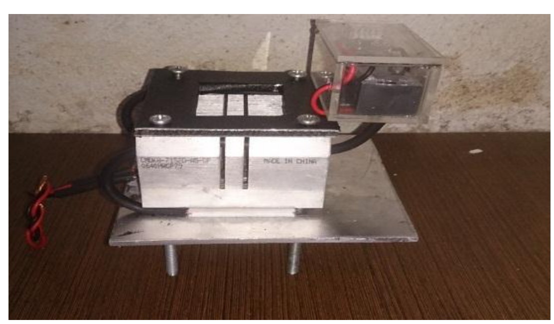

Figure 9. *Prototype TEG (Thermal electric Generator) Small Modular*

Figure 9 to explain for tests equipment using 2 peltier modules 12-706 arranged in series with a variety of tests using fan-dc. This test produces data such as output current, output voltage, output power and temperature of the hot side and the cold side as a function of time.

4.2. Analysis of Output Power

Testing is done with a variation on the TEG by using one element peltier, and two elements peltier that cemented series, and variety testing his other was on the cooler parts of the test equipment using a fan dc and does not use a fan-dc, the results can be seen in Figure 10 and Figure 11.

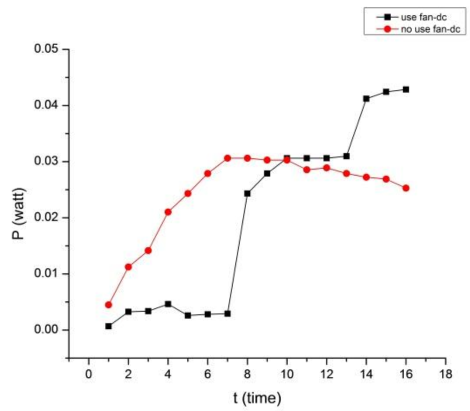

Figure 10. *The ratio of output power versus time using one peltier element with a variety of fan-dc*

From the graph the ratio of power output in Figure 10 shows that the two variations of a given, using cooling-dc fan capable of generating the greatest power compared with other variations. With a rated power output: (1) with fan-dc are: 0.042849 Watt (to 15 minute), ΔT = 18.1 °C, (2) Do not use the fan-dc: 0.030625 Watt (to 7 minute), ΔT = 15.1 °C.

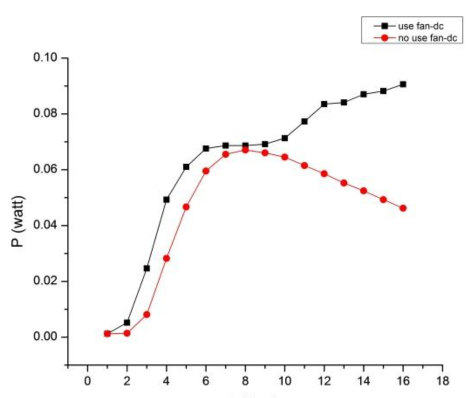

Figure 11. *Graph of the ratio of power output versus time using two peltier elements with a variety of fan-dc*

Output power of a comparison chart in Figure 11 seen that from the two variations of a given, using cooling-dc fan capable of generating the greatest power compared with other variations. With a rated power output: (1) with fan-dc are: 0.090601 Watt (to 15 minute), ΔT = 22.7 °C; (2) Do not use the fan-dc: 0.067081 Watt (to 7 minutes), ΔT = 16 °C.

4.3. Analysis of Output Voltage

In testing the output voltage is to know how much voltage is generated from the first TEG and second TEG, the results obtained from this test directly channeled to the dc-dc converter to determine whether the test equipment is functioning optimally to generate electric power to be applied to electronic devices or not, below is a graph of output voltage generated by the first TEG and second TEG, can be seen in Figure 12 and Figure 13.

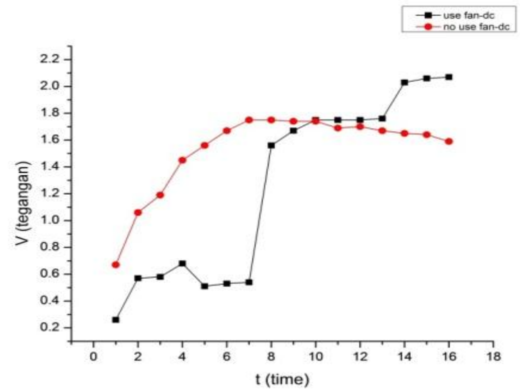

Figure 12. *Graph comparison voltage (v) output versus time using one peltier element with a variety of fan-dc*

Figure 12, explained electric potential difference increases with increasing temperature difference. So the higher the difference temperature (ΔT) on the peltier element is the voltage that is produced will be even greater. Rated output voltage produced by one peltier elements: (1) With fan-dc are: 2.07 Volt (to 15 minute), ΔT = 18.1 °C; (2) Do not use the fan-dc: 1.75 Volt (to 6 minute), ΔT = 22 °C.

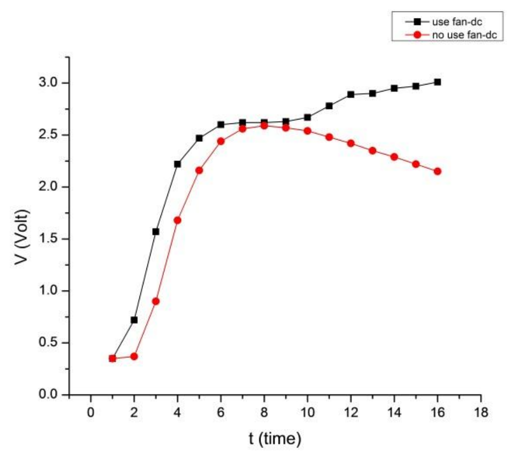

Figure 13. *Graph comparison voltage (v) output versus time using two Peltier elements with a variety of fan-dc*

Figure 13, explained that there was increase in the output voltage by using two elements Peltier which cemented the series by using a fan-dc reaches 3 volts to a maximum voltage of it, while the element Peltier that do not use the fan-dc or just rely on air circulation room at the time of testing The maximum voltage up only 2.59 volts. Rated output voltage generated by two Peltier elements: (1) With fan-dc are: 3 Volt (to 15 minute), ΔT = 22.7 °C; (2) Do not use the fan-dc: 2.59 Volt (to 7 minute), ΔT = 16 °C.

4.3. Analysis of Output Current Electric

Broadly speaking during a heat source of methylated turned on, an increase in the output current from 1 minute to minute 16. The temperature of the hot plate aluminum will rise during that time period. Figure 14, this proves the presence of heat received on the hot side of the Peltier and the temperature difference there will be a current flow in the semiconductor Peltier coupling, can be seen in Figure 14 and Figure 15.

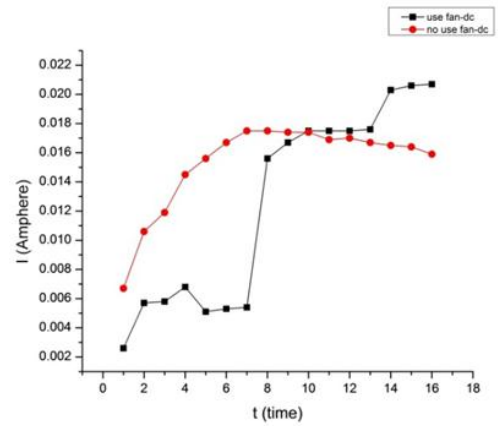

Figure 14. *Graph comparing current (I) output versus time using one Peltier element with a variety of fan-dc*

Figure 14 to explain current value of output produced by one Peltier element: (1) With fan-dc are: 0.207 Ampere (minute of 15), ΔT = 18.1 °C; (2) Do not use the fan-dc: 0.0175 Ampere (minute of 7), ΔT = 15.2 °C.

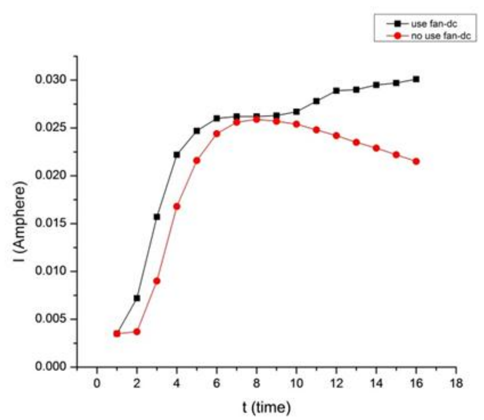

Figure 15. *Graph comparing current (I) output versus time using two Peltier elements with a variety of fan-dc*

If observed more specific to one or two Peltier elements in series, either using fan-dc or not, output current rapid increase from minute 1 to around minute 11. Then, from minute 11 to minute 15, the output current relative experience slow rise even have a value that is almost stable. Figure 15, so after the maximum output current value is reached, the current value may be repeated again in the next few minutes because the value ΔT after 15 minutes nearly stable between 21-22 °C. As for the Peltier element that does not use a fan-dc an increasing rate of output currents rapidly from minute 1 to minute 11. But after 12 minutes of a decline in the flow. The current rating is very volatile as well as its ΔT values between 14-18 ° C. Current value of output produced by two Peltier elements: (1) With fan-dc are: 0.0301 Ampere (minute of 15), ΔT = 22.7 °C; (2) Do not use the fan-dc: 0.0259 Ampere (minute of 7), ΔT = 16 ° C.

5 Conclusion

Based on test results conducted thermoelectric characterization can be drawn the conclusion that the results of characterization studies thermoelectric generator with two thermoelectric modules are installed in series in generating power output of thermoelectric plants is approximately 3.01 volt thermoelectric structure has a role to generate a certain voltage or strong currents. To generate a high voltage Peltier should be arranged in series, while the strong current to get high, thermoelectric must be arranged in parallel. Thermoelectric in series to produce greater power than the thermoelectric arranged in parallel. Broadly speaking, the powers generated in thermoelectric power plants are still quite small. However, it has been shown that the thermoelectric plants have a bright prospect in the future as an alternative electrical energy. So, wherever there is waste heat, thermoelectric plants can transform waste heat into electrical power.

References

[1] A. Farid, Lagiyono, Y. Ivayana, 2011, Thermoelectric Power System Analysis Based on a series circuit with Heat Utilization Remove Machine Toyota 4K mode, Journal of Engineering, Vol. 2 No. 1

[2] F. Keith and A. Priyono, 1986, Heat Transfer, Erlangga, Jakarta

[3] G. Min, and D. M. Roe, 1994, Handbook of Thermoelectrics, Peltier Device As Generator, CRC Press LLC, Florida, p.479

[4] S. O'Halloran, 2012, Power and Efficiency Measurement In A Thermoelectric Generator, AC 2012-3976, University of Portland.

[5] Ryanuargo, S. Anwar, and S. P. Sari, 2013, Thermoelectric Generator Mini Principles of Hot Steam Condensers in Refrigeration Systems, Journal of Rekayasa Elektrika Vol. 10, No. 4, pp. 180-185

[6] N. Putra, R. A. Koestoer, M. Adhitya, A. Roekettino, and B. Trianto, 2009, Thermoelectric Power Plants Potential for Hybrid Vehicles, Makara, Teknologi, Vol. 13, No. 2, pp. 53-58

[7] R. Wirawan, 2012, Analysis Using Heat Pipe On Thermoelectric Generator, Final Project of Undergraduate, Faculty of Engineering, Universitas Indonesia

[8] R. Riksanagara, 2012, Design and Implementation of Thermoelectric Module On Fire Charging System For Customers Ascent, Journal, Telkom University, Bandung.

[9] N. Sulistiyanto, 2014, Thermoelectric Cooling System Modeling at Super Luminance LED Module, Jornal of EECCIS Vol. 8, No. 1, pp. 67-72

[10] Z. Djafara, N. Putra, R.A. Koestoer, 2010, Experimental

Study of Development of Thermoelectric Generators As Power Source, Proceeding of the 9th National Seminar of Mechanical Engineering, Palembang

[11] K. H. Mahmud, S. A. Yudistirani, A. I. Ramadhan, 2016, Model Thermoelectric Generator (TEG) Small Modular As Micro Electricity Plant at Indonesia Part 1: Design and Material, International Journal of Scientific and Technology Research, Vol. 5 No 9, pp. 1-6