Model Thermoelectric Generator (TEG) Small Modular As Micro Electricity Plant At Indonesia Part 1: Design And Material

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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 study was conducted to determine the potential of the electric energy of the two Peltier modules which would be an alternative source for micro electricity plant using heat from methylated. The focus of this research is to design a model TEG (Thermoelectric Generator) Small Modular to produce the kind of material that is optimum for a TEG on the simulation Computer Aided Design (CAD) with a variety of four different materials that Bi2Te3 (Bismuth Telluride), PbTe-BiTe, CMO-32 -62S Cascade and CMO-32-62S [Calcium Manganese Oxide], to its cold side using the heat sink fan and simulating heat aluminum plate attached to the hot side of the TEG modules with heat source of methylated. Model simulation results on TEG Small Modular micro electrical plant material obtained CMO-32-62S Cascade thermal material that has a value greater than 3 other material.

Index Terms: Thermoelectric generators, TEG Material, Thermoelectric Cooling, Semiconductor, Micro electric plant

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. 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].

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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 create the design concept model of Thermoelectric Generator (TEG) Small Modular As electric plant micro, using Computer Aided Design (CAD). So it can be described in the form, size, geometry, position, placement, and the function of each individual component test equipment that can later be simplified into an application so shaped in design and then simulated using CAD Simulation software.

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.

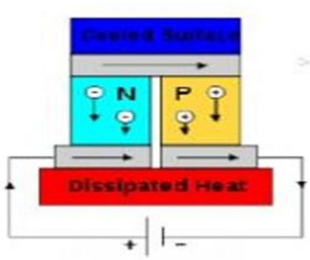

Figure 1. Schematic illustration of the Peltier effect [8]

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.

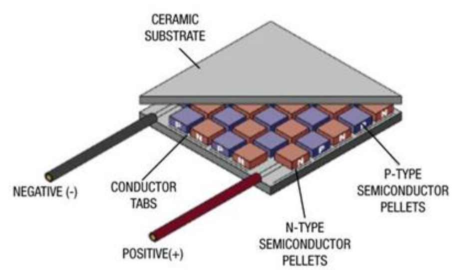

Figure 2. Construction thermoelectric modules [9]

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].

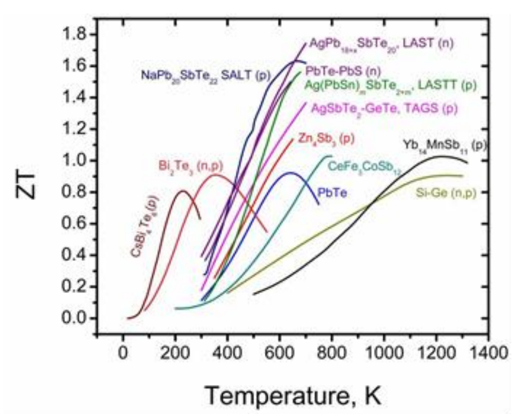

Figure 3. Graph of ZT value of the variation of thermoelectric materials [10]

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.

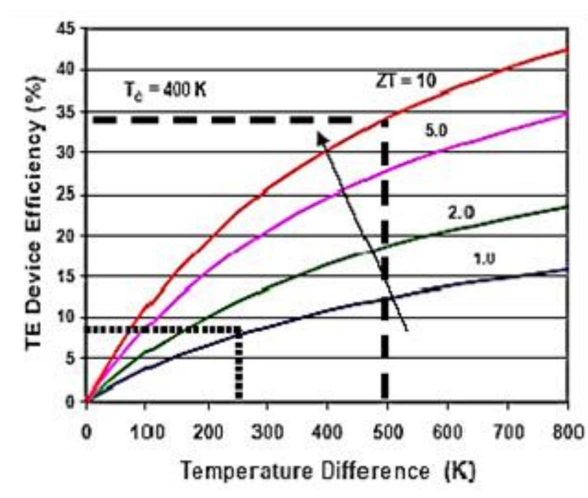

Figure 4. Efficiency as a function of the temperature difference [10]

3 Research Method

3.1. Design Model Thermoelectric Generator (TEG) Small Modular

Making this design uses software Computer Aided Design (CAD), as early conceptualizing the design of each component model of TEG (Thermoelectric Generator) and CAD SIMULATION, as a tool simulation to determine the heat transfer, the difference temperature of each different material and produce the type of material that is optimum. Component data models created can be seen in Table 1.

Table 1. Data of Model Component of Thermoelectric Generator (TEG) Small Modular

Part	Size [mm]				
	Length	Width	High	Diameter	Thickness
Heat sink	76	68	45	-	-
Fan	76	68	17	32	-
TEG Module	40	40	40		3
Cork Thermal Insulator	76	68	-	-	3
Hot Sink Alu Plate	110	110	-	-	3
Buffer Plate	101	68	-	-	3
Box Electronic	76	20	-	-	-
Bolt	130			3	

Using the data in Table 1 above are made in advance the design of the Model Thermoelectric Generator (TEG) Small Modular for micro plant electricity, assuming the modeling are: the hot side (Th) and the cold side (Tc), the hot side looks no component called Hot Sink Alu is a surface conductivity which absorbs the heat source toward (TEG), and at the top of Thermoelectric there is the cold side (Tc) that are above it there is a component Heat sink is for cooling at (TEG) to avoid overheating and damage to the module Thermoelectric, in Figure 5.

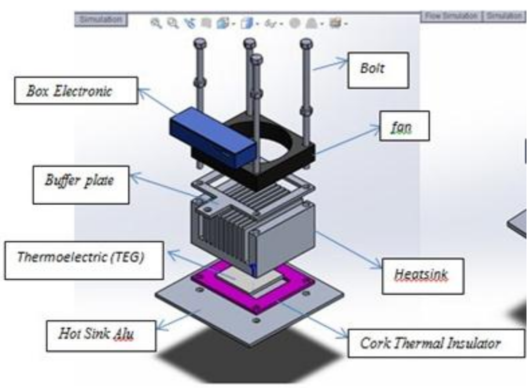

Figure 5. Design of Model Thermoelectric Generator (TEG) Small Modular

Things need to be done first to design the model thermoelectric generator (TEG) as the micro plant electricity, there are several things to consider, among other things: designing a heat sink, design fan, make design TEG Module, design Cork Thermal Insulator, and make hot sink Aluminium plate, design buffer plate, electronic Box Design, making bolts and nuts as a binder. Each individual 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, as shown in Figure 6.

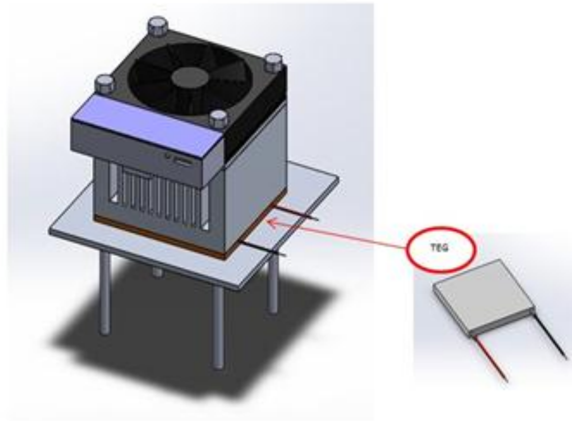

Figure 6. Prototype Design of Model Thermoelectric Generator (TEG) Small Modular

Once the design model of TEG so then do the simulation process on the TEG to know the kind of good material for micro plant electricity in this study, and then create a design prototype TEG, to medium heat his chosen from aluminum which comes from heating of methylate and sides her paired thermoelectric cooler heat sink, so that the temperature remains cool. Then the electricity at thermoelectric voltage output measured using a multicenter, and to know temperature using digit-thermo or infra-red thermometer tool.

3.2. Simulation with CAD Simulation

Computer Aided Design is a computer program to draw a product or part of a product. Products that want to be described can be represented by lines and symbols that have meaning and a certain size. The ability of a CAD system is the creation of graphs, sketches, diagrams, digitized maps and design drawings or design, giving annotation, image formation perspective, modeling of two-dimensional and three-dimensional, and some spatial analysis. Spatial analysis of every CAD system is very varied, most do not perform spatial analysis such as calculation of the distance, circumference, area, forming a buffer zone, and so forth. Modeling and simulation is done with CAD Simulation, as shown in Figure 7.

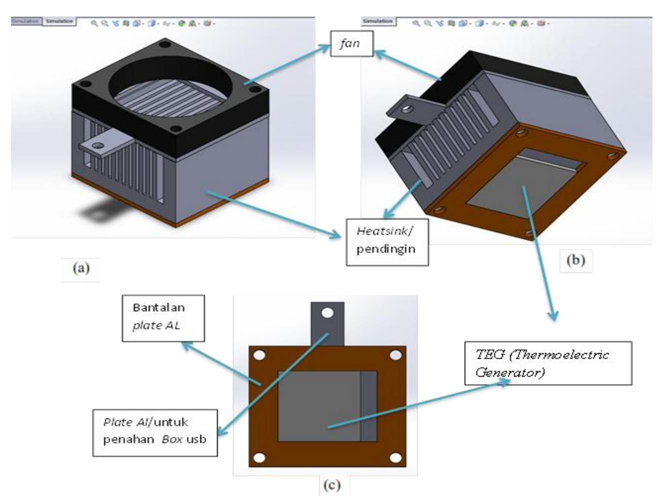

Figure 7. (a) Design Prototype TEG three-dimensional device, (b) bottom view, (c) cuts down design a model TEG

4 RESULTS AND DISSCUSSION

4.1. Simulation Design Model Thermoelectric Generator (TEG) Small Modular

The simulation was performed on a standard material that is Bi2Te3 and reference material. Reference material used to compare the resistance of the material standard material with other materials that have similar specifications. Reference material used is PbTe-BiTe, CMO-32-62S and CMO-CASCADE-32-62S, can be seen in Table 2.

Table 2. Specifications of material on Thermoelectric Generator (TEG) Small Modular

Product Name	Material Specification			
	Bi2Te3	PbTe.BiTe	CMO-Cascade	CMO-32-62S
Th (Hot Side) [oC]	50	350	480	800
Tc (Cold Side) [oC]	27	50	45	50
DTmax [oC]	70	300	435	750
Open Circuit Voltage [V]	1.2	9.2	19.45	12.8
Load Resistance [Ω]	-	0.97	8.62	3.38
Load of Output Current [A]	6.1	4.7	1.13	1.92
Load of Output Power [W]	61.4	21.7	11.01	12.3

Using the data in Table 2, was used as a process simulation model of Thermoelectric Generator (TEG) as micro electrical plant, focused on thermoelectric module of the TEG, which for the purpose of knowing the strength of the material, the value of the temperature distribution of the materials used in the TEG. Important aspects of this simulation is that the thermal load thermal load, meaning parts that get hot load, thermal load is divided into 5 (five) namely temperatures, convection, heat flux, heat power, and radiation. In this simulation thermoelectric has two sides, namely the hot side and the cold side, and on the simulation of thermal will be done on both sides by putting temperature on the hot side and the cold side to the hot side of her is the bottom of the module and on the cold side it is part on module, the aim is that the performance of TEG modules can be optimum when it receives excess heat, because the location of the possibility of material damage is in the area of hot-side module that is the bottom, can be seen in Figure 8-10.

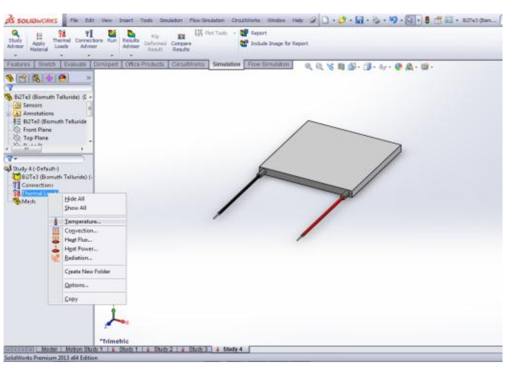

Figure 8. Simulation of thermal load on Thermoelectric Module

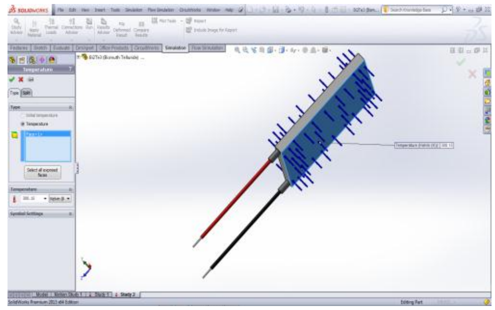

Figure 9. Simulation of the temperature on the hot side 27 (ºC), and the cold side 43 (ºC), the thermoelectric module

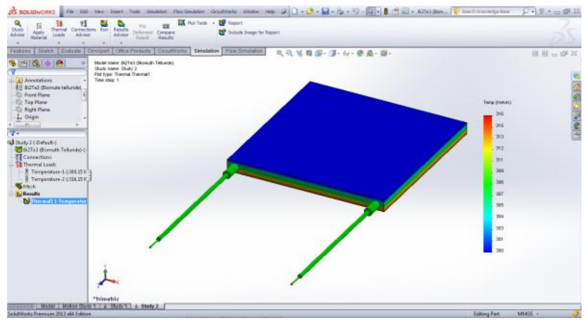

Figure 10. Simulation results thermoelectric module that will be used in model TEG

4.2. Value Thermal Material

Values obtained after obtaining the thermal material temperature with the reference value of the cold side (Tc) and the hot side (Th) on the thermoelectric module on the material. In this simulation taken five layout node that is at each point of a layer of thermoelectric module, since a major part in this mini power plant. Here the value of the thermal material on the thermoelectric module Bi2Te3 [Bismuth Telluride] material with thermal data value capture material at five nodes or points as shown in Figure 11:

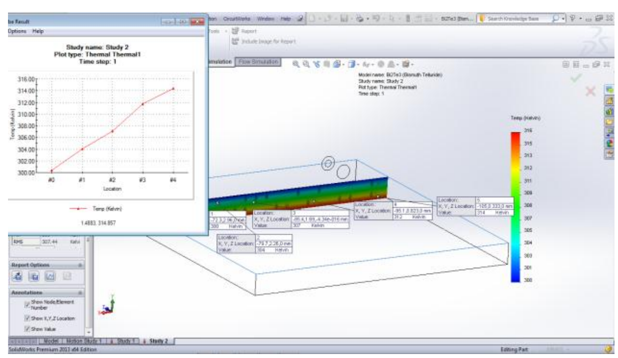

Figure 11. Thermal material of Bi2Te3 [Bismuth Telluride]

The simulation results of Figure 11, explains that the red color on the slices thermoelectric module shows the high value of the thermal material, while blue indicates low values of thermal material, the higher the value of the thermal material, the material will be more quickly produce large power. In Table 3 below shows the thermal material will each on temperatures in layout node.

Table 3. The value of thermal five nodes with different materials

Material	Size [mm^2]	Thickness [mm]	Node	T [°C]
Bi2Te3	40 x 40	3	1	27
			2	31
			3	34
			4	39
			5	41
PbTe-BiTe	56 x 56	3	1	48
			2	119
			3	162
			4	257
			5	317
CMO-32-62S Cascade	64 x 64	3	1	146
			2	259
			3	440
			4	607
			5	747
CMO-32-62S	64.50 x 64.50	3	1	81
			2	149
			3	250
			4	353
			5	439

Table 3 above can be made a comparison graph of thermal value of each - each material is Bi2Te3 [Bismuth Telluride], PbTe-BiTe, CMO-32-62S Cascade, and CMO-32-62S [Calcium Manganese Oxide] with a value temperature take 5 points according Figure 12:

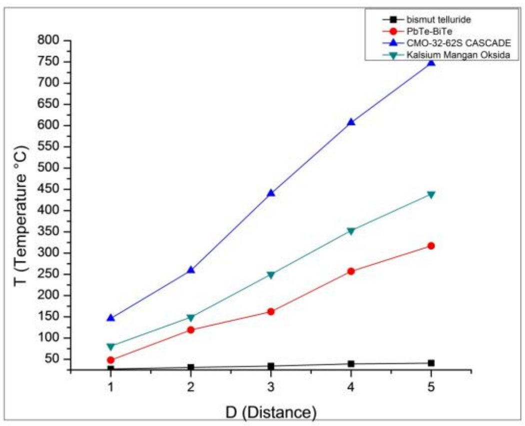

Figure 12. The relationship of temperature distribution of the variety of materials Thermoelectric Generator (TEG) Small Modular

Figure 12 shows material that has a thermal resistance values from 50 to 800 (° C) is the CMO-32-62S Cascade, CMO-32-62S [Calcium Manganese Oxide], PbTe-BiTe, and materials to the four resilient material on this thermal simulation is Bi2Te3 (Bismuth Telluride). On CMO-32-62S Cascade material, has a thermal value (Tc) cold side is 146 (° C), and will survive the thermal conditions at the point 5, namely when it reached 747 (° C), but the value of the thermal material CMO-32- 62S [Calcium Manganese Oxide] at point 1 is 81 (° C), and in hot conditions it is 439 (° C), and the material which in turn is PbTe-BiTe at the point to 1 is 48 (° C) and at the point to 5 show number 317 (° C) and the final material is Bi2Te3 (Bismuth Telluride) has a thermal value (TC) it is 27 (° C) and value (Th) it is 41 (° C). Type Thermoelectric Generator (TEG) For material CMO-32-62S Cascade, both used to make micro electrical plant is by its thermal resilience reached 747 (° C), and for material CMO-32-62S [Calcium Manganese Oxide], endurance thermal reached 439 (° C), while for the material PbTe-BiTe, endurance thermal reached 317 (° C) and on materials that fourth is Bi2Te3 (Bismuth Telluride) having resistance thermal under 100 (° C) at 41 (° C).

5 Conclusion

From the results of this research provide the following conclusions:

1. Design model of Thermoelectric Generator (TEG) Small Modular for micro plant electricity can be simulated by using some variation of the material used, namely: CMO-32-62S Cascade, CMO-32-62S [Calcium Manganese Oxide], PbTe-BiTe and Bi2Te3 [Bismuth Telluride].
2. Simulation model design Thermoelectric Generator (TEG) Small Modular for micro plant electric conducted in this study were obtained most excellent material for micro electrical plant is the CMO-32-62S Cascade, which has a thermal value on the cold side (Tc), it is 146 (°C), and will survive the conditions of heat when it reaches 747 (°C).
3. The process of cooling at TEG will determine the magnitude of the voltage generated, because the greater the temperature difference (ΔT) is generated, the greater the output voltage is obtained.

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