Performance Improvement of Thermoelectric Generator System Using Controlled Converter

Mohamad Choirul Anwar, Muhamad Faisal Ali, Abdur Rokhim, Delvi Picalista, Faiq Aprilian Romzi, Bambang Sujanarko

***Abstract*— Thermoelectric generator is a renewable power generation that using temperature difference of two semiconductors to be converted into electrical energy through a thermoelectric element is based on the principle of Seebeck effect. However, the efficiency of this generator is lower than 10%. In this research, the a DC / DC converter implemented in thermoelectric generators system to improve the energy produced and to be located at the point of maximum employment despite the changes in load and temperature changes. The energy produced by thermoelectric generators system will be stored in 6 V batteries and DC / DC converter on the thermoelectric generator can stabilize 7.36 volts. The experiment result show that the voltage can stabilized and the efficiency can improve until 30%.**

***Index Terms*— Thermoelectric Generator, DC/DC converter, alternative energy, battery charging.**

I. INTRODUCTION

The energy needs of the world is increasing. Similarly, Indonesia is becoming a developing country. Moreover, increasing the consumer behavior of energy consumption led to more exploitation of the natural resources of fossil energy. This will result in an energy crisis. To meet the energy crisis, Indonesia is planning the construction of mega power projects of 35,000 MW [1]. The use of alternative energy is one solution to overcome the problem of energy crisis that occurred at this time. This is why research on thermoelectric generator.

The utilization of flue gas as a producer of alternative electric energy began to be applied. Utilization of exhaust gas energy is based on the amount of energy they waste gas discharged into the environment. For example for gas power plants and steam, the heat energy used to generate electricity only around 30-40% of energy. In addition to the energy transport also contributes to exhaust the amount of energy that is large enough to average vehicle efficiency energy only around 35-40% [2]. In Figure 1 is shown that the heat energy is utilized only about 34% while the remaining 66% is wasted into the environment.

Several studies related to the use of exhaust gas *(waste heat)* has been performed. In the study conducted by (Rashid, 2008: 153) it can be seen that by utilizing the waste heat from the *condenser* steam power plant to be converted into electrical energy with the addition of binary cycle, the results show the efficiency of heat recovery from power plants increased by 10% while power generated by plants rose to 123.46 MW, or approximately 13%. While the wasted heat into the environment decreased to 10% [3].

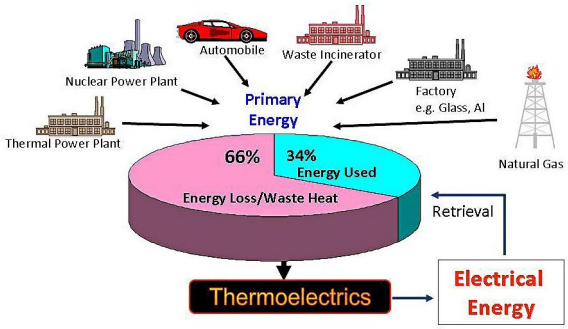

Figure 1. Percentage of exhaust gas energy

Thermoelectric generator is a renewable power generation that utilizes the temperature difference energy both sides of thermoelectric elements to be used as electrical energy. The greater the temperature difference both sides of the energy, the greater the energy produced by these elements. However, because of the difficulty of maintaining a temperature difference, then the efficiency of the tool is still small in the amount of 10%. So, we have to increase the efficiency for more application. Like, battery charging, different load, or many other application..

II. THERMOELECTRIC GENERATOR

Thermoelectric generator (TEG) is a power plant based on the Seebeck effect, which was first discovered in 1821 by Thomas Johann Seebeck [4] , Seebeck concept illustrates that when two pieces of metal semiconductor material in the environment connected with two different temperatures, then the material will flow electric current or electromotive force.

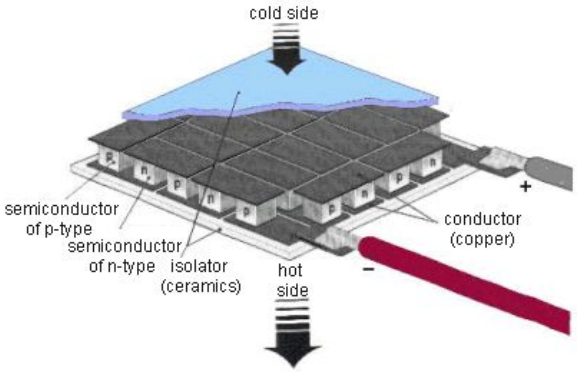

Figure 2. Structure thermoelectric element

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In the generator using thermoelectric elements, materials semikondoktor role in the production process where the electric current when a temperature difference at the junction or *junction* [5]. Generation system is called the Seebeck effect. The voltage generated by TEG formulated as follows [6].

$$V = N \,.\, \alpha \,.\, \Delta T \qquad (1)$$

From this formula V is the voltage generated by the TEG. N is the number junctions of semiconductoror connections P / N on the thermoelectric element. A is the Seebeck coefficient. ΔT is a temperature difference occurs at the junction in units of kelvin.

III. BUCK-BOOST CONVERTER

Value thermoelectric element efficiency can be improved by adding a DC to DC converter circuit in thermoelectric generators. *Buck boost converter* is a type of DC-DC converter which can convert the input voltage into the output voltage has a level higher or lower than the input voltage level [7]. The amount of change in the output voltage can be adjusted by changing the amount of *duty cycle* on the *buck boost*converter.When the *duty cycle* is greater than 50%, the value of voltage *output* thewill be higher than thevoltage, *input*otherwise when the *duty cycle* is less than 50% then voltage *theoutput* will be lower than thevoltage *input* [8].

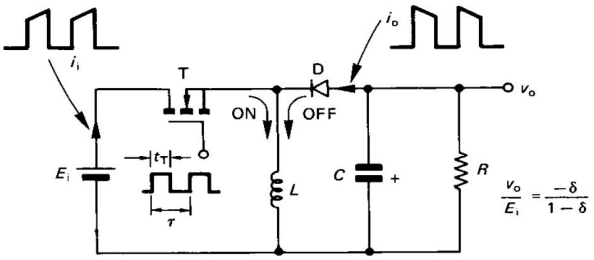

Figure 3. The circuit of buck boost converter

From the circuit above , when the transistor (T) *on* the inductor gets the voltage of *the input* and result in the current passing through the inductor based on the same time the capacitor in a condition to throw *(discharge)* and a source of voltage and current at the load. When the transistor (T) *off* thevoltage *input* is disconnected causing the onset of decreased flow and cause a negative end of the diode and the inductor supply capacitor *(charge)* and load. So by the time *switch on* the load current is supplied by capacitors, but at the time of *switch off* the load current is supplied by inductor [9]. The efficiency value of the DC / DC converter is formulated as follows:

$$\eta = \frac{P\,out}{P\,in} \qquad (2)$$

The use of a DC / DC converter in thermoelectric generators intended to stabilize the energy produced by the thermoelectric generator to be located at the point of maximum employment, despite the changes in load and temperature changes caused by external factor [10].

IV. METHOD

Overall design of thermoelectric generators that will be made in this study are shown in Figure 4.Thermoelectric generator design in this study using 9 pieces of thermoelectric elements are placed on 4 sides. We use TEC element not original TEG element. The of *body* the generator uses aluminum with a thickness of 3 mm. For *body* the outside has a size of 500x200 mm. While *body* the inside of the used for the placement of the thermoelectric element and the *heatsink* has a size of 100x300 mm.

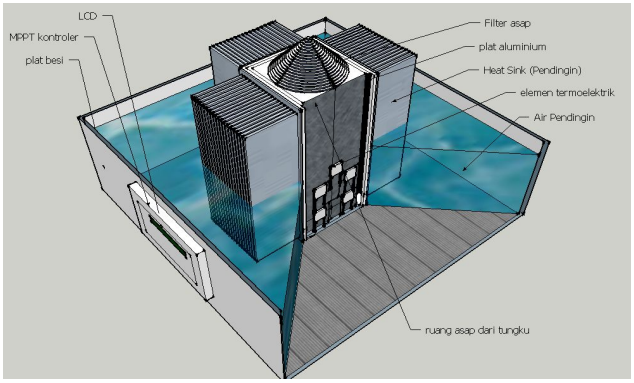

Figure 4. Design of thermoelectric generators

On the hot side of the thermoelectric Genarator used fire coming from the furnace while the cold side using media such as water which is equipped with a heatsink. *Heatsink* is used to help improve heat dissipation on the cold side so it will increase thermal efficiency in the thermoelectric cooler element. In this study, nine pieces of thermoelectric elements arranged in series. Installation of thermoelectric elements in series intended to make the generator can produce a larger voltage. But the generator have low current.

Testing tools done using gas cylinders *portable* used as fuel for the furnace. For the temperature sensor used is 2 pieces of thermocouples mounted on the side of the furnace and soaked in water. Current and voltage measurements using current sensors and a voltage sensor. Read current and voltage on the sensor is processed by the Arduino to be displayed on the LCD.

Figure 5. Portable Generator thermoelectric

Voltage produced by the thermoelectric generator occurs due to a temperature difference on both sides of the thermoelectric element. The temperature difference in the thermoelectric generators due to the heat absorbed by the upper surface of the element thermoelectric direct contact

with the inner side of the generator, while the lower surface of the element thermoelectric be in direct contact with the generator which is expected to release the heat as much as possible so that the temperature difference energy either side elements thermoelectric greater. When the temperature difference the greater the voltage that would be generated by the thermoelectric generator will also increase.

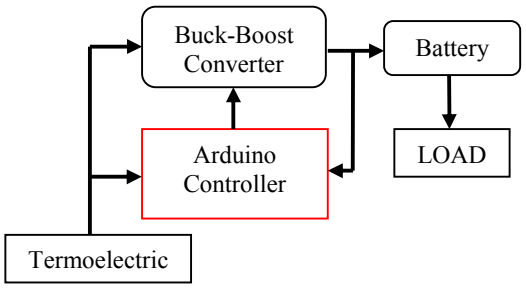

Figure 6. Block diagram of a thermoelectric generator

For a controller in this study using the Arduino microcontroller. Microcontroller device serves as a useful process to process current and voltage read by the sensor and then be ditampilna on the LCD. The display on the LCD in the form of the amount of current, voltage, power and temperature on the thermoelectric generator. Furthermore, the current and voltage of the thermoelectric element will be connected to the buck boost converter. In this study, the energy produced by thermoelectric generators will be stored in the battery function of the battery is to store the power generated by the thermoelectric generator before it is piped to the load. Therefore, the point of maximum employment of thermoelectric generator adapted to the nominal voltage for charging batteries. For this study, we make the main point is 7.4 V, for charge battery 6V.

V. RESULT AND DISCUSSION

A. Thermoelectric

In this research, the data was taken as a data output from the thermoelectric generator. Parameters measured quantities in the form of (1) the current, voltage and power generators, (2) current, voltage and battery power, (3) the temperature of the cold side and the hot side of the thermoelectric element. In this study, testing for generator by using *a DC / DC converter* is done for 10 minutes. Here's a thermoelectric generator test data.

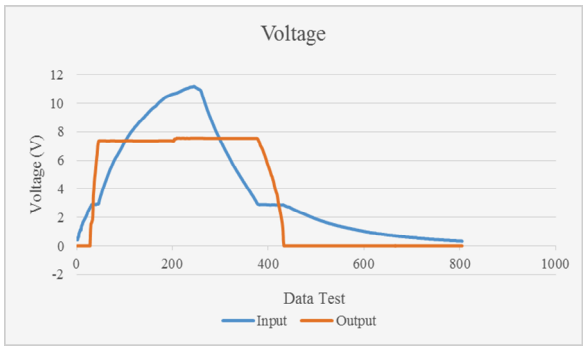

Figure 7. Thermoelectric generator voltage

Figure 7 is a graph of voltage thermoelectric generators. In the graph using the input voltage *DC / DC converter* is seen that the voltage rises significantly to the value of 2.75 volts and then slowed down toward the value of 3.13 volts. This voltage rise is slowing due to voltage adjustment by the *DC / DC converter* for charging the battery. Once the battery voltage is met at 7.36 volts, the voltage generator will continue to rise to a maximum value of which is equal to 11.18 volts. A voltage of 11.18 volts is reached at the time ⊗T at 68 °C. after the hot side of the thermoelectric generator reaches a temperature of 93 °C, the heat source in the form of gas will be turned off. When the heat source is turned off, the generator voltage will drop dramatically to the value of 3.05 volts and then slowed until the value of 2.85 volts. The voltage drop is slowing is due to the adjustment of the generator voltage with battery charging voltage.

In the graph output voltage by using *a DC / DC converter* is seen that the voltage rise significantly until the value of 7.36 volts when the generator voltage has reached a value of 3.13 volts, it because to qualify for the battery charging voltage. Because baetari used by 6 volt charging the minimum voltage that must be fulfilled by 7.3 volts. Then when the generator voltage reaches 10.7 volts charging voltage is also increased to 7.5 volts. The magnitude of the voltage generator and battery charging voltage is affected by the magnitude of the temperature difference on both sides of the thermoelectric element, which reached 68 °C. a temperature difference of 68 °C is reached when the temperature on the hot side of 93 °C and the temperature on the cold side of 25 °C. When the heat source is turned off charging the battery voltage remains stable at 7.5 volts, but when the generator voltage has reached a value of 2.9 volt charging the battery voltage drops to 0 volts.

Figure 8. Thermoelectric power generator

Figure 8 is a graph of a thermoelectric power generator , In the graph of input power by using *a DC / DC converter* is seen that the greatest power that can be generated by the thermoelectric generator of 1.02 watts. Input power from thermoelectric generator does not look too stable. When the temperature difference of the two sides of the element is high enough then the power generated by the generator is also getting bigger and when the heat source is turned off the power would drop drastically. In contrast to the power output of the DC / DC converter, the output voltage of the graphics can be seen that the output power is more stable. The output power of the DC / DC converter is stable in the range of 0.5 watts. Similarly when the heat source is turned off power output is also not straight down drastically. This is because adjusting the power supplied to the battery. For the efficiency of the DC / DC converter that has a value of approximately

50% efficiency when the temperature difference is located at the highest value that is equal to 68 °C. when the temperature difference the lower the efficiency of the DC / DC converter will also be lower.

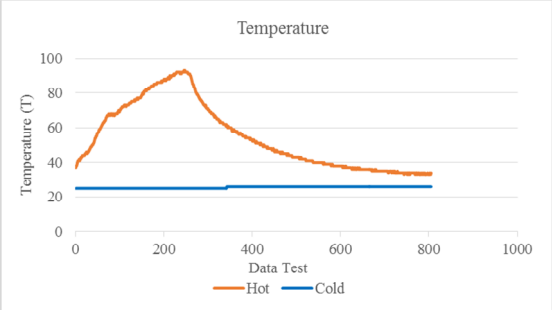

Figure 9 Temperature difference

Figure 9 shows a graph of the temperature difference between the hot side and the cold side of the thermoelectric generator. When using a *DC / DC converter* biggest temperature difference has a value of 68 °C with a temperature on the hot side of 93 °C and the temperature on the cold side at 25 °C.

B. Duty cycle of DC-DC Converter

In addition to testing the magnitude of the voltage and power output in this study will also be taken data of duty cycle for the buck boost converter. The duty cycle take from arduino PWM source. Duty cycle data is presented in Table 1.

Table 1. D*uty cycle* of DC/DC converter

Duty Cycle (%)	PWM Arduino	Voltage (V)
0	0	7,3
10	25,5	7,25
20	51	7,2
30	76,5	7,1
40	102	7
50	127,5	6,9
60	153	6,7
70	178,5	5,4
80	204	4,15
90	229,5	3,4
100	255	2,7

From the table above it is known the greater the duty cycle, the output voltage of the DC / DC converter will be smaller. From the table it can be seen with a duty cycle of 90% voltage DC / DC converter at 3.4 volts, while the 30% duty cycle output voltage DC / DC converter of 7.1 volts. in this study, the output voltage is set at 7.3 when the voltage is decreased, then Mikrokontrol will automatically raise the voltage by reducing the large duty cycle. so as to keep the process of charging the battery or load.

C. Efficiency

Overall efficiency of the use of a DC / DC converter on the thermoelectric generator is shown in Figure 10.

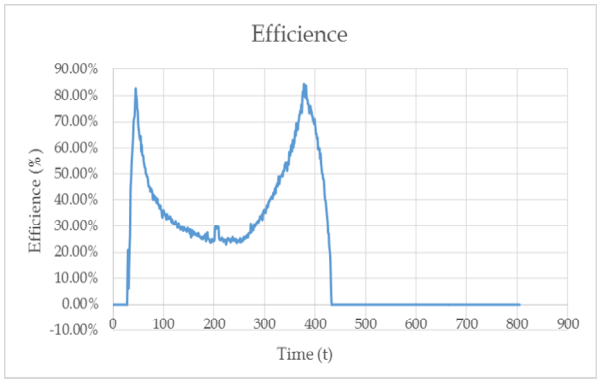

Figure 10 Efficiency

From the graph of efficiency DC/DC converter above can be seen that the efficiency of the DC / DC converter varies according to the temperature change that occurs in the thermoelectric element. In the initial condition when the temperature increases, the efficiency of the DC/DC converter will rise rapidly until it reaches 82%. When the temperature difference condition has stabilized efficiency DC/DC declined slightly up in a state average of 60%. After the temperature difference again changed due to the heat source is turned off then the efficiency will directly decrease drastically towards the figure 0%.

For data efficiency DC/DC converter output voltage obtained an average of DC/DC converter of 0.2219 volts while the input voltage DC/DC converter obtained a value of 0.3658 volts. Of the average input voltage and the output voltage is then obtained nlai average efficiency of the DC/ DC converter of 0.6066% or can be rounded up to 0.61%

From the testing that has been done is proven that when there is a temperature difference between the two sides of the thermoelectric element there will be a potential difference at both ends of the thermoelectric elements. The greater the temperature difference on both sides of the elements of the electrical energy produced will be even greater, this is in accordance with the theory of the Seebeck effect.

The use of a DC DC converter affects the battery charging voltage is more stable. When using a DC/DC converter charging the battery voltage stabilized at a voltage of 7.36 volts to 7.53 volts. In addition the use of a DC / DC converter also affect the power produced by the thermoelectric generator. When using a DC / DC converter power that can be generated by the generator can achieve 1.02 watts. But, it cant charge the batter, because the current to small. The battery with 4.5Ah need current minimum under 100mAh, but the generator thermoelectric who we use just can generate current under 100mAh. So, the high voltage cant charge battery without high current.

VI. CONCLUSION

Based on the results of testing that was done using DC/DC converter on the effect on the thermoelectric generator output voltage and battery charging voltage. Application of DC/DC converter in a thermoelectric generator capable of charging the battery voltage to stabilize at a nominal voltage of 7.36 volts to 7.53 volts. In addition to the DC/DC converter power generated thermoelectric generator can achieve 1.02 watts of power.

Based on the test results for the amount of duty cycle on the DC/DC converter is known that the greater the duty cycle, the magnitude of the output voltage of the DC / DC converter will be smaller to get the charging voltage of 7.25 volts need duty cycle of 10%. As for the average efficiency of the DC/DC converter that is used has a value of 61% efficiency.

The amount of power produced by the thermoelectric generator is still quite small. But power plants with renewable energy sources such thermoelectric generators have good prospects to become a future energy is environmentally friendly. The use of thermoelectric generators to utilize flue gas heat from the furnace could be a solution to overcome the energy crisis as well as an environmentally friendly alternative energy.

For more application, we suggest to use the original TEG with the best specification not like TEC element with low specification, and use parallel circuit for high current, for charge the battery. Because, for charge battery with high current capacity, need also high current charging.

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