A Research for the Thermoelectric Energy Harvester to Improve the Power Generation Efficiency

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Abstract— This study suggests using thermoelectric element to generate electric energy from the heat source efficiently. This generator system consists of a Heater, the Lower Heat Transfer Plate to absorb heat from the Heater, Two-Stage Thermoelectric Device module to generate the electric power with the heat transferred from the Lower Heat Transfer Plate, the Upper Heat Transfer Plate to convey the heat from the Two-Stage Thermoelectric Device module to Hat Sink, and the Heat Sink to release the heat from the Upper Heat Transfer Plate. By comparing the Two-Stage Thermoelectric Device module system with using one thermoelectric element, we have found that the Two-Stage method is more efficient to generate electric energy from the same heat source.

Keywords— Thermoelectric Generator, Energy Harvester, Seebeck Effect.

I. INTRODUCTION

Recently, as eco and energy problems are being a wide issue, a new energy development and energy reduction solution is needed. As a result, there are many studies of energy harvester to increase the usable energy by recycling the trash energy while driving. There are overall two energy harvesters. One uses vibration to convert kinetic energy to electric energy. And the other changes the heat from the system to electric energy, which is called 'Thermoelectric generation'. Thermoelectric generation uses thermo-electric effect. Thermo-electric effect is a phenomenon that creates electromotive force when the electrons and electric holes move due to the temperature difference between two sides of an element.[1] This is shown by Seebeck effect and Peltier effect. The Seebeck effect is that the electric current flows when two different metals or a metal and a semiconductor are contacted and one of them is heated.[2][3] The Peltier effect is that heat emits or absorbs heat when electric current is flowing between two different metals or a metal and a semiconductor. Thermo-electric Generator (TEG) connects a P-type and a N-type thermoelectric semiconductor element with conductor, and places insulation layer on top.

When there is a temperature difference in each side, the electrons in P-type semiconductor move from high temperature side to low temperature side, while the electric holes in N-type semiconductor moves from high temperature side to low temperature side.[4] This causes the electric current to flow, and creates electromotive force. The performances of a thermoelectric element are decided by Seebeck coefficient, electric conductivity, and heat conductivity, and are shown by the Performance Index. The thermoelectric generation system has low energy convert efficiency, and the total cost is high. However, it can change heat energy to electrical energy directly, making it semi-permanent and easy to maintain. Therefore, not considering the economics, it can generate power from any heat source. And there are many studies to increase thermoelectric generation efficiency to solve this problem.[5][6]

This study suggests thermoelectric generation, using thermoelectric element to generate electric energy from the heat source efficiently. This generator system consists of a Heater, the Lower Heat Transfer Plate to absorb heat from the Heater, Two-Stage Thermoelectric Device module to generate the electric power with the heat transferred from the Lower Heat Transfer Plate, the Upper Heat Transfer Plate to convey the heat from the Two-Stage Thermoelectric Device module to Hat Sink, and the Heat Sink to release the heat from the Upper Heat Transfer Plate. By comparing the Two-Stage Thermoelectric Device module system with using one thermoelectric element, we have found that the Two-Stage method is more efficient to generate electric energy from the same heat source.

II. EXPERIMENTS

A. The structure of the Thermoelectric Generation System Equipments

Figure1 shows the overall picture of the structure of the Thermoelectric Generation System for the efficiency test. The Thermoelectric Generation System in figure1 consists of a Heater, Upper and Lower Heat Transfer Plates, Two-Stage Thermoelectric Device, and a Cooling Fin.
The Upper and Lower Heat Transfer Plates are attached with thermometers. Here, the heater can control the temperature and the Lower Heater Transfer Plate above the Heater fixes the Thermoelectric Device and conveys the heat from the heater to the Two-stage Thermoelectric Device.

The Two-stage Thermoelectric Device uses the heat to generate electric energy and conveys some of the heat to the Upper Heater Transfer Plate. The Upper Heater Transfer Plate fixes the Two-stage Thermoelectric Device and conveys the heat to the Cooling Fin.

Then the Cooling Fin emits the heat to the air. Also, the thermometers attached to the Upper and Lower Heat Transfer Plates measure the temperatures of the Upper and Lower Heat Transfer Plates.

In Figure 2, \( Q_H \) and \( Q_L \) show thermal calories transferred each from the heat source (Heater) to the Thermoelectric Device and from the Thermoelectric Device to the heat sink. These can be expressed by below mathematics expressions [7].

\[
Q_H = kA(T_H - T_1)/H \quad (1)
\]
\[
Q_L = kA(T_2 - T_L)/H \quad (2)
\]

The surface temperature of the Thermoelectric Device, \( T_1 \) and \( T_2 \) can be got by below expressions.

\[
Q_H = N\alpha T_1 - N\alpha R/2 + Nk(T_1 - T_m)/H_T \quad (3)
\]
\[
Q_m = N\alpha T_m + N\alpha R/2 + Nk(T_1 - T_m)/H_T \quad (4)
\]
\[
Q_m = N\alpha T_m - N\alpha R/2 + Nk(T_m - T_2)/H_T \quad (5)
\]
\[
Q_L = N\alpha T_2 + N\alpha R/2 + Nk(T_m - T_2)/H_T \quad (6)
\]

\( N, \alpha, R, k, \) and \( H_T \) show each the number, Seebeck coefficient, the inner resistance, and the height of the thermocouple respectively. \( T_m \) can be calculated from the Expression (4) and (5) as follows.

\[
T_m = \frac{N\alpha R_T + Nk_T T_1 + Nk_T T_2}{2Nk_T} \quad (7)
\]

Here, let \( T_1 \rightarrow T_H \) and \( T_2 \rightarrow T_L \), \( T_m \) can be got as follows.

\[
T_m = \frac{N\alpha R_T + Nk_T T_1 + Nk_T T_2}{2Nk_T} \quad (8)
\]

Above Expression (3), (4), (5), and (6) are induced from the thermal resistance and thermoelectric theories, as the current generated in the Two-stage Thermoelectric Device is calculated as follows.

\[
I_1 = \frac{N\alpha(T_H - T_m)}{NR + R_L} \quad (9)
\]
\[
I_2 = \frac{N\alpha(T_m - T_L)}{NR + R_L} \quad (10)
\]

\( I_1 \) and \( I_2 \) from the Expression (9) and (10) show the current generated in the Lower and Upper (Two-stage) Thermoelectric Device. The generated power is as follows.

\[
P_L = I_1^2R_L + I_2^2R_L \quad (11)
\]

\( PL \) at the Expression (11) shows total electric power generated in the Two-stage Thermoelectric Device.
C. Then the Cooling Fin emits the heat to the air. Also, the thermometers attached to the Upper and Lower Heat Transfer Plates measure the temperatures of the Upper and Lower Heat Transfer Plates.

III. RESULTS

Figure 3 shows the model of Thermoelectric Generating module used in this study. Here, Thermoelectric Generating module is consisted of multiple Thermocouples which is made up of Pellets, Interconnects, and Insulating Layer. Pellet is P-type or N-type semiconductor element, which is connected in series electronically and connected in parallel thermally.

![Figure 3 The Structure Of The Thermoelectric Generator Module](image)

Table 1 shows the specifications of the Thermoelectric Device used in this study.

<table>
<thead>
<tr>
<th>Type</th>
<th>Dimension</th>
<th>Rac. Ohm(Ω)</th>
<th>Volts (V)</th>
<th>Amps (I)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGM127</td>
<td>40×40</td>
<td>4.3</td>
<td>2.2</td>
<td>2.0</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.2</td>
</tr>
</tbody>
</table>

Then we measured the voltage in each side of the Thermoelectric Device. This experiment was conducted at each temperature being divided by 10°C, from 25°C to 170°C.

![Figure 4 The Experimental Equipments Of The Thermoelectric Generator System](image)

Figure 5 shows the difference in temperature between the Upper Heat Transfer Plate and the Lower Heat Transfer Plate corresponding to the increase of the Lower Heat Transfer Plate.

The Two-Stage Thermoelectric Module shows that the temperature difference is 8°C when the Lower Heat Transfer Plate temperature is 25°C, and 133°C when 170°C while the standard One-Stage Thermoelectric Module has the temperature difference of 8°C when 25°C, and 116°C when 170°C.

Here, the mathematics expression of the temperature difference graph by the increase of the Lower Heat Transfer Plate temperature in the Two-Stage Thermoelectric Module is $\Delta T=0.86T-13.6$ while the expression in the One-Stage Thermoelectric Module is $\Delta T=0.75T-10.6$.

From here, it is proven that Thermoelectric Generator system using the Two-Stage Thermoelectric Module has steeper graph than that of the One-Stage Thermoelectric Module. This suggests that the Two-Stage Thermoelectric Module has more heat resistance than One-Stage Thermoelectric Module.
It can be seen that since the Thermoelectric Generator system with Two-Stage Thermoelectric Module has more heat resistance, the voltage generated in the Two-Stage Thermoelectric Module is also larger than the one generated in the One-Stage Thermoelectric Module in NO-LOAD condition.

IV. CONCLUSION

To increase the efficiency of Thermoelectric Generator system, we have suggested the Thermoelectric Generator system using Two-Stage Thermoelectric Module. And these are the results of comparison to the standard One-Stage Thermoelectric Module.

1) On low temperature environment, the temperature difference of the cold-side and the hot-side of the Thermoelectric Generator Module are similar in the Two-Stage Thermoelectric Module and the One-Stage one. However, the difference increases as the temperature rises. This means that Thermoelectric Generator system with Two-Stage Thermoelectric Module has more heat resistance than the one with One-Stage Thermoelectric Module.

2) Since the Thermoelectric Generator system with Two-Stage Thermoelectric Module has more heat resistance, the voltage generated in the Thermoelectric Module is also larger.

Therefore, the Thermoelectric Generator system with Two-Stage Thermoelectric Module can use heat more efficiently due to high heat resistance, and can contribute greatly to enhancing the generator efficiency.

REFERENCES