THERMOELECTRIC GENERATOR SIMULATION BY USING MATLAB/SIMULINK

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Abstract

Due to the limited and inefficient sources of energy in our world, the search of new alternative energy sources and methods are continued. One of these sources is geothermal and waste heat energies. Thermoelectric generators (TEGs) can be used to convert these energies into electrical energy. Particularly, generating energy using waste heat energy is a big advantage. It provides an energy efficiency. In this paper, a MATLAB/Simulink simulation of a TEG system has been handled for accelerating of the TEG research, development and installation phases. The equations of TEGs has been embedded in the Simulink program. The user can find out by simulation how to get a result by entering specific values related to TEG system outputs. By means of the carried out simulation program, practitioners provide great benefits great benefits in terms of time and cost.

Keywords: thermoelectric, thermoelectric generator, geothermal energy, waste heat, energy, MATLAB/Simulink.

INTRODUCTION

Energy is an indispensable part of our life that is used in every field such as industry, health sector, transportation and home. Nowadays, energy is obtained are oil, coal, hydroelectric, geothermal, wind, solar and nuclear power plants.

The most used energy resources are limited resources in nature and they would be soon run out because they are used extensively. The using of these resources is also harmful for the environment. Moreover, a considerable part of these resources are wasted without being converted into electrical energy as waste heat. The using of hydroelectric, geothermal, wind, use of solar energy resources is insufficient compared to the use of other energy resources. Whereas, these resources are friendly resources. In addition, they are always in the world and are always renewing.

In the world, there is a need to produce energy with eco-friendly methods for the increased energy demand. One of the important methods is the employing of thermoelectric generators (TEGs) [1].

In 1821, a new feature of some semiconductors was discovered by Thomas Seebeck. These semiconductors generate electricity when there is a temperature difference between the two surfaces. It was called Seebeck Effect. The widely employed thermoelectric materials in TEGs are Bismuth Telluride (Bi_2Te_3). These are utilized until 350°C. Their efficiency is less than %10. However, the value is not small when considering the energy save from waste heats. For this reason, the energy save from waste heats comes at the forefront of TEG applications. In here, as an example, it can be given an automobile exhaust system that energy of 0.94 kW was extracted from waste exhaust heat [2].

On the other hand, TEGs have many advantages. They do not have moving parts, do not require maintenance and last long. But their yields are a little low and a little expensive.

THERMOELECTRIC GENERATOR

Thermoelectric materials are called semiconductors that generate current when

there is a temperature difference between two surfaces. A thermoelement that is illustrated in Figure 1 is obtained from conjunction of p- and n-type semiconductors.
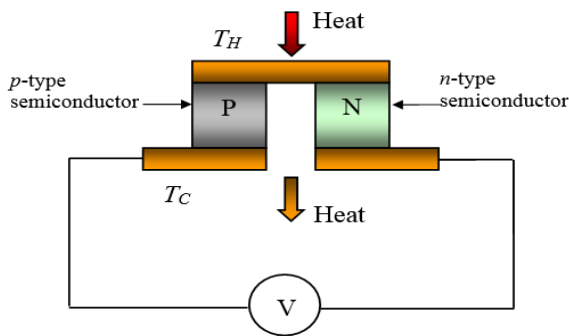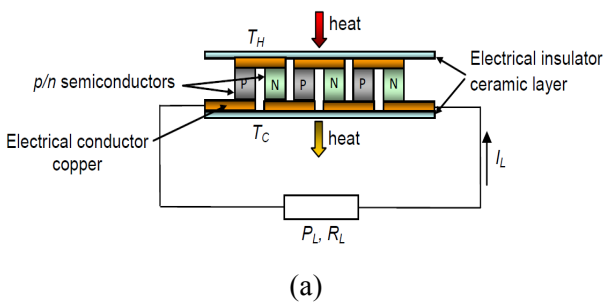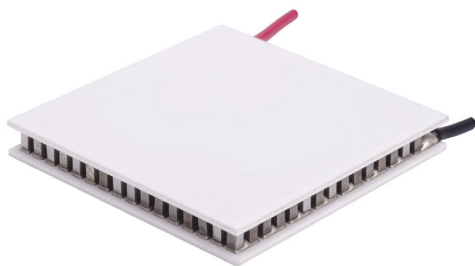

Fig. 1. Thermoelement

Many TEs that are connected in electrically series to increase voltage and in thermally parallel to decrease thermal resistance by means of ceramic plates consist of a thermoelectric module (TEM). A thermoelectric module picture is depicted in Figure 2. Figure 2a shows parts of TEM in TEG mode and Figure 2b demonstrates a TEM picture.

(a)

(b)

Fig. 2. A Thermoelectric module (a) in TEG mode and (b) a TEM

THERMOELECTRIC EQUATIONS

The electricity generation of TEGs depends on the Seebeck coefficient α. The Seebeck coefficient is a value depending on the property of the semiconductor [3]. Bi_2Te_3 of Seebeck coefficient is greater than 500 µV/°C. The obtained voltage from TEG is directly proportional with Seebeck coefficient and temperature difference. The equation is given as below:

$$V = \alpha.\Delta T \tag{1}$$

where, V is obtained voltage and ΔT is the temperature difference between the TEG surfaces. Seebeck coefficient is a constant value and it is clarified as below:

$$\alpha = \frac{2V_{max}}{\Delta T} \tag{2}$$

where, V_{max} is obtained maximum voltage from the TEG. The temperature difference is explained as follows:

$$\Delta T = T_H - T_C \tag{3}$$

where, T_H and T_C are hot and cold surface temperatures, respectively.

When there is not a load at the ends of a TEG, the obtained voltage is called the open circuit voltage V_{OC}. When the pins of a TEG is short-circuited, the passing current is called the short circuit current I_{SC}. The derived maximum power from the TEG is a maximum value when the open circuit voltage and the short circuit current have a half value. This situation is given as follows:

$$P_{max} = \frac{V_{OC}}{2} \cdot \frac{I_{SC}}{2} \tag{4}$$

where, P_{max} is the maximum power generated from the TEG. In TEGs, the figure of merit (FOM) Z is very important and is given as follows:

$$Z = \frac{\alpha^2}{R_{in}\kappa_{th}} \tag{5}$$

where, R_{in} and κ_{th} are the internal resistance and the thermal conductivity of the TEG, respectively. In order to an efficient conversion of the TEG, internal resistance of

the TEG and the connected load resistance R_L have to match. The rate of the internal and the load resistances is given as follows:

$$m = \frac{R_L}{R_{in}} \qquad (6)$$

The resistance rate is used for energy efficiency, current and thermal conductivity. The thermal conductivity is expressed as like:

$$\kappa_{th} = \frac{\alpha^2}{R_{in}Z} \qquad (7)$$

Depending on the resistance rate, the obtained current I from the TEG is given as follow equation:

$$I = \frac{\alpha \cdot \Delta T}{(1+m)R_{in}} \qquad (8)$$

The efficiency of the TEG is expressed as both TEG properties and system input power. Depending on the resistance rate, it is explained as like [4]:

$$\eta = \frac{m \cdot Z \cdot \Delta T}{(1+m)^2 + Z[(m+0.5)T_H + 0.5T_C]} \qquad (9)$$

Moreover, depending on the system input power Q_H, the TEG efficiency is represented as follow:

$$\eta = \frac{I^2 \cdot R_L}{Q_H} \qquad (10)$$

The maximum efficiency of TEG being not depending on the resistance rate is clarified as follows:

$$\eta_{max} = \frac{Z \cdot \Delta T}{4 + Z(1.5T_H + 0.5T_C)} \qquad (11)$$

If the efficiency value is known, then the FOM value can also be found by the equation given below:

$$Z = \frac{4\eta_{TEG}^{max}}{\Delta T - \eta_{TEG}^{max}(1.5T_H + 0.5T_C)} \qquad (12)$$

Paying attention to the above equations, the efficiency of the TEG is highly dependent on the temperature difference and the load resistance. When the load connected to the output of the TEG matches the internal resistance of the TEG, the highest power is taken. But this does not always happen. Various converters are used with TEGs to stabilize both the voltage of the TEG and the impedance balance. Many maximum power point tracing (MPPT) methods are used to provide impedance matching.

TEG SIMULATION AND RESULTS
Simulations provide benefits both cost and time rather than the actual physical implementation for researchers. For this purpose, a simulation of the TEG has been carried out in the paper by using above TEG equations. The simulation is performed by MATLAB/Simulink program. The program is suitable and user friendly. Also it gives flexible solutions.

To examine the characteristic value of a TEG that is heated by a surface waste heat and cooled by the other surface water, input temperatures and Seebeck coefficient are employed. The first values is obtained from the datasheet of TEG. According to the input temperatures, the obtained values is illustrated in Figure 3. In Figure 3, the output values of only one TEG is given. For applications, much more TEGs are used. They are connected in series and in parallel. The parallel connection is preferred when the voltage is insufficient and the series connection is preferred when the current are insufficient. In order to realize this situation, serial and parallel numbers are placed in the simulation as shown in Figure 4 and calculations have been executed for three parallel braches to which four TEGs are connected in series.
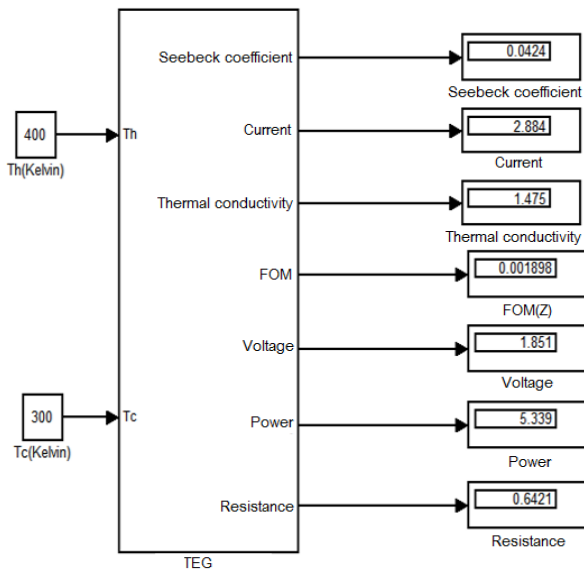
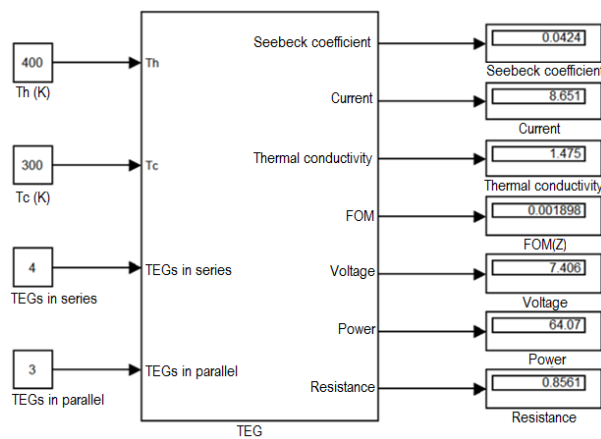**Fig. 3.** *According to the input temperatures, the obtained values of the TEG*

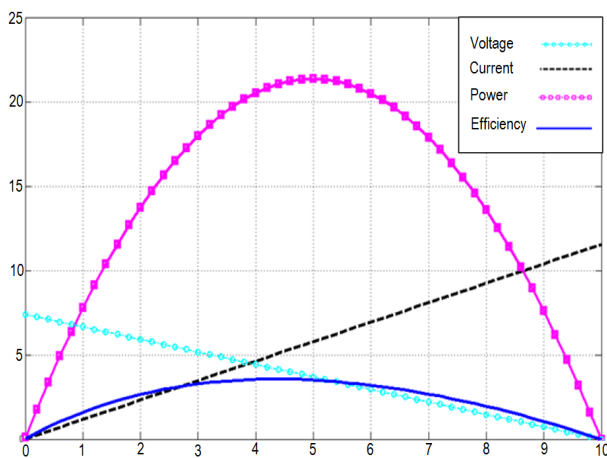**Fig. 4.** *Calculations for parallel and series connections of TEGs*

Fig. 5. *Current, voltage, power and efficiency as a function of the load resistance*

For three branch in parallel connection, each of them consist of four in series connected TEG, the internal resistance of TEG increases by 4/3. The current rises to three times and the voltage climbs to four times. As a result of all this, the generated power reach 12 times. Other values remain constant.

According to the obtained data, current, voltage, power and efficiency can be plotted as a function of the load resistance. These curves is presented in Figure 5. In Figure 5, the cold and heat side temperatures of TEG are arranges as 30°C and 130°C. In this case, the maximum power of 22 W is obtained. The power useful that can operate many devices and tools.

CONCLUSION AND FUTURE WORK

By means of the study, TEGs was modelled in MATLAB/Simulink software. The number of parallel and serial branches to be used in a TEG system can be easily entered with the developed software. The maximum power and efficiency values that can be obtained from the TEG can easily be plotted by means of the used software as a function of the load resistor.

In another study, these values will be connected to a dc-dc converter. The algorithms to be used in the DC-DC converter will provide MPPT.

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