SIMULINK MODEL OF SEEBECK THERMOELECTRIC MODULE FOR POWER GENERATION

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Abstract

Thermoelectric Generators (TEG), developed using the Seebeck phenomenon, recover some of the waste heat as electrical energy. TEGs are one of the green technologies that can be used to increase energy efficiency. TEG models, which are generally used in simulations in academic studies, are run at certain temperature differences by keeping some parameters constant. However, when the temperature values on the TEG surfaces change, the internal resistance of the TEG changes depending on the temperature, even if the temperature difference remains constant. In this study, a TEG module, which is commercialized and also used in academic studies, is modeled according to datasheet information. In this model, the power delivered from the TEG, open circuit voltage, short circuit voltage and internal resistance of the TEG match the data of the real TEG module depending on the hot surface and cold surface temperatures. The simulation results with the TEG system created using this model show that this new model produces more realistic results.

Keywords: Thermoelectric Generators, Thermoelectric Module, Simulink Model, Seebeck.

INTRODUCTION

Thermoelectric generators (TEGs) are semiconductor devices that convert the temperature difference between their surfaces directly into electrical energy using the Seebeck Phenomenon [1], [2]. To increase the voltage produced by TEGs, *p* and *n* type thermoelements (TEs) are connected electrically in series and thermally in parallel to increase thermal conductivity [3]. They are used as small-powered electrical energy sources to recover electrical energy from waste heat and to increase energy efficiency [4].

When the load is connected directly to the terminals of the TEGs, if the connected load and the internal resistance of the TEG are not equal, the efficiency of the TEG drops further. This is referred to as impedance imbalance [5], [6]. To avoid this situation, converters capable of both maximum power point tracking (MPPT) and power regulation are used with TEGs [7]. Tsai and Lin proposed a model for TEGs in [8]. In this model, they designed a user-friendly interface with a dialog box similar to the Simulink library. But in this design, every parameter must be defined as a function. Similarly, Kennedy's TEG model uses current and voltage functions [9]. Burnete *et al.* proposed a detailed Simulink model for TEGs [10]. This detailed and well-organized model can be a bit of a challenge for researchers who are just starting to work on TEGs. However, in TEG models used in simulation studies, the temperature-dependent internal resistance is usually not taken into account and is not mentioned.

In this study, a simple TEG model is proposed that calculates the temperature-dependent internal resistance and Seebeck coefficient parameters of a TEG module using manufacturer data. In this method, comparison tables are prepared in Simulink using manufacturer data and graphics, and output data is sent according to the incoming information. It is a simple model with very little processing overhead. The biggest disadvantage is that a separate dataset must be formed for each module that is planned to be used. However, the model formed with the dataset constituted once can be used continuously. In this study, TGM-199-1.4-0.8 [11] thermoelectric module is used for simulations and testing. By means of the proposed model, more realistic results have been obtained.

THERMOELECTRIC MODULE POWER GENERATION PRINCIPLE

As shown in Figure 1, the electrical equivalent circuit of the TEG consists of a temperature dependent voltage source and an internal resistor, R_{int}. The load, R_L, is connected to deliver power from the TEG. When this load value and the internal resistance of the TEG are equal ($R_{int} = R_L$), the delivered power from the TEG reaches the maximum power point (MPP) [12]. As the load value changes, the delivered power value from the TEG decreases.

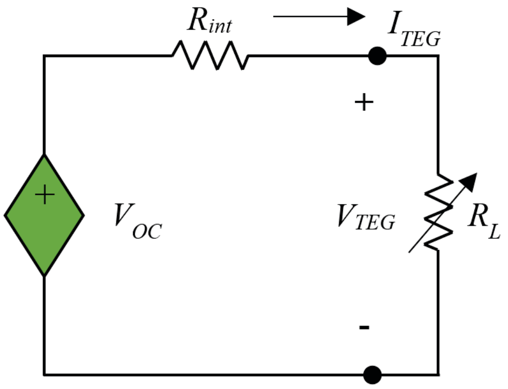

Fig. 1. Electrical equivalent circuit of TEG

When the power value delivered from the TEG is at the MPP point, the open circuit voltage and short circuit current are at their half values as explained below:

$$V_{MPP} = V_{OC}/2 \text{ and } I_{MPP} = I_{SC}/2 \qquad (1)$$

where, V_{MPP} and I_{MPP} are voltage (V) and current (A) at maximum power point, respectively. I_{SC} is the short-circuit current (A). With these values, MPP can be determined. The current value passing through the TEG is given below:

$$I_{TEG} = V_{OC}/(R_{int} + R_L) \qquad (2)$$

where, I_{TEG}, R_{int}, and $R_L$are TEG current (A), TEG internal resistance (Ω), and load resistance (Ω), respectively. The power delivered from the TEG depending on the load resistance and internal resistance is as follows:

$$P = \frac{V_{OC}^2}{(R_{int}+R_L)^2} \cdot R_L \qquad (3)$$

where, P is the power (W) generated from the TEG. As can be understood from Equation 3, the power generated from the TEG depends on the internal resistance of the TEG, R_{int}, and the load resistance connected to the TEG, R_L. MPPT methods are used with a converter to deliver maximum power from the TEG by equating the load resistance to the internal resistance of the TEG. However, when making this impedance matching in simulation studies, the TEG internal resistance, R_{int}, which changes with temperature, should also be taken into account and should not be used as a fixed value. Because, in experimental studies, R_{int} TEG changes due to the nature of the module and temperature changing. Maximum power can be reached when impedance matching is done with MPPT algorithms.

If the temperature-varying R_{int} is not modeled in simulation studies, there will be discrepancies between the simulation results and the experimental results. Therefore, in this study, a temperature-dependent internal resistance change model is proposed for the TGM-199-1.4-0.8 TEG module.

METHOD

The proposed Simulink model uses the manufacturer data of the TEG module and produces results compatible with these data. Firstly, the information presented graphically in the manufacturer's data is converted into usable data in Matlab with curve fitting methods and methods of obtaining data from the graph [13]. These data are then used as comparison tables in the Simulink. By using the temperature and temperature difference information, the R_{int} value closest to reality is used in the model through comparison tables. After the R_{int} value is modeled in accordance with the module data, the Seebeck coefficient, whose information is not given in the manufacturer's data, is also modeled depending on the temperature. Because the Seebeck coefficient also changes depending on the temperature fluctuations [14].

Simulation studies are carried out by keeping the cold surface temperature, T_H, constant at 30°C and varying the hot surface temperature between 40°C and 220°C. The variation of the calculated Seebeck coefficients are shown in Figure 2.

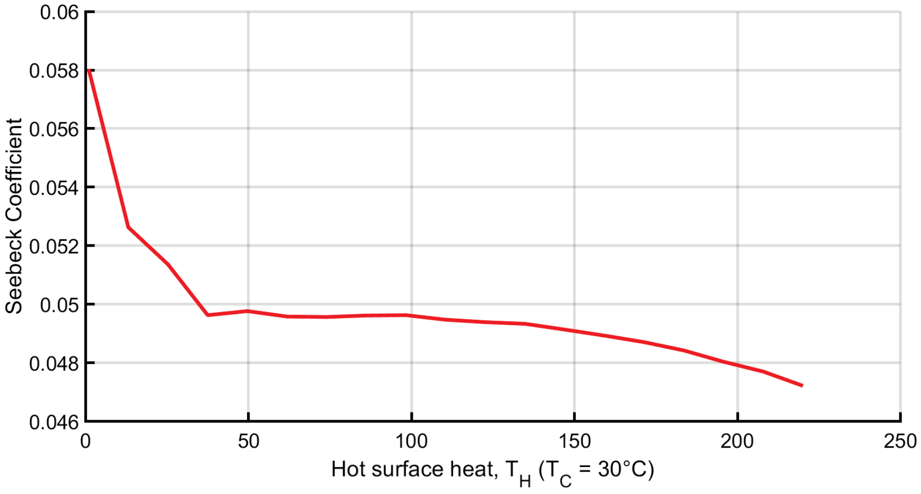

Fig. 2. *Calculated Seebeck Coefficient according to hot surface heat*

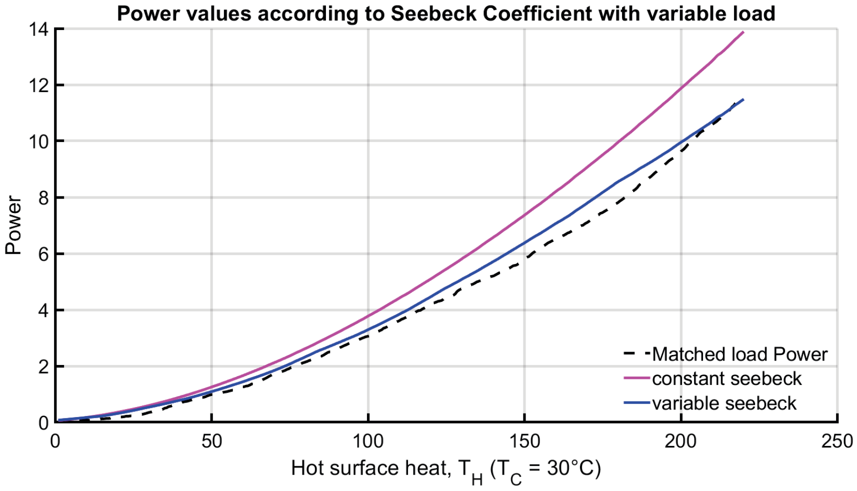

Fig. 3. *Power values according to Seebeck Coefficient with variable load*

The constant Seebeck coefficient is used as 0.053, and the variable Seebeck coefficient ranges from 0.058 to 0.0472. Figure 3 shows the comparison of the effect of Seebeck coefficients on power with the manufacturer's data.

CONCLUSION

To deliver maximum power from TEG modules depends on the temperature difference between the hot surface and the cold surface. The greater the temperature difference, the greater the power supplied from the TEG module. The internal resistances and Seebeck coefficients of TEG modules change depending on the temperature. Since these values change because of the nature of the modules in experimental studies, impedance equalization can be fulfilled automatically with the converter and MPPT algorithms and does not pose a problem. However, keeping the internal resistance of the module and the Seebeck coefficient constant in simulation studies would cause incorrect results. In order to prevent this, the internal resistance of the module and the Seebeck coefficient should be modeled in a way that changes depending on the temperature in simulation studies.

In carried out the study, TGM-199-1.4-0.8 module has been modeled. The Seebeck coefficient and the internal resistance of the module, which vary with temperature, allowed to obtain results closer to the manufacturer's data. With this method, more accurate simulation results could be obtained. As a disadvantage, this method have to be designed specifically for a

TEG module. But once the model is created, it could be used continuously.

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