Modeling and Analysis of a Thermoelectric Power Generator

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***Abstract*—Thermoelectric Generator (TEG) was developed using the Seebeck phenomenon. It consists of many thermocouples connected thermally in parallel and electrically in series to increase energy efficiency. TEGs instantly convert thermal energy to electrical energy with no rotating parts and are less likely to fail due to no moving parts. With the rising cost of fossil fuels and their negative impact on the atmosphere, it is time to consider TEGs as renewable energy sources with applications ranging from mW to W power. This study derives a mathematical model of a TEG module and validates it with MATLAB/SIMULINK.**

***Index Terms*—Thermo Electric Generator, TEG, Mathematical Modeling, Seebeck effect, Peltier effect, Heat flow**

I. INTRODUCTION

With population growth and continued demand for energy resources, there is a need to establish clean and environmentally sustainable alternative energy sources. These alternative energy sources, such as solar and wind, contribute to lower carbon emissions by reducing fossil fuel consumption (CO_2) [1] [2]. Thermoelectric generators (TEGs) are one of the alternative sources of renewable energy.

A thermoelectric power generator is a device that converts heat energy into electrical energy using the thermoelectric effect. The thermoelectric effect is the conversion of a temperature gradient into a voltage difference or converting of electricity to obtain a temperature gradient between two different materials that conduct electricity. This thermoelectric effect is used in thermocouples. With the advancement of modern semiconductor materials, the thermoelectric effect could be utilized for thermoelectric power generation. The thermoelectric effect consists of three effects, the Seebeck effect, the Peltier effect, and the Thomson effect [3].

The thermoelectric generator typically consists of two materials, metals or semiconductors, joined at two different temperatures to form a thermocouple. One end of the thermocouple is heated, while the other is cooled. This temperature difference creates an electric potential difference, which can be used to generate electricity. With the advancement of modern semiconductor materials, the thermoelectric effect could be utilized for thermoelectric power generation. The thermoelectric effect consists of three effects, the Seebeck effect, Peltier effect, and the Thomson effect [3].

Thermoelectric power generators are commonly used when a small amount of electrical power is needed, and a heat source is available. For example, they may be used to power sensors, remote monitoring systems, or other small electronic devices. They are also used in some automotive applications to convert waste heat from the engine into electricity, improving fuel efficiency.

One of the advantages of thermoelectric power generators is that they have no moving parts, making them durable and reliable. They are environmentally friendly as it operates without noise pollution, have no maintenance or replacement cost; have a wide power generation range (µW-kW); compact size; and no intermediate forms of energy conversion [4] [5]. The use of thermoelectric generators is increasing due to the tightening of (CO_2) emission regulations. Given its size, there are mainly two types of TEGS. Large TEGs are widely used in industry because they can deliver a high power, reaching hundreds of watts when the heat is very high. Micro TEGs can generate power in the microwatt to milliwatt range.

However, their efficiency is relatively low compared to other electrical power generation methods. They are typically only used when other power sources are not available or practical. Research is ongoing to improve the efficiency of thermoelectric power generators and to explore new applications for this technology. In [6], the authors designed and built two photovoltaic and thermal hybrid solar collectors, one of which is an integrated TEG module. In [5], the authors discussed the applications of TEGs for powering biomedical wearable sensors.

To model a thermoelectric power generator, several factors need to be considered as the used materials, the geometry of the device, and the operating conditions. The thermoelectric properties of the used materials in the device are critical to its performance. The materials should have a high Seebeck coefficient (which determines the voltage generated per unit temperature difference), a low thermal conductivity (to maximize the temperature difference across the device), and a high electrical conductivity (to minimize losses). The geometry of the device can also affect its performance. For example, the thermocouples' length and cross-sectional area can affect the device's electrical and thermal resistance. The distance between the hot and cold sides can also affect the temperature difference across the device, affecting the voltage generated. The temperature difference across the device, the temperature of the hot and cold sides, and the electrical load connected to the device can all affect its performance. Optimizing these parameters requires careful consideration of the specific application and operating conditions.

To model a thermoelectric power generator, one typically uses mathematical equations and computer simulations to predict its performance under different conditions. This may involve using finite element analysis (FEA) or other numerical methods to simulate the flow of heat and electricity through the device. The model can then optimize the device's design and predict performance under different operating conditions. Matlab/Simulink is a powerful tool for modeling and simulating thermoelectric power generators.

Modeling TEGs attracted many researchers. In [7], the article presents a detailed model of the Peltier and Seebeck modules using MATLAB/Simulink. The paper includes the electrical and thermal aspects of the modules, and the model is used to analyze the modules' performance under different operating conditions. In [8], the article presents a detailed model of a thermoelectric generator (TEG) for maximum power point tracking (MPPT). The model includes both the electrical and thermal aspects of the TEG, and is developed using Matlab/Simulink. In [9], the article presents a detailed model of thermoelectric generation of materials using Matlab/Simulink. The paper includes the electrical and thermal aspects of the materials, and the model is used to analyze the performance of the materials under different operating conditions.

Modeling thermoelectric generators can be challenging due to several factors. Thermoelectric generators exhibit nonlinear behavior due to the complex interaction between thermal and electrical properties. This can make it difficult to develop accurate models of the device. The performance of a thermoelectric generator is highly dependent on the properties of the materials used in the device. However, obtaining accurate material properties for modeling can be challenging, as these properties can vary with temperature and other factors. The geometry of the thermoelectric generator can also affect its performance, but modeling the geometry accurately can be challenging. Using three-dimensional models can be computationally expensive, and simplifying the geometry can lead to inaccuracies in the model. The performance of a thermoelectric generator is highly dependent on the operating conditions, such as the temperature difference across the device and the electrical load connected to the generator. Accurately modeling these conditions can be challenging, as they vary during operation. Validating the models of thermoelectric generators can also be challenging, as experimental data on the device's performance may be limited or difficult to obtain.

This study aims to present mathematical modeling for a thermoelectric module (TEM) for circuit simulation using MATLAB/Simulink software. The HZ-20 commercial TEG with its manufacturer data is used to validate the derived modeling. The organization of the paper is as follows. Section II describes the TEG structure and the thermoelectric effects with the associated equations. Section III derives the thermal and electrical models. Section IV derives and analyzes the generated power and the TEG efficiency. Section V presents the essential TEG parameters and identifies the commercial TEG that is used in the validation step. Section VI shows the simulation step.

II. THE TEG STRUCTURE AND THE THERMOELECTRIC EFFECTS

The heart of a TEG is the Thermoelectric Module (TEM), where many thermoelectric effects occur. The structure of the TEG power module consists of a pair of p-type and n-type semiconductor materials (thermocouple, TEC) with high thermoelectric coefficients. A TEG has many thermocouples formed by n-type and p-type semiconductor materials connected electrically in series and thermally in parallel to increase the output voltage or current, as shown in Fig. 1. These thermocouples are typically electrically connected to form an array of multiple thermocouples. A thermoelectric module has hot and cold side heat sinks, boundary layers, and insulating layers to prevent heat from spreading to the cold side. Most thermoelectric power module manufacturers use many thermoelectric pairs sandwiched between two sheets of non-conducting material. Furthermore, the material needs thermal conductivity to ensure good heat transfer and using two thin ceramic wafers to form thermoelectric modules. Each module contains dozens of thermoelectric pairs and is called a thermoelectric generator module. However, there are performance differences from module to module, depending on the purpose of the module.

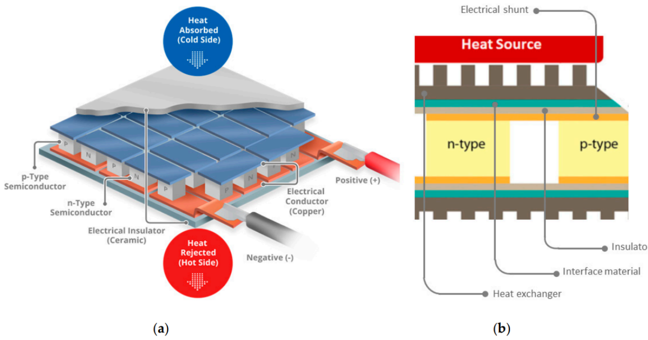

Fig. 1: (a) Working principle of TEG; (b) components of a typical thermoelectric generator [5].

Four essential energy phenomena occur in the TEM: the Seebeck effect, the Peltier effect, thermal conduction, and Joule heating. As the charge carriers have higher thermal energy on the hot side compared to the cold side, a diffusion of charge carriers from the hot side to the cold side in the thermoelectric material exists, resulting Seebeck effect. The gradient of charge carrier distribution generates an opposite electric field that restricts the diffusion process until the equilibrium state. Thus, The Seebeck effect generates a difference in the potential between two dissimilar materials when imposed to a temperature gradient. The Seebeck open-circuit voltage for a TEM composed of N thermocouples is expressed in Eqn. 1.

The Peltier effect is the reverse process of the Seebeck effect. Peltier phenomenon results in heat absorption/dissipation due to current flow through a junction of two dissimilar materials. TEM Peltier effect is described in Eqn. 2.

Joule heating effect exists when a current flows through a resistive element. The dissipated heat from this effect is given in Eqn. 3 [10].

The thermal conduction effect displays the thermal conductivity or resistivity of materials. For a TEM, the heat transfer of thermal conduction is given in Eqn. 4.

$$V_{OC,TEM} = \alpha_{total} \bigtriangleup T = N\alpha_s \bigtriangleup T \tag{1}$$

$$Q_{a/d} = \alpha_{total} I T_{hot/cold} \tag{2}$$

$$Q_{Joule} = I^2 R_{E,TEM} \tag{3}$$

$$\begin{aligned} Q_{p,n}(x) &= -\frac{A_{p,n}}{\rho_{T,p,n}} \frac{dT_{p,n}}{dx} \\ &\simeq -\bigtriangleup T \left(\frac{A_p}{\rho_{T,p} L_p} + \frac{A_n}{\rho_{T,n} L_n} \right) = -\frac{\bigtriangleup T}{R_T} \end{aligned} \tag{4}$$

where α_s is the Seebeck coefficient (V/K), $\bigtriangleup T = T_{hot} - T_{cold}$, $T_{hot/cold}\,(K)$ is the hot/cold temeratures, $I\,(A)$ is the current flowing through the material, R_E is the electrical resistance of the semiconductor material, $A_p\left(m^2\right)$ and $A_n\left(m^2\right)$ are the p and n cross-section areas, $L_p\,(m)$ and $L_n\,(m)$ are the p and n lengths, $\rho_{T,p}\,(mK/W)$ and $\rho_{T,n}\,(mK/W)$ are the p and n thermal resistivity.

III. TEG MATHEMATICAL MODELING

For the pn thermocouple, the electrical resistance $R_E\,(\Omega)$, and the thermal resistance $R_T\,(K/W)$ are given in Eqn. 5.

$$\begin{aligned} R_E &= R_{E,p} + R_{E,n} = \frac{\rho_{E,p} L_p}{A_p} + \frac{\rho_{E,n} L_n}{A_n} \\ R_T &= R_{T,p} \parallel R_{T,n} = \frac{\rho_{T,p} L_p \rho_{T,n} L_n}{\rho_{T,p} L_p A_n + \rho_{T,n} L_n A_p} \end{aligned} \tag{5}$$

where $\rho_{E,n}\,(\Omega m)$ and $\rho_{E,n}$ are the p/n electrical resistivity.

A. Thermal Modeling

The heat-flow variation along the PN-length (L) is described by a differential equation of the conduction at a distance dx from the initial position x, Eq. 6.

$$\begin{aligned} dQ_{p,n} &= Q_{p,n}(x + dx) - Q_{p,n}(x) \\ &= I_{TEM}^2 \;\, dR_{E,p,n}(x) \\ &= I_{TEM}^2 \;\, \frac{\rho_{p,n} dx_{p,n}}{A_{p,n}} \end{aligned} \tag{6}$$

where $Q_{p,n}$ is the conduction heat flow and $I_{TEM}^2 dR_{E,p,n}(x)$ represents the joule heating generated by the flow of current I_{TEM}.

The heat conduction rate at the hot and the cold junctions of the n-type and p-type thermocouple can be obtained from Eqns. 4, 6, and the temperature boundary conditions: $T_{p,n}(0) = T_{hot}$ and $T_{p,n}(L) = T_{cold}$, Eqn. (7).

$$\begin{aligned} Q_p(0) &= \frac{\bigtriangleup T}{R_{T,p}} - \frac{I_{TEM}^2 R_{E,p}}{2} \\ Q_p(L) &= \frac{\bigtriangleup T}{R_{T,p}} + \frac{I_{TEM}^2 R_{E,p}}{2} \\ Q_n(0) &= \frac{\bigtriangleup T}{R_{T,n}} - \frac{I_{TEM}^2 R_{E,n}}{2} \\ Q_n(L) &= \frac{\bigtriangleup T}{R_{T,n}} + \frac{I_{TEM}^2 R_{E,n}}{2} \end{aligned} \tag{7}$$

The rate of heat transfer from the heat source to the single-couple TEG and from the device to the heat sink can be obtained by adding the Peltier terms $\alpha I_{TEM} T_{hot}$ and $\alpha I_{TEM} T_{cold}$ at the boundary points, Eqns. (8).

$$\begin{aligned} Q_{hot} &= Q_p(0) + Q_n(0) + \alpha I_{TEM} T_{hot} \\ &= \frac{\bigtriangleup T}{R_T} - \frac{I_{TEM}^2 R_E}{2} + \alpha I_{TEM} T_{hot} \\ Q_{cold} &= Q_p(L) + Q_n(L) + \alpha I_{TEM} T_{cold} \\ &= \frac{\bigtriangleup T}{R_T} + \frac{I_{TEM}^2 R_E}{2} + \alpha I_{TEM} T_{cold} \end{aligned} \tag{8}$$

For a TEG with N couples, update the Seebeck coefficient: $\alpha_{total} = N\alpha$, thermal resistance: $R_{TEM,T} = \frac{R_T}{N}$, and the electrical resistance: $R_{TEM,E} = NR_E$.

B. Electrical Modeling

Per a TEG, the generated electrical power is given in Eqn. 9, and the electrical model is depicted by Eqn. (10). If the connected load and the internal resistance of the TEG are not equal, the efficiency of the TEG drops further, which is called impedance imbalance. Thus, TEG application systems should include maximum power point tracking (MPPT) and power regulation devices [11].

$$\begin{aligned} P_{TEM} &= Q_{hot} - Q_{cold} = V_{TEM} I_{TEM} \\ &= V_{TEM,OC} I_{TEM} - I_{TEM}^2 R_{TEM,E} \end{aligned} \tag{9}$$

$$\textit{By dividing both sides by } \; I_{TEM}$$

$$V_{TEM} = V_{TEM,OC} - I_{TEM} R_{TEM,E} \tag{10}$$

IV. POWER AND EFFICIENCY ANALYSIS

Equating the discriminant of the quadratic power Eqn. 9 to zero, the maximum power and maximum current are as follows.

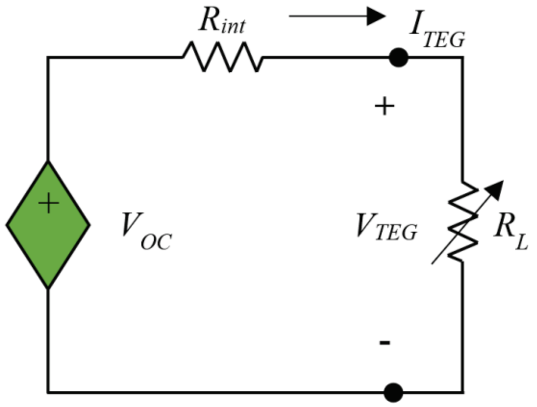

Fig. 2: Electrical equivalent circuit of a TEM.

$$\begin{aligned} &V^2_{TEM,OC} - 4R_{TEM,E}P \quad \geq 0 \\ &P_{max} = \frac{V^2_{TEM,OC}}{4R_{TEM,E}} && (11) \\ &I_{TEM,max} = \frac{V_{TEM,OC}}{2R_{TEM,E}} && (12) \end{aligned}$$

Equating the power P in Eqn. 9 to zero, the zero-power occurs at $I_{TEM} = 0$, which is the open-circuit case, and at $I_{TEM} = (I_{TEM})_{SC} = \frac{V_{TEM,OC}}{R_{TEM,E}}$, which is the short-circuit case.

Taking the current I_{TEM} from Eqn. 10, and substituting in the power Eqn. 10, we'll get:

$$\begin{aligned} P =& V_{TEM,OC}\left[\frac{V_{TEM,OC} - V_{TEM}}{R_{TEM,E}}\right] \\ &- \left[\frac{V_{TEM,OC} - V_{TEM}}{R_{TEM,E}}\right]^2 R_{TEM,E} \\ P =& \frac{V_{TEM}\left(V_{TEM,OC} - V_{TEM}\right)}{R_{TEM,E}} && (13) \end{aligned}$$

Equation 13 shows that the zero-power occurs at two cases: when $V_{TEM} = 0$, which is the short-circuit case, and when $V_{TEM} = V_{TEM,OC}$, which the open-circuit case.

Differentiating Eqn. 13 with respect to V_{TEM}, and equating the result to zero, the condition at which the power is a maximum and its value are given below.

$$\textit{the condition: } V_{TEM,max} = \frac{V_{TEM,OC}}{2} \qquad (14)$$

$$P_{max} = \frac{V^2_{TEM,OC}}{4R_{TEM,E}} \qquad (15)$$

Equations 12, and 14 show that the maximum power occurs when the load resistance equals the internal electrical resistance.

The efficiency of the TEG is the ratio of the generated electrical power and the heat power, as follows.

$$\eta = \frac{P_{TEM}}{Q_{hot}} = \frac{V_{TEM,OC}I_{TEM} - I^2_{TEM}R_{TEM,E}}{\frac{\triangle T}{R_T} - \frac{I^2_{TEM}R_E}{2} + \alpha_{total}I_{TEM}T_{hot}} \qquad (16)$$

The system has a zero-efficiency at two cases: when $I_{TEM} - 0$, which is the open-circuit case, and when $I_{TEM} = \frac{V_{TEM,OC}}{R_{TEM,E}}$, which is the short-circuit case.

High α_s, low R_E, and low thermal conductivity $\frac{1}{R_T}$ are essential for the best TEG's performance. The TEG's efficiency depends on the figure-of-merit Z, given by Eqn. 17. The Z values greater than 1.5 are preferred for power generation [12].

$$Z = \frac{\alpha^2_{total}R_{TEM,T}}{R_{TEM,E}} \qquad (17)$$

$$(18)$$

Solving Eqn. 16 for the maximum efficiency through differentiation, the optimum current and the highest value of efficiency are as follows [13].

$$\begin{aligned} I_{TEM,opt} =& \frac{2\triangle T}{R_{TEM,T}\ \ \alpha_{total}\left(T_{hot} + T_{cold}\right)} \\ &\times \left(\sqrt{1 + \frac{Z}{2}\left(T_{hot} + T_{cold}\right)} - 1\right) && (19) \\ \eta_{max} =& \frac{\triangle T}{T_{hot}} \frac{\sqrt{1 + \frac{Z}{2}\left(T_{hot} + T_{cold}\right)} - 1}{\sqrt{1 + \frac{Z}{2}\left(T_{hot} + T_{cold}\right)} + \frac{T_{cold}}{T_{hot}}} && (20) \end{aligned}$$

The materials, design, and optimization of TEGs are important considerations for maximizing efficiency [4]. The thermoelectric material researchers focus on achieving a high value of Z, a high Seebeck coefficient, low thermal conductivity, and high electrical conductivity. Most manufacturers use bismuth telluride $Bi2Te3$ with various additives in building TEMs.

V. ESSENTIAL TEG PARAMETERS AND TEG IDENTIFICATION

A typical TEM consists of TE elements, ceramic plates, and copper stripes that all induce thermal or electrical resistances, as in Fig. 3. Therefore, we will consider the equivalent parameters instead of the actual TE material properties when solving the TEM model.

Three essential parameters characterize TEG performance: Seebeck Coefficient α, thermal resistance R_T, and electrical resistance R_E. The output power depends on these three parameters and the boundary conditions. However, these parameters are always unknown and must be estimated. The equivalent TEG parameters are calculated according to Eqn. 21.

$$\begin{aligned} \alpha_{total} &= \alpha_m \times Num_{TEM} \\ R_{TEM,E} &= R_{m,E} \times Num_{TEM} \\ R_{TEM,T} &= \frac{R_{m,T}}{Num_{TEM}} && (21) \end{aligned}$$

where α_m, $R_{m,T}$, and $R_{m,E}$ are Seebeck coefficient, thermal and electrical resistances for a single module, respectively.

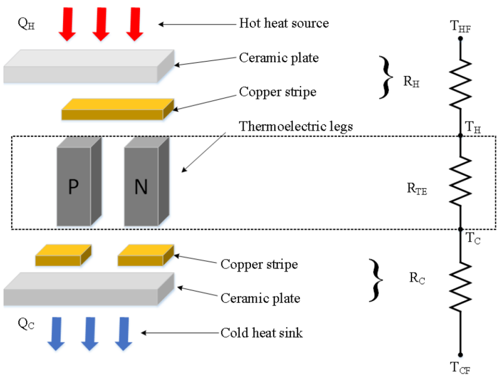

Fig. 3: Thermal resistance of a TEM [14].

The manufacturer datasheet provides the open circuit voltage, V_{oc}, under specific T_{hot}, T_{cold}, heat flux Q_H at a given temperature, electrical resistance R_e, and load current I_L. The equivalent TEG parameters are calculated as in Eqn. 22.

$$\begin{aligned} \alpha &= \frac{V_{OC}}{T_{hot} - T_{cold}} \\ R_{th} &= \frac{T_{hot} - T_{cold}}{Q_H - \alpha I_L T_{hot} + 0.5 I_L^2 R_e} \end{aligned} \tag{22}$$

If the TE leg geometries and material properties: thermal conductivity λ, and electric resistivity ρ are known, which can be used to simulate the system with custom-made TEMs.

The TEM key parameters: $\alpha_P, \alpha_n, R_{th}, R_e$ are calculated [15] and expanded to the TEG level using Eq. 21. The total heat flow, Seebeck coefficient, thermal resistance, and electrical resistance of the TE couple are given by Eqn. 23.

$$\begin{aligned} Q_H &= (\alpha_p - \alpha_n) I T_H - (T_C - T_H) \left(\frac{\lambda_p A_p}{\ell} + \frac{\lambda_n A_n}{\ell} \right) \\ &\quad - \frac{I^2}{2} \left(\frac{\rho_p \ell}{A_p} + \frac{\rho_n \ell}{A_n} \right) \\ \alpha &= \alpha_p - \alpha_n = \frac{Q_H}{I T_H} - \frac{(T_H - T_C)}{I T_H} \left(\frac{\lambda_p A_p}{\ell} + \frac{\lambda_n A_n}{\ell} \right) \\ &\quad + \frac{I^2}{2 I T_H} \left(\frac{\rho_p \ell}{A_p} + \frac{\rho_n \ell}{A_n} \right) \\ R_{th} &= \frac{1}{\frac{\lambda_p A_p}{\ell} + \frac{\lambda_n A_n}{\ell}} \\ R_e &= \frac{\rho_p \ell}{A_p} + \frac{\rho_n \ell}{A_n} \end{aligned} \tag{23}$$

where ℓ, and$A$ are length, m, and the cross-section area, m^2, of the PE leg, respectively.

This article considers the HZ-20HV-20W TEG module manufactured by Hi-Z Technology. This module has been tested in several pieces of research and under different conditions [16]. Part of its technical specifications is presented in Table I [17]. This module consists of 71 thermocouples arranged electrically in series and thermally in parallel. Each thermocouple consists of Bismuth Telluride-based semiconductors to give the highest efficiency at most waste heat temperatures. The metal conductors enable the module to operate continuously at temperatures as high as $250C^{\circ}$ without degradation.

TABLE I: Specifications, thermal, and electrical characteristics of the HZ-20 module.

Physical Properties	
Thermoelectrical material	Bismuth Telluride
Module dimension (mm)	$75 \times 75 \times 5.08$
Weight (g)	115
Number of active couples	71
Thermal Properties	
Maximum hot temperature (C°)	250
Cold temperature (C°)	50
Thermal conductivity $\lambda\,(W/cm * K)$	0.024
Heat flux (W/cm^2)	9.54
Heat flux (W/cm^2) at matched load	(15-17)
Electrical Properties	
Power (W) at matched load	(23.1 - 25.5)
Open-circuit voltage (V)	(10.3 - 11.3)
Matched load voltage (V)	(5.2 - 5.6)
Internal resistance (Ω)	(1.14 - 1.26)
Current (A) at matched load	(4.3 - 4.7)
Current (A) at short-circuit	(8.5 - 9.5)
Heat flow (W) at matched load	(703 - 777)
Heat flow (W) at open-circuit	(570 - 630)

VI. SIMULATION VALIDATION

Modeling a thermoelectric power generator using Matlab/Simulink starts by using the thermoelectric equations to describe the TEG's behavior. This includes the Seebeck coefficient, electrical conductivity, and the thermal conductivity of the materials used. Within the Simulink, creating blocks for each component of the device and connecting them together. Defining the inputs (such as the temperature of the hot and cold sides) and outputs (such as the voltage and current generated by the device) of the model. Finally, validate the model by comparing the simulation results with the manufacturer's data.

Figures 4, and 5 show the derived model in the Simulink environment.

The manufacturer's data of the HZ-20 TEG are sent to MATLAB. The simulation process is carried out by keeping the cold surface temperature at $50C^{\circ}$, and varying the hot surface temperature to reach the maximum value at $250C^{\circ}$. The calculated Seebeck coefficient is 0.056. The generated power, voltage, and current versus the temperature variation are plotted in Fig. 6, and 7. Figure 6 gives a maximum generated power of about 25.5 W at $\triangle T = 198K$. At the same $\triangle T$, the generated voltage and current are 5.7 V and 4.5 A. The maximum TEG efficiency is $\left(\frac{25.5}{777}\right) \times 100 = 3.3\%$.

VII. CONCLUSION

Delivering maximum power from TEG modules depends on the temperature difference between the hot and cold surfaces. The greater the temperature difference, the greater the power supplied from the TEG module. The internal parameters of a TEG module depend on the temperature variation. However, in this study, we kept the Seebeck coefficient constant and assumed a matched case in which the load resistance matches the internal resistance. In carrying out the study,

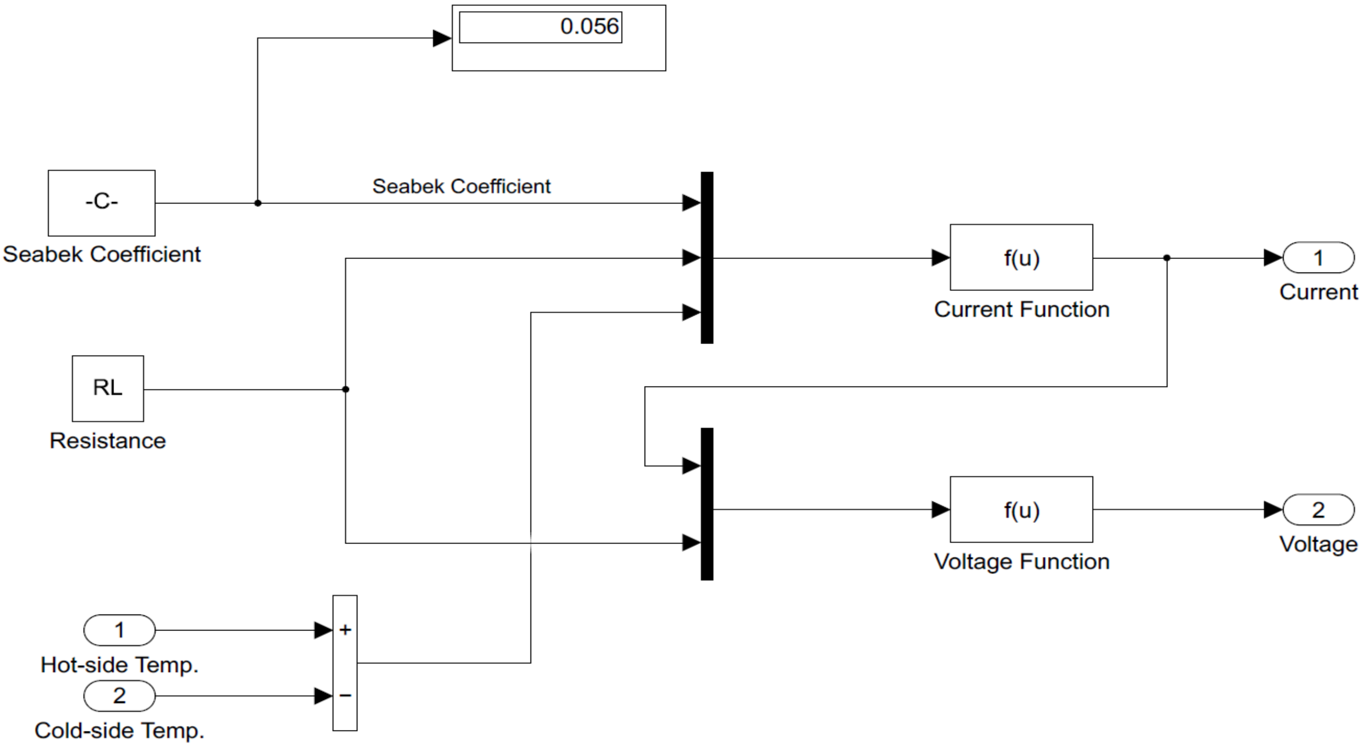

Fig. 4: Simulink validation part I.

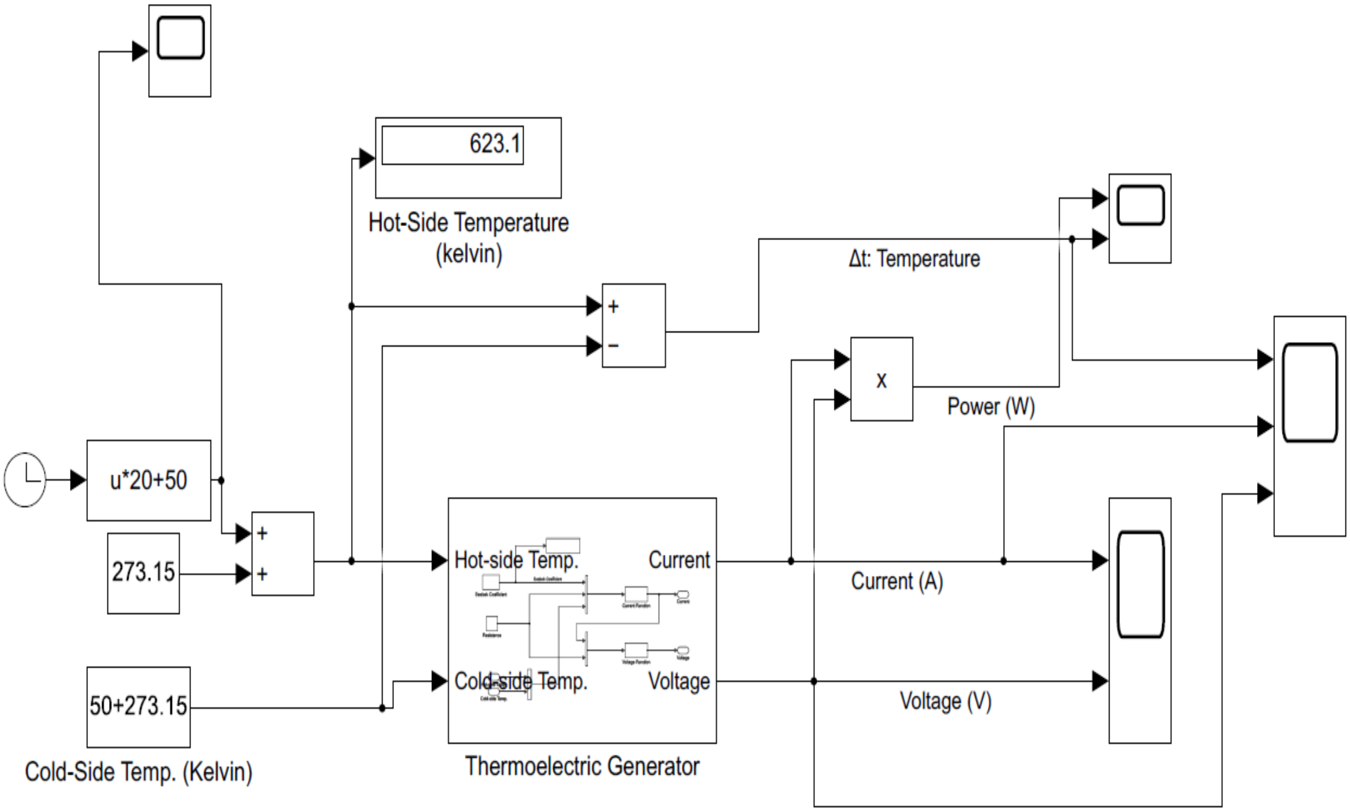

Fig. 5: Simulink validation part II.

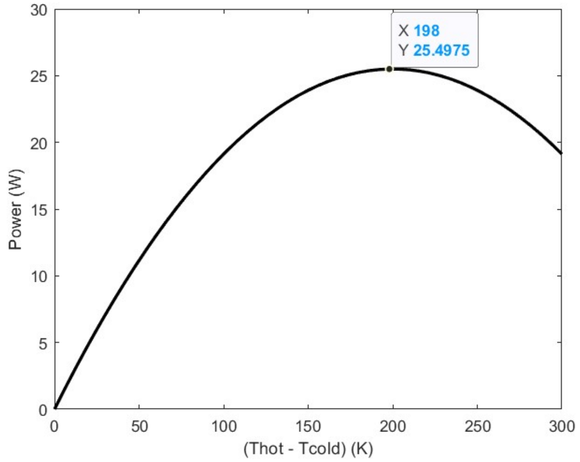

Fig. 6: The generated power versus $\triangle T$.

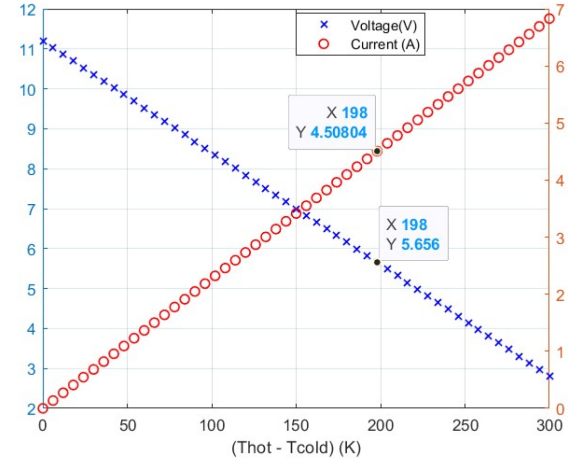

Fig. 7: The generated voltage and currents versus $\triangle T$.

the HZ-20 module has been modeled. The obtained results were so close to the manufacturer's data. With the validation through Simulink, this study highlights the importance of considering TEG as a source of green energy. It assures that Matlab/Simulink is a powerful platform for modeling and simulating thermoelectric power generators. As further work, the change of Seebeck coefficient and internal resistance with temperature variation is to be taken into consideration to have more accurate simulation results.

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