Full paper

Comparison of Thermoelectric Generator (TEG) Performance Parameter Between Modelling and Simulation Results and Manufacturer Datasheet For HZ-20 & HZ-14

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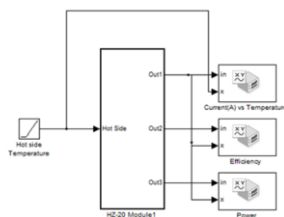
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Graphical abstract

Abstract

Currently, bio-medical and automotive industries use thermoelectric module to reproduce electrical energy from wasted heat energy. Thermoelectric generator (TEG) modeling and simulation will be hashed out further in this paper to achieve improvement. Finite element method (FEM) model, circuit equivalent model and mathematical/computer model are various methods employed to model the thermo-electric generator. Analysis of FEM modeling requires a high tier of knowledge of an engineer in material engineering. The circuit equivalent model uses the electrical circuit analogy to describe heat transfer and electrical behavior in TEG. In this work, the mathematical derivation of circuit equivalent model is used in computer models by using Simulink (Matlab). The result of the computer model can be an alternative model for electrical or electronics engineers to improve TEG performance in the future.

Keywords: Thermoelectric module; thermoelectric generator; finite element method (FEM); circuit equivalent model

■1.0 INTRODUCTION

Physical phenomena for thermoelectricity was firstly introduced by Thomas Johann Seebeck in 1821.[1] Installation of two dissimilar metals which having temperature difference between it, will generate electric potential. Peltier effect stated that cooling and heating effect are produced from electrified two dissimilar junctions which is working oppositely with Seebeck effect.[1] In early 1960, the idea of semiconductor was applied in thermoelectricity for improvement needs by doping n-type and p-type structure.[1] Nowadays, Thermoelectric Module (TEM) application is used in automotive and refrigerator systems.[1] TEM is a flexible device that can be used as Thermoelectric Cooler (TEC) or Thermoelectric Generator (TEG) which applies Seebeck and Peltier effect respectively. Producing electricity by using TEG is the most suitable application for TEM because it has benefit such as solid-state device which can provide compactness and noiseless. Usually, maximum efficiency is not exceeding more than 12%, so it is not suitable practically for a power station (according to Carnot's Law).[1] Heat energy is always being wasted by any sector to the sorrounding but the application of TEG will use some heat energy to be converted to electrical energy. Generally, low power integrated circuit like microelectronics devices and wireless sensors node can be powered up by TEG.[1]

Finite element model, circuit and/or computer model are various methods to model and simulate the behavior of TEG. Finite element model was designed by using the principle finite element method. The behavior of the device is described by using the limit value of the partial non-linear equation and it was justified by comparing with experimental results. This model concentrates more on material properties, geometry and material design. It requires material engineering and physical properties knowledge. Mainly, the niche software for managing this sort of simulation is ANSYS, which is in 3-D view of TEM geometry and condition for every mesh.[2] Circuit model uses the electrical circuit analogy to explain the heat transfer and generated voltage of TEG by having two different circuits (thermal equivalent circuit and electrical circuit). Temperature will be substituted as electrical voltage, thermal resistance to electrical resistance and heat flux to electrical current.[1] This model implementation is widely used in power electronic application. SPICE-like simulator is being used to make it easier to understand by electrical or electronics technologist community. Simulink or computer block model for control objectives such as temperature control and Maximum power point tracking (MPPT).[3] All formulas and parameters will be pluged into formula block diagram in temperature and current domain.

◾2.0 FUNDAMENTAL PRINCIPLE OF THERMOELECTRIC MODULE

Usually, a TEM's basic circuit equivalent is the same for TEG or TEC that can be practiced to simulate and model their characteristic and physicals effect such as heat transfer from hot side to cool side. TEM also consists of p-type and n-type pair in N-couples of series metal connection. There are four physical energy phenomenon taking part in TEM: thermal conduction, Joule heating, Peltier cooling/heating, Seebeck effect. Thompson effect was assumed zero because the value is too small to be considered.

Thermal conductivity shows the existence of Fourier processes and that is described by thermal conductivity κ_{th} of any material and the high temperature transfer of thermal conduction is written down:

$$Q_{th}= -\Delta T \kappa_{th} \qquad (1)$$

Where:

$$\Delta T = T_H - T_c \qquad (2)$$

Electrical poterntial energy across TEG/TEC produces power dissipation across internal resistance R or load resistance R_L. This phenomenon is called as Joule Heating dissipated in TEG/TEC:

$$Q_J = I^2 R \qquad (3)$$

Peltier effect happens when the junction of two dissimilar conducting materials is having the presence of a flowing electrical current. The cold and hot junction $Q_{H/C}=SIT_{H/C}$ where S is replaced as Seebeck coefficient. Finally, by applying energy balance equation for every hot and cold side by summing all heat energy transfer formula.

$$Q_H = SIT_H - 0.5I^2 R - \Delta T \kappa_{th} \qquad (4)$$

and

$$Q_C = SIT_c + 0.5I^2 R - \Delta T \kappa_{th} \qquad (5)$$

TEM output voltage is given as V= Vs+IR with V_s represents Seebeck voltage. Application of line integration is used to formulate generated Seebeck voltage:

$$V = \int_{T_C}^{T_H} S \, dT = S\Delta T \qquad (6)$$

Figure of merit (FOM) is a constant value to determine the TEG application which combines with a large Seebeck coefficient and low R can be expressed

$$Z = \frac{S^2}{R\kappa_{th}} \qquad (7)$$

2.1 Determination of TEG Performace Parameters

Generally, parameters in the datasheet from TEM manufacturers cover hot side temperature (TH), cool side temperature (Tc), matched ratio load with internal resistance power (Wm) which mean (RL=R) will produce matched voltage (Vm=VR) [1]–[6]. Hence, the given parameters are useful to calculate electrical parameter for the TEG circuit model by referring the datasheet.

$$R_L = R = \frac{V_m^2}{W_m} \qquad (8)$$

and

$$S = \frac{2V_m}{\Delta T} \qquad (9)$$

Where

$$R_L = mR \qquad (10)$$

Current flows and value depends on the temperature different.

$$I = S\Delta T/((1+m) \, R) \qquad (11)$$

At matched load

$$I = S\Delta T/2R \qquad (12)$$

The thermal efficiency of TEG value is a ratio between powers at load resistance to heat energy at hot side junction.

$$n_{th} = \frac{I^2 R_L}{Q_H} = \frac{mZ\Delta T}{[(1+m)^2 + Z[(m+0.5)T_H + 0.5T_c]]} \qquad (13)$$

At matched load

$$n_{th}^m = \frac{Z\Delta T}{4 + Z[1.5T_H + 0.5T_c]} \qquad (14)$$

Short circuit current at load resistance will double up the matched load current flow through internal resistance.

$$I_{SC} = 2I_m \qquad (15)$$

So, the voltage output can be formulated as

$$V = -R(I - I_{sc}) \qquad (16)$$

◾3.0 SIMULATION RESULT AND DISCUSSION(HZ-20)

Figure 1 shows the main block for subsystems to run the simulation for HZ-20 (TEG) module from the manufacturer. Hot side temperature is an input variable to monitor HZ-20 module output from current, efficiency and power scope which uses ramp function. From the observation, efficiency and power are measured from the current domain perspective. All parameters that obtain from datasheet are being used in subsystem's paramters implementation: W_m= 22.0W, T_c=303K, V_m=2. 38 and n_{max}=4. 5% of matched load.
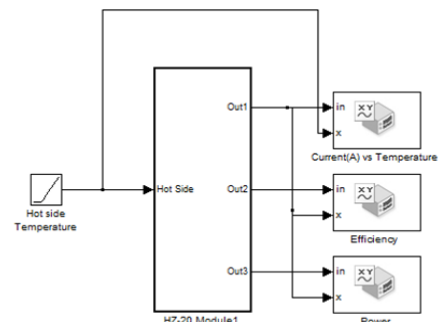

Figure 1 Main Block System for HZ-20 module

Figure 2 shows the relation between linear relationship current and hot side temperature. From the graph, it shows that current starts flowing after 303K by using equation 12. Increment of current is too slow compared to the increment of temperature because it depends on material selection.
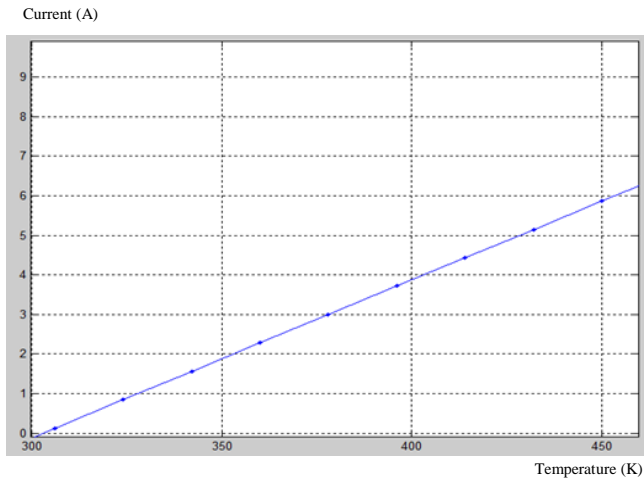
Current (A)

Temperature (K)

Figure 2 Simulation result for Current - Hot Side temperature

Figure 3 shows the simulation result for efficiency and it is represented in current function. HZ-20 module is having optimum efficiency at 4.8%, and current (I) approaches about 8.0 A.

Efficiency (%)
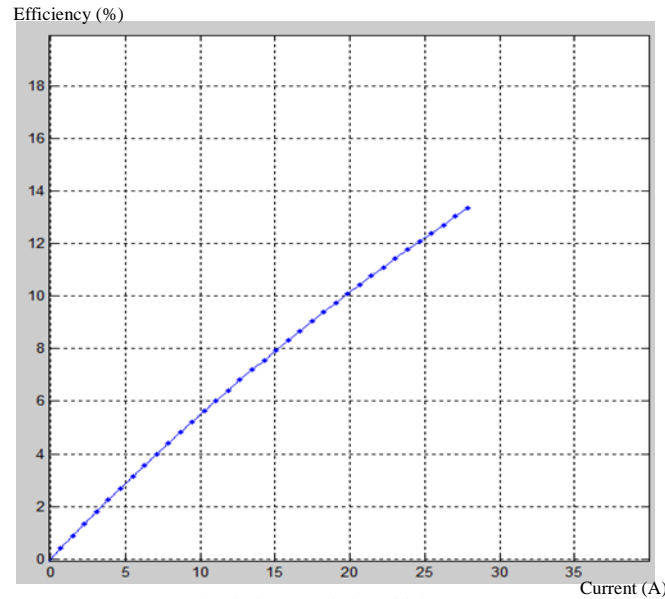
Current (A)

Figure 3 Simulation Result for Efficiency – Current

Figure 4 shows power curve from simulation result for HZ-20 module which is similar to manufacturer datasheet (Figure 5). The maximum power dissipated across load resistance (RL) is around 22W and the current is about 9.80A. Figure 5 also shows that when the efficiency is 4.8%; Current is 8.0A. It means themaximum efficiency does not come from maximum power which is the same as Figure 3 explanation.
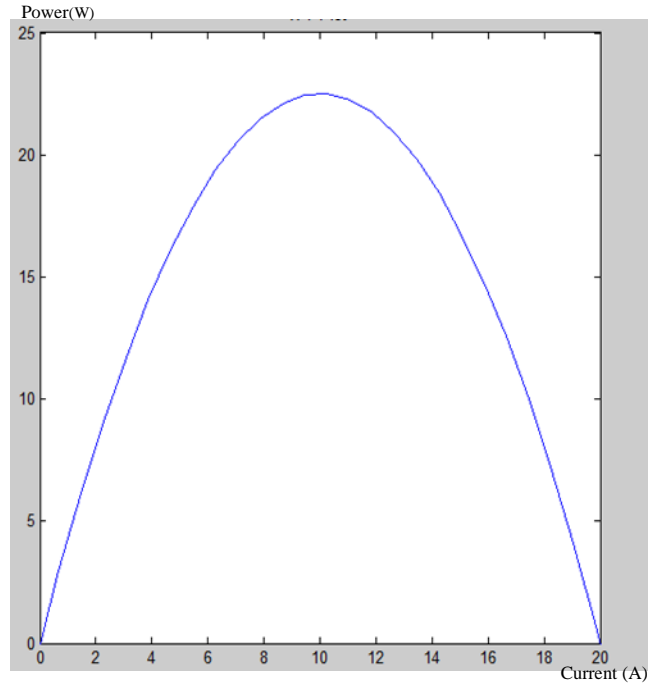
Power(W)

Current (A)

Figure 4 Simulation Result for Electrical Power - Current
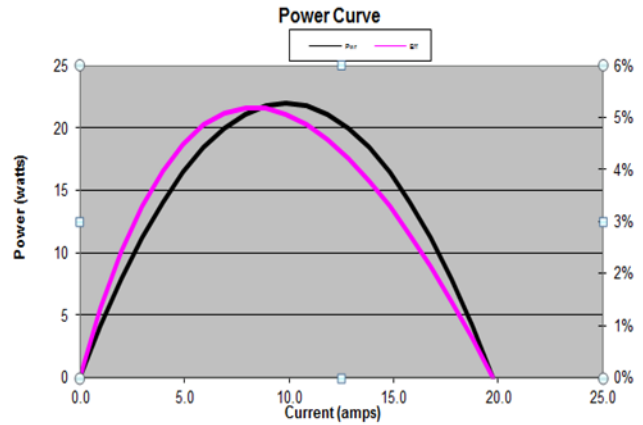

Figure 5 Hi-Z 20 Manufacturer characteristic datasheet for Power-Current and Efficiency-Current

3.1 Simulation Result and Discussion (HZ-14)

Figure 6 shows the main block for subsystems to run the simulation for HZ-14(TEG) module from the Hi-Z manufacturer. Hot side temperature is an input variable to monitor HZ-14 module output from current, efficiency and power scope which uses ramp function From the observation, efficiency and power are measured from the current domain perspective. All parameters that is obtained from datasheet are being used in subsystem's parameters implementation: W_m= 15.2W, T_c=303K, V_m=1.54 and n_{max}=4. 5% of matched load.
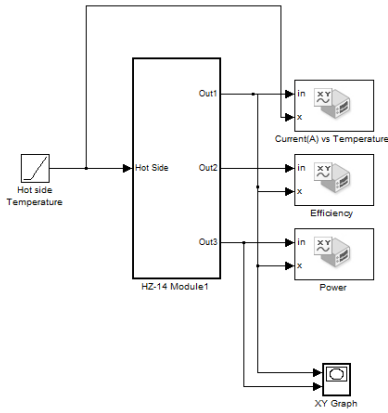
Figure 6 Main Block System for HZ-14 module

Figure 7 shows the relation between linear relationship between current and hot side temperature. From the graph, it shows that current starts flowing after 303K by using equation 12. Increment of current is too slow compared to the increment of temperature because it depends on material selection.
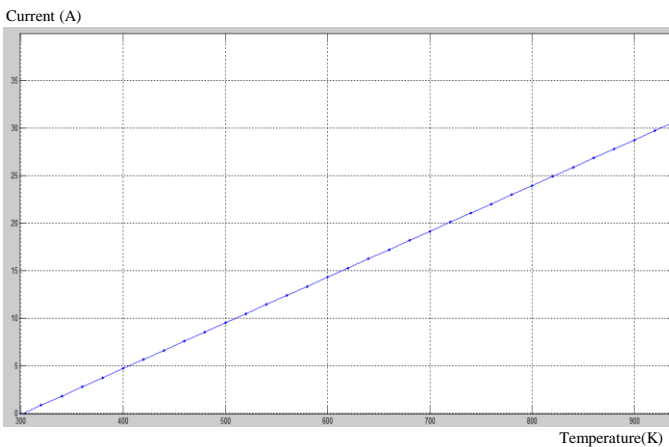

Figure 7 Simulation result for Current - Hot Side temperature

Figure 8 shows the simulation result for efficiency and it is represented in current function. HZ-14 module is having optimum efficiency is 4.8%, and current is 7.80A.
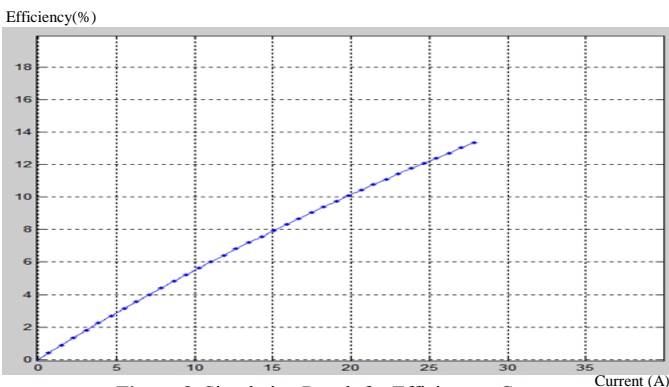

Figure 8 Simulation Result for Efficiency - Current

Figure 9 shows power curve from simulation result for HZ-14 module which is similar to manufacturer datasheet (Figure 10). The maximum power dissipated across load resistance (RL) is around 15.2W and current is about 9.86A. Figure 10 also shows that when the efficiency is 4.8%; current is7.8A, it means the maximum efficiency does not come from maximum power which is the same as Figure 8 explanation.
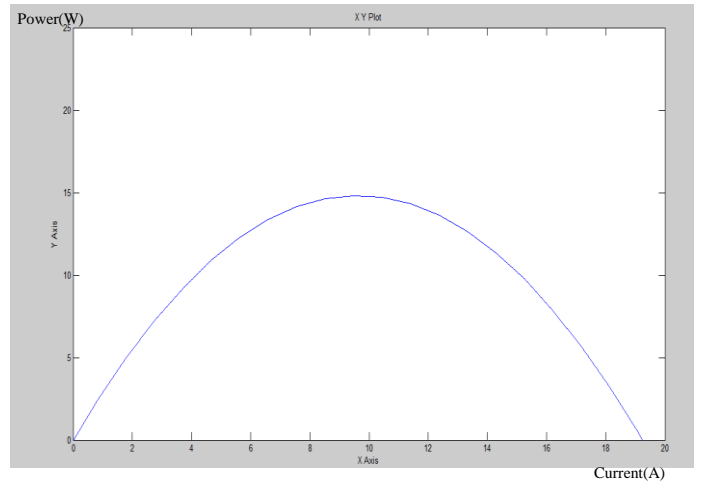

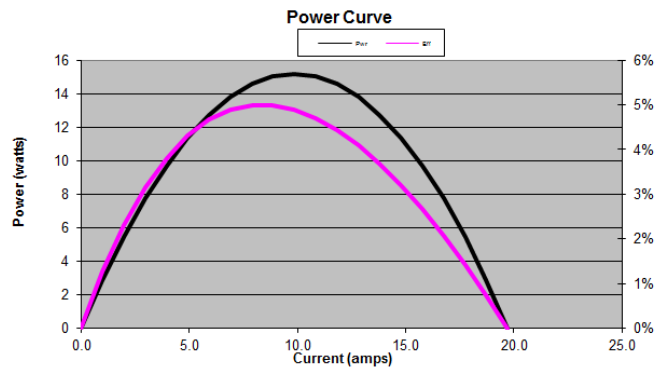**Figure 9** Simulation Result for Electrical Power - Current

Figure 10 HZ-14 Manufacturer characteristic datasheet for Power-Current and Efficiency-Current

■**4.0 CONCLUSION**

Based on the comparison between two modules (HZ-20 & HZ-14) performance results from simulation and manufacturer datasheet, Simulink/computer block modeling can be used to replace experimental method in order to obtain the result. This type of modeling is most suitable for electrical engineer or any other related engineer who have limited knowledge in material engineering to study the performance for various types of TEG. Simulink block libraries also support electronics circuit simulation. Therefore, more improvement for TEG can be done to monitor performance due to loading effect.

References

[1] P. Dziurdzia. 2010. Modeling and Simulation of Thermoelectric Energy Harvesting Processes.

[2] T. Seetawan, U. Seetawan, a. Ratchasin, S. Srichai, K. Singsoog, W. Namhongsa, C. Ruttanapun, and S. Siridejachai. 2012. Analysis of Thermoelectric Generator by Finite Element Method. *Procedia Eng*. 32: 1006–1011.

[3] H.-L. Tsai and J.-M. Lin. 2009. Model Building and Simulation of Thermoelectric Module Using Matlab/Simulink. *J. Electron. Mater.* 39(9): 2105–2111.

[4] S. Lineykin and S. Ben-Yaakov. 2007. Modeling and Analysis of Thermoelectric Modules. *IEEE Trans. Ind. Appl.* 43(2): 505–512.

[5] G. Snyder. 2008. Small Thermoelectric Generators. *The Electromechanical Society Interface*. 2: 54–56.

[6] A. Montecucco and A. R. Knox. 2014. Accurate Simulation of Thermoelectric Power Generating Systems. *Appl. Energy*. 118:166–172.

[7] Nlshio, S. 2003. Thermoelectric Generator Utilizing Boiling-Condensation (Experiment and Modeling).

[8] Note, A. 2008. Control Integrated Power System (CIPOS^{TM}). 1–13 Sept.

[9] Olsen, M. L., Warren, E. L., Parilla, P. a., Toberer, E. S., Kennedy, C. E., Snyder, G. J., Ginley, D. S. 2013. A High-temperature, High-efficiency Solar Thermoelectric Generator Prototype. *Energy Procedia*. 49: 1460–1469. doi:10.1016/j.egypro.2014.03.155.