PARAMETRIC MODEL OF THERMOELECTRIC GENERATOR

Milan JUS[1], Jiří BALLA[2]

Ing. Milan Jus, PhD., Faculty of Special Technology, Alexander Dubček University of Trenčín, Pri Parku 19, 911 06 Trenčín, Slovakia
prof. Ing. Jiří Balla, CSc. Faculty of Special Technology, Alexander Dubček University of Trenčín, Pri Parku 19, 911 06 Trenčín, Slovakia
Corresponding author E-mail address: milan.jus@tnuni.sk

Abstract

The paper presents the creation of a parametric model and simulation of a thermoelectric generator (TEG), which should be supplemented by a photovoltaic panel. Such a modification should be used in an Grid-Off system.

Keywords: thermoelectric effect, thermoelectric generator, Seebeck effect, composite material, multilayer material

1 Introduction

This paper presents the possibility of adding a thermoelectric generator (TEG) to a photovoltaic panel, which is shown in Fig. 1.

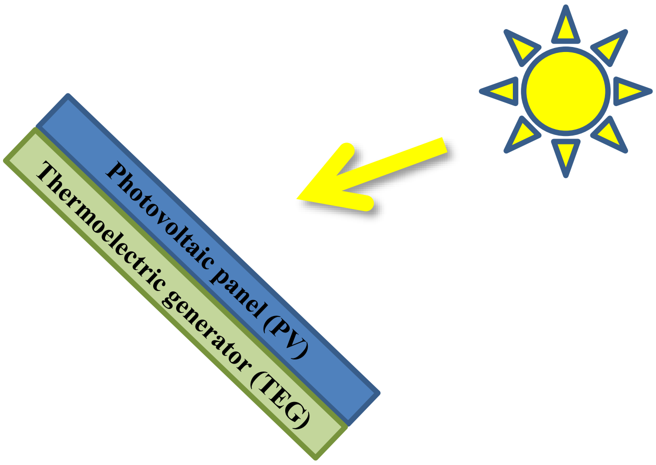


***Fig. 1** Addition photovoltaic panel (PV) thermoelectric generators (TEG)*

2 Thermoelectric generator (Seebeck effect)

The thermoelectric phenomenon comprises three separate phenomena called the Seebeck effect, the Peltier effect and the Thomson effect. [1],[2]

Heat conduction can be expressed by the equation (1)

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \cdot \nabla T) = Q \tag{1}$$

where ρ expresses the density of the material, C_p the heat capacity at the same pressure, k is the thermal conductivity, T is the thermodynamic temperature and Q is the heat source.

Furthermore, the expression holds for the current conservative field, which can be expressed by equation (2) and subsequently the equation of Ohm's law is given (3):

$$\nabla \cdot \boldsymbol{J} = 0 \tag{2}$$

$$\boldsymbol{J} = \sigma \boldsymbol{E} \tag{3}$$

where $\boldsymbol{J}$ is the current density, σ is the electrical conductivity and $\boldsymbol{E}$ is the intensity of the electric field.

The heat source that occurs in equation (1) can be expressed by the equation that expresses Joule's heat (4)

$$Q = \boldsymbol{J} \cdot \boldsymbol{E} \tag{4}$$

In the case of a thermoelectric generator (TEG) we use the Seebeck phenomenon whose basic expression is that when two different materials are formed and a temperature gradient (∇T) is formed at these connected points, an electromotive voltage is generated when the circuit is closed is going through an electric current. This fact is illustrated in the following Fig. 2, which shows these two options. [3]

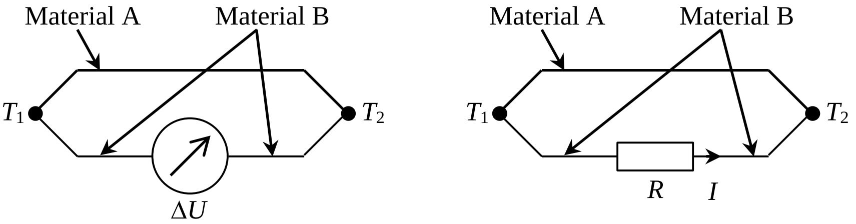


Fig. 2 Seebeck effect, $T_1>T_2$, open circuit and closed with load R

The electromotive force is expressed by the equation (5)

$$\boldsymbol{E_f} = -S\nabla T \tag{5}$$

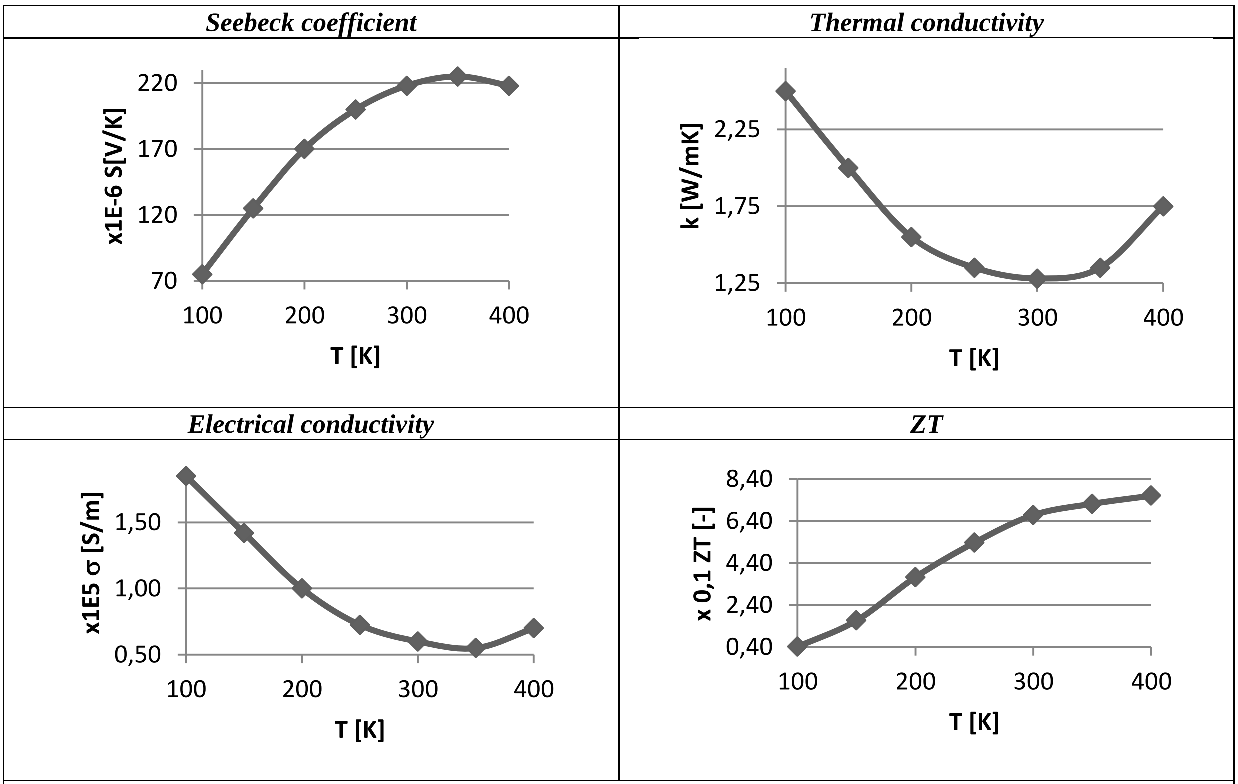
where S is the Seebeck coefficient. [3]

Furthermore, the current density in the case of the Seebeck effect can be expressed by the equation (6)

$$\boldsymbol{J} = -\sigma S\nabla T \tag{6}$$

In the case of the connected load R shown in Fig. 2, it is possible to express the magnitude of the current I, the equation (7)

$$I = \frac{S\Delta T}{R} = \frac{S(T_1 - T_2)}{R} \tag{7}$$


Seebeck coefficient

Thermal conductivity

Electrical conductivity

ZT

Fig. 3 Graphical dependence of Seebeck coefficient, thermal and electrical conductivity and *ZT*, material Bi_2Te_3

In the previous equations, there were constants that are in fact dependent on the material used, but also on temperature, so they need to be taken into account as dependencies. Specifically, the electrical and thermal conductivity and the Seebeck coefficient. This is taken into account by the parameter *ZT*, referred to as efficiency (figure of merit), expressed by the equation (8) [1][4][5]

$$ZT = \frac{\sigma S^2 T}{k} \tag{8}$$

Therefore, when using TEG, it is necessary to apply such materials to maximize ZT efficiency. We encounter materials where electrical conductivity is satisfactory, but thermal conductivity is unsatisfactory, or vice versa, but still in contradiction. Therefore, materials that are composed of multiple materials or semiconductors are used, but also as composite materials. If semiconductors are used, this is a combination of P-type and N-type semiconductor, which depends on the predominant conductivity of electrons (N-type) or holes (P-type). The materials used are: BiSbTe, MgAgSb, PbTeS, SnSe, BiTeSe, AgPbSbTe, SiGe, Bi_2Te_3 and other. [6][7][8][9]

As an example, Fig. 3 shows the dependence of electrical, thermal conductivity, Seebeck constant and material efficiency Bi_2Te_3. [8][10][11][12]

3 Parametric model and simulation of Thermoelectric generator

A parametric model was created, which contains type P and N type Bi_2Te_3 semiconductor materials. Simulation was performed for different temperature gradients and the generated voltage was evaluated. The simulation took into account the change in model parameters related to the width (square section) and the height of the material. This model together with the electrical potential display is shown in Fig. 4.

Fig. 4 TGM model with type P and type N semiconductor and potential shown

Simulation generated voltage values for various temperature gradients, heating temperature values of 50 to 80 °C with steps 10 °C and colder side temperatures of 20, 30 and 40 °C. In the model, simulations were performed for different sizes of semiconductor composite material. The simulated values are shown in Fig. 5 - 8.

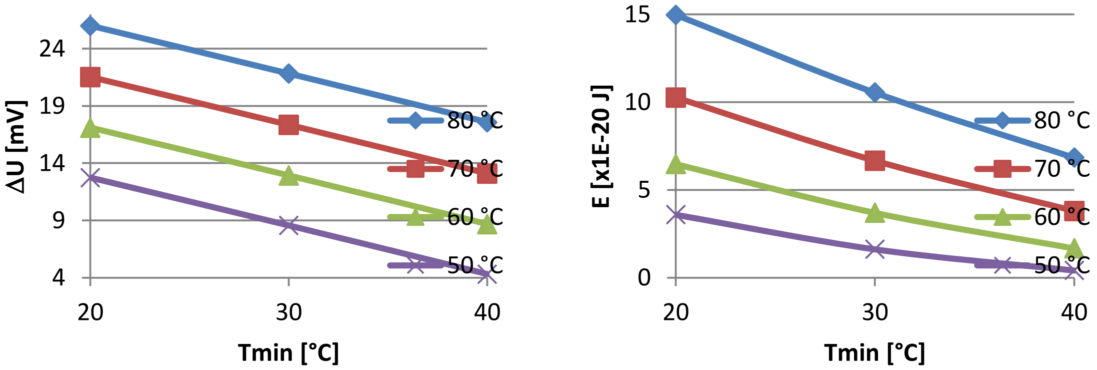


Fig. 5 Simulated TEG parametric model, width 1 mm, height 10 mm

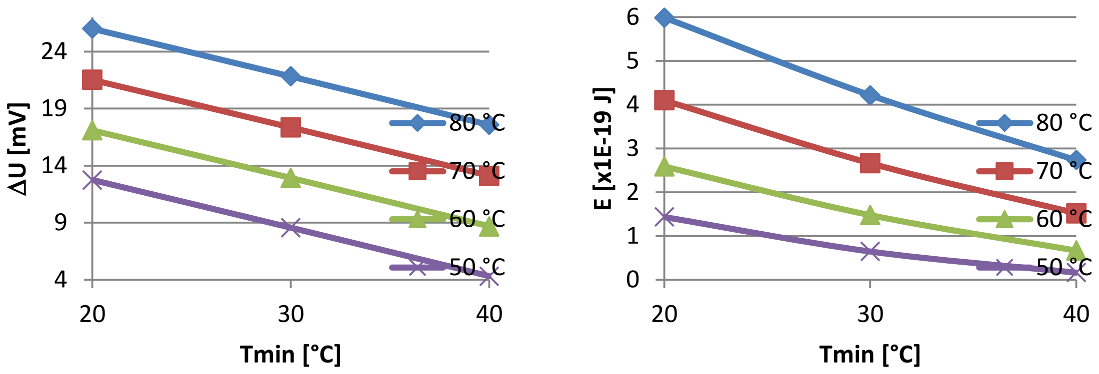


Fig. 6 Simulated TEG parametric model, width 2 mm, height 10 mm

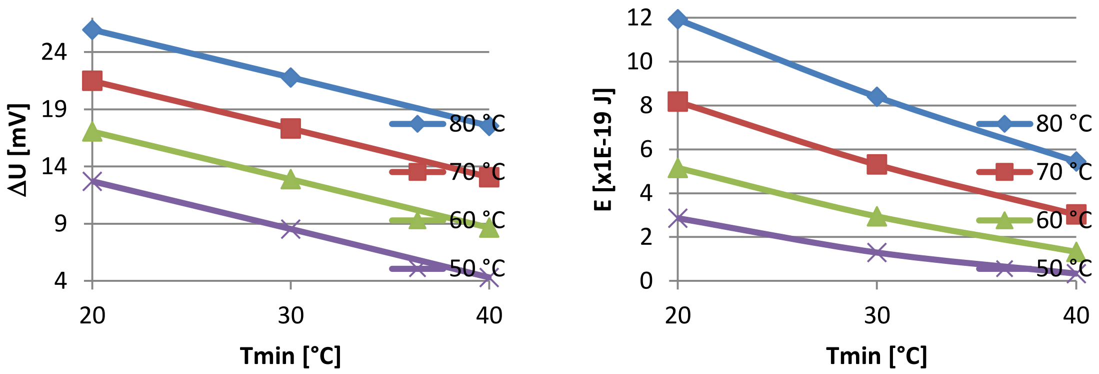


Fig. 7 Simulated TEG parametric model, width 2 mm, height 5 mm

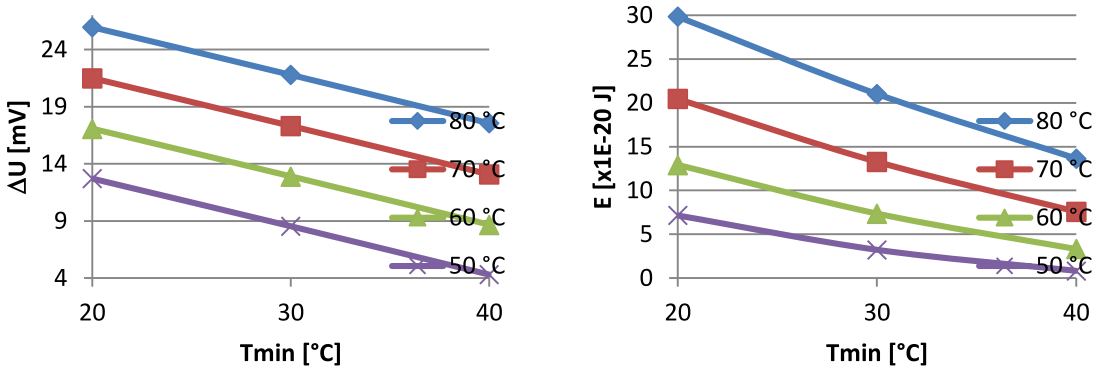


Fig. 8 Simulated TEG parametric model, width 1 mm, height 5 mm

4 Description of achieved results

From the simulated data obtained Fig. 5-8 of the parametric model shows that the highest stress values were obtained for material dimensions with a square section of 1 mm and a height of 10 mm, but did not differ greatly from the others.

From the application point of view, the amount of TEG energy obtained is important. These data are also obtained by simulation, which is shown in Fig. 5-8. The highest values were obtained from a simulation of a third parametric model with Bi_2Te_3 type P and type N semiconductor material, where the semiconductor material represented a block of 2 x 2 x 5 mm. The conductive contacts were 0,1 mm copper, on which there was still an insulating layer of alumina with a thickness of 0,2 mm.

Considering a photovoltaic panel with dimensions of 1640 x 992 x 35 mm, which we then cover with a TEG whose area would be 2 x (2,5 x 2,5 mm), what it represents 12,5 mm^2, theoretically it would:

$$S_{FV} = 1{,}64 \cdot 0{,}992 = 1{,}62688\ \mathrm{m}^2 \tag{9}$$

$$S_{TEG} = 12{,}5 \cdot 10^{-6}\ \mathrm{m}^2 \tag{10}$$

$$N_t = \frac{S_{FV}}{S_{TEG}} = \frac{1{,}62688}{12{,}5 \cdot 10^{-6}} = 130150{,}4 \cong 130150 \text{ pieces} \tag{11}$$

where N_t is theoretically achievable value. Practically, it should be taken into account that the TEG will not represent one continuous unit of N_t with the S_{FV} area, but will be realized rather than the TEG of a smaller area with the corresponding amount of TEG formed by a pair of type P and type N semiconductor material, 50 x 50 mm would contain 200 semiconductor pairs.

Furthermore, an S_{FV} area coverage of 95 % and 90 % was considered. The simulated supply power values are shown in Fig. 9.

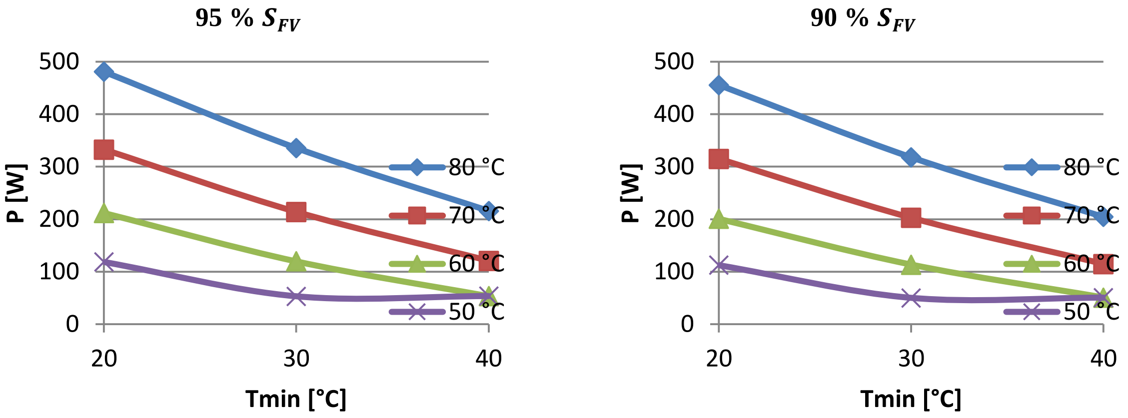


Fig. 9 Simulated TEG Power Supply

The power calculation was performed by applying a load R (shown in Fig. 10) to the TEG, then the power can be expressed as

$$P = U \cdot I = \frac{U^2}{R} \tag{12}$$

Considering the geometric dimensions of the load with area S, length l and electrical conductivity σ, equation (12) can be written as

$$P = \frac{\sigma U^2 S}{l} \tag{13}$$

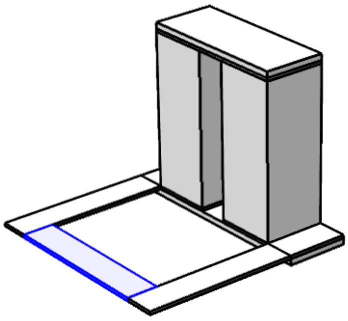


Fig. 10 Simulated TEG with load *R*

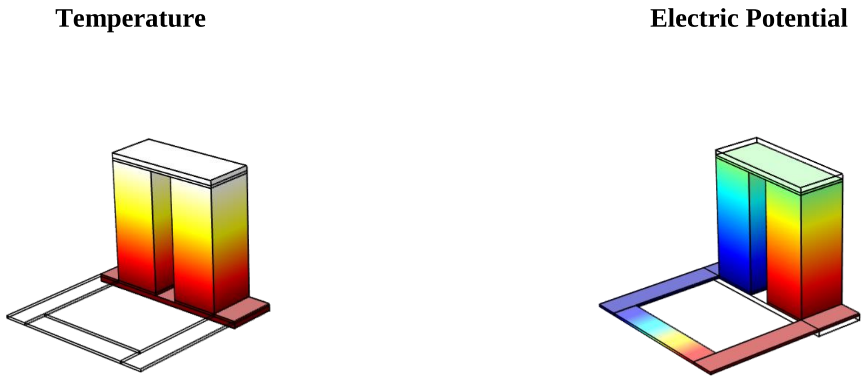


Fig. 11 Display of temperature difference and electrical potential of the parametric TEG with load *R*

5 Conclusion

This paper presents the use of a thermoelectric generator as an additional power source in island systems. The simulations carried out on the parametric model show that under normal conditions the performance comparable to that of photovoltaic panels would be achieved.

Acknowledgements

The paper was treated within the project no. ITMS 26220220083 "Research technological base for designing applications for renewable energy in practice" EU operational program "Research and Development".

Európska únia
Európsky fond regionálneho rozvoja

Agentúra
Ministerstva školstva, vedy, výskumu a športu SR
pre štrukturálne fondy EÚ
Podporujeme výskumné aktivity na Slovensku
Projekt je spolufinancovaný zo zdrojov ES

Operačný program
VÝSKUM a VÝVOJ

Authors are grateful for the support of experimental works by project „New materials and technologies for the 21st century industry “, ITMS code 2014+:313011T546, of the Operational Program OPVaI.

References

[1] Z. Ouyang, D. Li: Modelling of segmented high-performance thermoelectric generators with effects of thermal radiation, electrical and thermal contact resistances, Science reports, 2016.
[2] [20.11.2019], https://en.wikipedia.org/wiki/Thermoelectric_effect
[3] Richard A. Secco: Thermal conductivity and Seebeck coefficient of Fe and Fe-Si alloys:Implications for variable Lorenz number, Physics of the Earth and Planetary Interiors 265, 23-34, 2017.
[4] Y. Zhang et al.: Double thermoelectric power factor of a 2D electron system. Nat. Commun. 9, 2224, 2018.
[5] [23.11.2019], https://www.energy.gov/eere/solar/project-profile-concentrated-solar-thermoelectric-power
[6] S. Shimizu et al.: Giant thermoelectric power factor in ultrathin FeSe superconductor, Nature comunications 10, Article number 825, 2019.
[7] X. Luo, B. C. Schroeder, Ch. Di, J. Mei: Flexible and Printed Organic Thermoelectrics: Opportunities and Challenges, Material Matters, 12.3, 2017.
[8] Jus, M.: Využitie termoelektrického efektu v grid-off fotovoltických systémoch. In: Výzbroj a technika ozbrojených síl 2019 : 25. medzinárodná vedecká konferencia. - Liptovský Mikuláš : Akadémia ozbrojených síl generála Milana Rastislava Štefánika, 2019. - ISBN 978-80-8040-585-4. - s.83-88.
[9] [24.11.2019], https://automationforum.in/t/principles-and-applications-of-thermo-electric-effect/5026
[10] [24.11.2019], https://www.slideshare.net/Mahendrac48/introduction-overview-of-thermoelectric-generator-by-chaudhari-mm?next_slideshow=3
[11] [24.11.2019], http://www.bookbootusers.co.uk/thermo2.htm
[12] [25.11.2019], https://automationforum.co/what-are-thermopiles-applications-of-thermopile/