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Solar Energy Harvesting using Hybrid Photovoltaic and Thermoelectric Generating System

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Abstract

Optimization of geometry of thermoelectric devices using the analytical expression is presented. The geometry optimization helps in achieving a maximum power output and minimizes the consumption of thermoelectric materials. The hybrid photovoltaic and thermoelectric (PV/TE) system consist of a PV cell on the top of the hot side of a TEG while the cold side of it is attached to a heat exchanger with ice block. The experimental results from the PV/TE system shows that an increase in both the overall power output and conversion efficiency is achieved by incorporating a thermoelectric generator (TEG) to harvest waste heat from photovoltaic cell.

Keywords: Thermoelectric generator, Photovoltaic cell, Hybrid PV/TE system

1. INTRODUCTION

The light energy in solar radiation is converted into electrical energy by using Photovoltaic cell. At the same time the heat energy from the solar radiation is converted into electrical energy by using Thermoelectric generator. A large proportion of solar energy is converted to waste heat in a photovoltaic (PV) cell, due to thermalization of excited, high energy electrons and absorption of low energy photons, raising the temperature of the photovoltaic cell. Therefore, there has been considerable interest in cooling PV cells using a number of cooling techniques, including the use of thermoelectric (TE) coolers. An alternative approach is to use the thermoelectric device as a generator[5-13] to convert waste heat to electricity. In a hybrid system, the dimension of the TEG has significant influence on the overall power output because it determines the operating temperature of the solar cell and the temperature difference across the TEG. The results indicate that the hybrid system is more efficient in generating electricity than using one system. The objective of this paper is to present the determination of optimal geometry of TEG using the analytical expressions to achieve maximum overall power output for a hybrid PV/ TE system. In this paper we also measure the performance parameters of the PV/TE by using a solar panel with TEG and also Solar panel with TEG along with cooling. Experimentally the performance of a 5W, 25cm×20cm solar panel and a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed with solarradiation. The 25cm×20cm solar panel is combined with 4cm×4cm thermoelectric generator experimentally. The Performance is much improved by cooling the cold side of 4cm×4cm thermoelectric generator with ice block.

2. DESIGN OPTIMIZATION

One of the main requirements in the design of a TE module is to determine the optimum geometry module, in order to obtain high performance from the TEG. The generating performance of a TE module is gauged primarily by the conversion efficiency and power per unit area. The power output and conversion efficiency of a TE module are dependent upon thermo-element length for a given figure of merit, contact properties and temperature difference of operation.

The optimum length necessary to obtain maximum power output differs from that for maximum conversion efficiency. Evidently, an appropriate thermo-element length for power generation will be a compromise between the requirements for maximum power output and maximum conversion efficiency. In cases where the input thermal energy is free, the thermo-leg length should be optimized such that the power output is maximum neglecting the conversion efficiency.

A typical thermocouple(TC) module consists number of n-type and p-type semiconductor thermo-elements connected in series by highly conducting metal strips and sandwiched between two ceramic plates is shown in figure 2.1. The electrical power generated from a module depends on the number of TCs in a module, TE properties of thermo-element, thermal and electrical properties of contact layer and the temperature difference across the module.

The specification of the TC module are the length of thermo-leg l, thickness of the contact layer l_c, cross sectional area of the thermo-element A_c, number of TCs connected in series N, Resistivity of p type thermo-leg ρ_p, Resistivity of n type thermo-leg ρ_n, Resistivity of contact layer ρ_c, Thermal conductivity of n and p- type thermo-legs k, Thermal conductivity of contact layer k_c, Seebeck coefficient α , Hot side temperature T_h, Cold side temperature T_c, Temperature difference ΔT.

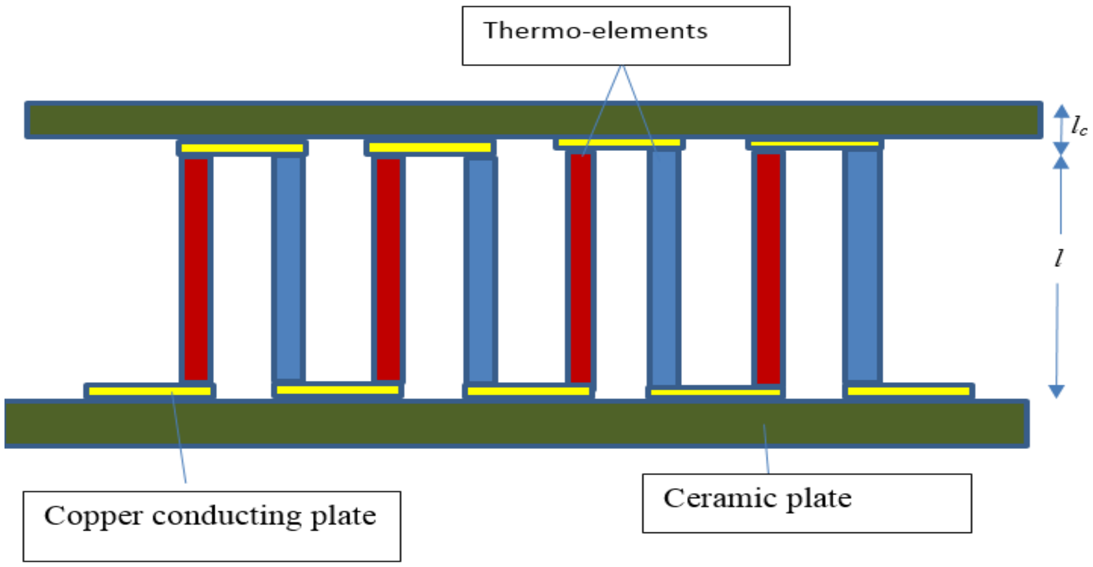

Figure 2.1 More realistic model of thermoelectric module

3. PERFORMANCE ANALYSIS OF µTEG

Based upon the improved theoretical model which takes in to account the thermal and electrical contact resistances, the formulas for output voltage, current and power are given in [2]. The variation of voltage with respect to the length of the thermo-leg is calculated using the Equation (3.1)

$$V = \frac{N\alpha(T_h - T_c)}{1 + 2rl_c / l} \tag{3.1}$$

The variation of current is calculated with respect to the length of thermo-leg using the Equation (3.2)

$$I = \frac{A\alpha(T_h - T_c)}{2\rho(n+1)(1+2rl_c / l)} \tag{3.2}$$

The variation of power is calculated with respect to the length of thermo-leg using the Equation (3.3)

$$P = \frac{\alpha^2 AN(T_h - T_c)^2}{2\rho(n+1)(1+2rl_c/l)} \quad (3.3)$$

where $n = 2\frac{\rho_c}{\rho}$, and $r = \frac{k}{k_c}$.

3.1 Design of a single thermocouple

The design of a single TC consist of a p- type and n-type thermo-leg with an interconnect layer is shown in figure 3.1. The length of thermo-leg is l and the thickness of the interconnect isl_c. The length of thermo-leg is optimized for maximum power output. The length is optimized by varying its length and the power is obtained. The length corresponds to the maximum power is the optimum length.

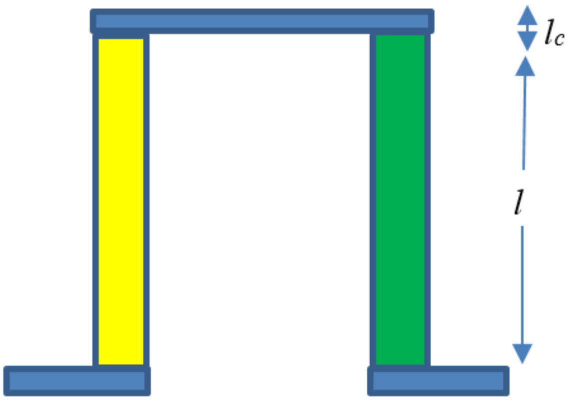

Figure 3.1 Design of single thermocouple

3.2 Optimization of design module

The cross sectional area of micro TEG (µTEG) is 50 µm×50 µm. The thermoelectric properties of the material are thermal conductivity(k)is2.875W/(m-K), electrical resistivity(ρ) is $260\times10^{-5}\Omega$m and Seebeck coefficient(α) is 235µV/ K[4]. The temperature of the hot side is varied from 303 K to321 K in steps of 2 K. The cold side temperature is 260 K. The thickness of contact layer is 2µm.The contact layer material used is copper and k_c is385 W/(m-K). The value of r is 0.00857. The optimum length calculated for all operating temperature is 2.5µm.Table 3.1 gives the maximum power output and the optimum length for hot side temperature varying from 303K to321K in steps of 2K with a cross sectional area of 50µm×50 µm.

Thus for the Perovskite type $CaMn_{0.98}Nb_{0.02}O_3$ compound based single thermocouple the maximum power output is 2.17µW with optimum length of 2.5µmand a cross sectional area of 50µm× 50 µm. The hot side temperature is 321 K and the cold side temperature is 260 K.The calculated power with a single thermocouple of with die area 200µm×200µm is 2.17µW. The calculated power of 4cm×4cm TEG module is 0.08W. The calculated power of 25cm×20cm TEG module is 2.7125W.

Table 3.1. Performance of perovskite type $CaMn_{0.98}Nb_{0.02}O_3$compound based µTEGwith a cross sectional area of 50µm×50 µm.

Sl.No.	T_h(K)	P_{max}(µW)	L_{opt}(µm)
1.	303	1.078	2.5
2.	305	1.181	2.5
3.	307	1.288	2.5
4.	309	1.4	2.5
5.	311	1.517	2.5
6.	313	1.638	2.5
7.	315	1.764	2.5
8.	317	1.894	2.5
9.	319	2.030	2.5
10.	321	2.17	2.5

4. EXPERIMENTAL ANALYSIS

A 5W, 25cm×20cm solar panel and a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed separately with solar radiation. The 25cm×20cm solar panel is combined with 4cm×4cm thermoelectric generator and analyzed experimentally. The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter with a load rsistance of 3.3 Ω and the power is calculated. A 5W, 12V, 0.52A, 25cm×20cm solar panel is analyzed with solar radiation with a load of 3.3Ω. The corresponding voltage and current were measured in Solar panel with a multi meter and the power is calculated.

4.1 Experimental analysis of solar panel:

Figure:4.1. Solar panel

Table 4.1. Experimental analysis of PV panel

Sl.no	Time (24 hours format)	Temperature (°C)	Voltage (V)	Current (A)	Power (W)
1	11.10	35	7.86	0.12	0.94
2	11.20	41	8.2	0.21	1.72
3	11.30	43	9.2	0.27	2.4
4	11.40	45	9.4	0.29	2.72
5	11.50	46	9.5	0.34	3.33

4.2 Experimental analysis of TEG

Bismuth Telluride based thermoelectric generator of area 4×4 cm^2 with 127 thermocouples connected in series along with heat dissipater at the cold side is fixed on a stand. The terminals of the cold side are connected to multi meter and 3.3Ω load. The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter and the power is calculated.

Table 4.2. Experimental analysis of TEG

Sl.no	Time (24 hours format)	Temperature Gradient (°C)	Voltage (V)	Current (A)	Power (W)
1	11.10	20	0.52	0.071	0.036
2	11.20	26	0.67	0.077	0.046
3	11.30	30	0.69	0.082	0.055
4	11.40	34	0.73	0.091	0.066
5	11.50	37	0.82	0.097	0.073

4.3 Experimental analysis of solar panel with TEG:

A 5W, 25cm×20cm solar panel and a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed with solar heat.The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter and the power is calculated.

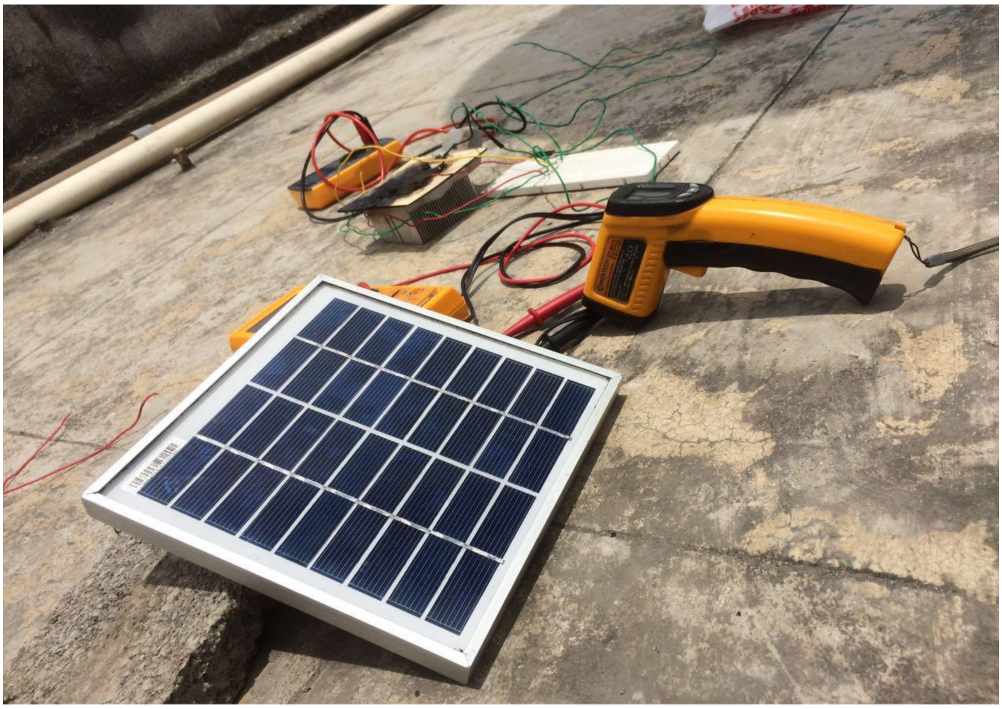

Figure.4.2. Solar panel with TEG

Table.4.3. Experimental analysis of Solar panel with TEG

Sl.no	Time (24 Hours format)	Hot side Temperature (Th) in °C	Cold side Temperature (Th) in °C	Temperature Gradient (°C)	Voltage (V)	Current (A)	Power (W)
1	12.10	34	26	8	8.49	0.193	0.985
2	12.20	43	34	9	8.92	0.289	1.776
3	12.30	44	36	8	9.95	0.355	2.463
4	12.40	46	37	11	10.19	0.382	2.792
5	12.50	48	39	11	10.37	0.434	3.381

4.4 Experimental analysis of solar panel and TEG with cooling:

A 5W, 25cm×20cm solar panel and a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed with ice block at the cold side of TEG.The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter and the power is calculated.

Table.4.4. Experimental analysis of Solar panel with TEG with ICE cooling.

Sl.no	Time (24 Hours format)	Hot side Temperature (T_h) in °C	Cold side Temperature (T_c) in °C	Temperature Gradient (°C)	Voltage (V)	Current (A)	Power (W)
1	1.20	33	-20	53	8.56	0.191	0.994
2	1.30	42	-12	54	8.97	0.286	1.77
3	1.40	45	-10	55	9.98	0.356	2.467
4	1.50	47	-9	56	10.24	0.385	2.799
5	2.00	48	-10	58	10.38	0.437	4.22

Figure.4.3. Solar panel with TEG with ICE cooling

5. CONCLUSION

Optimization of thermo leg length is done for maximizing the power output. As the temperature gradient increases, the voltage and current also increases thus increasing the power output. The power output from the combination of PVpanel and TEG is more compared to that of PVpanel alone. The performance of a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed with solar heat and an average power of 0.0552 W is obtained. A 5W, 40cm×15cm solar panel is analyzed with solar heat and the average power output is 2.222W. When the 40cm×15cm solar panel is combined with 4cm×4cm thermoelectric generator experimentally the average power obtained is 2.2794W. Performance is improved by cooling the cold side of 4cm×4cm thermoelectric generator with ice block and an average power of 2.45W is obtained experimentally. When the entire area of the solar panel is combined with thermoelectric generator, the estimated power of 4.292 W can be obtained. Similarly when the entire area of the solar panel is combined with cooled thermoelectric generator and estimated power output of 10.772 W can be obtained. The heat dissipated at the cold side of the TEG can be harvested by placing phase change material(PCM) at the cold side of TEG [14,15].

REFERENCES

[1] Hasim, H., Bomphrey, J.J., and Min, G., 2016, "Model for geometry optimization of thermoelectric devices in a hybrid PV/TE system," Renewable energy, 87 pp.458-463.

[2] Rowe, D.M., Min, G., 1996, "Design theory of thermoelectric modules for electrical power generation," EE Proceeding on Science Measurement

Technology, 143(6).

[3] Rowe, D.M., 2006, "Thermoelectrics Handbook Macro to Nano", CRC Press, BocaRaton, London/New York.

[4] Lassikarvonen, Petr Tomes, AnkeWaidenkaff, 2011, “Thermoelectric Performance of Perovskite – type oxide materials” , material matters, , 6(4), pp.92-99.

[5] Christofer Hierold , 2009, "Bi_2Te_3Based Flexible Micro Thermoelectric Generator with Optimized Design-Journal of Micro Electro Mechanical Systems".

[6] Fabrication and Characterization of CMOS-MEMS Thermoelectric Micro Generators,

[7] Pin-Hsu Kao, 2010, Journal of sensors, National Chung Hsing University, Taiwan.

[8] Guan-Ming Chen, 2011, "Development of a Novel Transparent Micro thermoelectric Generator for Solar Energy Conversion," IEEE International Conference at Yat-sen University Kaohsiung, Taiwan.

[9] Jin Xie, 2010, "Fabrication, and Characterization of CMOS-MEMS-Based Thermoelectric Power Generators" IEEE Journal of Micro Electro Mechanical Systems.

[10] Jin Xie, 2010, "Wafer-Level vacuum sealing and encapsulation for Fabrication of CMOS" IEEE conference on MEMS Thermoelectric Power Generators"

[11] Y.Li , 2011, "Chip-Level Thermoelectric Power Generators based on High Density Silicon Nano wire Array Prepared with Top-Down CMOS Technology," IEEE Electron Device letters.

[12] A Review of Thermoelectric MEMS Devices for Micro-power Generation, Heating and Cooling Applications, Chris Gould-Micro Electronic and Mechanical Systems Book by Kenichi

[13] Jose M.Borrego,1963, Carrier Concentration Optimization in Semiconductor Thermo elements, IEEE Transactions on Electron Devices.

[14] Amen Agbossou, Qi Zhang, Gael Sebald and Daniel Guyomar., 2010, “Solar micro –energy harvesting based on thermoelectric and latent heat effects.Part I: Theoretical analysis,” Sensors and Actuators A,163,pp. 277–283.

[15] Qi Zhang, Amen Agbossou, Zhihua Feng and Mathieu Cosnier., 2010, “ Solar micro –energy harvesting based on thermoelectric and latent heat effects. Part II: Experimental analysis,” Sensors and Actuators A, 163,pp. 284–290.