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Thermoelectric Generator for Low Voltage Applications

Zayad M. Sheggaf
Libyan Center for Engineering Research and Information Technology
Bani Walid, Libya
zayad1976@gmail.com

Montaser .A. Qasem
Department of Electrical Engineering
Faculty of Technical Sciences
Bani Walid, Libya
almontaser436@gmail.com

Fathi Masoud
Department of Communications
Faculty of Electronic Engineering
Bani Walid, Libya
fshuggaf@gmail.com

***Abstract*— K-thermocouples and solar parabolic dish concentrator are used to fabricate a thermoelectric generator. Thermoelectric generator is a system, which changes heat into electricity by utilizing a procedure called the Seebeck impact. In this system the heat source harvested from sun to get a clean electrical energy, which is suitable for low voltage applications. The efficiency of the system has been calculated using experimental measurement and Matlab simulation. The results showed that the designed system is capable to produce power using the heat from solar collector. The amounts of voltage, current and power are increased proportionally with the heat. In addition, adding more thermocouples into the system leads to increase the harvested power.**

Keywords*— *renewable energy, thermoelectric generator, parabolic dish, Thermocouple

I. INTRODUCTION

Due to their undesirable effects on atmospheric pollution and global warming, the ordinary systems of producing electricity have become disadvantageous for our universe. Natural gas resources are recoded 28% in 2014, and 35% in 2018 [1]. therefore, energy should be produced from the nature to supply infinite, sustainable, green, and costless electrical power. at the present time the increasing concern in using renewable energy, which can be acquired from many green sources such as radiofrequency (RF) radiation, thermal, solar, vibratory/mechanical energy, etc., and converting it into electrical in order to supply the globe, is increasing rapidly. Thermal energy is one of the richly existing energies that could be found in various places such as operating electronic devices (integrated circuits, phones, computers, etc.), running vehicles, in-door buildings, and even in human body (in-vivo). In 1821, Thomas Seebeck suggested a thermoelectric phenomenon (TE), called the Seebeck effect. Thermoelectric (TE) is the immediate transfer of temperature difference between the junctions of two different materials (thermocouple) to electricity. A solid-state thermoelectric generator device transfers heat flux directly into electrical energy through the Seebeck effect phenomenon. Thermocouples are sensors used to measure temperatures. They are made up of two wires of separate metals joined together (soldered or welded) to form a junction at one end. These junctions are different, considering that one acts as a reference and the other as the one to be measured. Voltage is produced as long as there is a difference in temperature at the joint. This voltage can then be converted to temperature using the thermocouple reference tables or a data logger. A data logger is a machine that converts the voltage (millivolts) to temperature with the help of impulses sent by external thermocouples attached to it. This machine can then be integrated with a computer system to form the obtained temperatures in Excel format. The data logger machine was used in our experiment. One type of thermocouple was used is K type (made of chromel as positive side and alumel (nickel -5 %, aluminum and silicon)), which was used when the expected temperature at a point was expected to be higher than 150 °C [2].

TABLE I. CHARACTERISTICS OF PATTERN NOBLE METAL AND METAL BASED THERMOCOUPLES

Type	Positive material	Negative material	Sensibility at 20 °C (µV/°C)	Range of temperature (°C)
E	Chromel (nickel 10% chromium)	Constantan (nickel 45% copper)	58.7	−270 to 1,000
G	Tungsten	Tungsten 26% Rhenium	19.7 (600 °C)	0 to 2,320
C	Tungsten 5% rhenium	Tungsten 26% rhenium	19.7 (600 °C)	0 to 2,320
D	Tungsten 3% rhenium	Tungsten 26% rhenium	19.7 (600 °C)	0 to 2,320
J	Iron	Constantan (nickel 45% copper)	50.4	−210 to 760
K	Chromel (nickel 10% chromium)	Alumel (nickel 5% aluminum and silicon)	39.4	−270 to 1,372
N(AWG 14)	Nicrosil (84.3% Ni, 14% Cr, 1.4% Si, 0.1% Mg)	Nisil (95.5% Ni, 4.4% Si, 0.1% Mg)	39	−270 to 400
N(AWG 28)	Nicrosil (84.3% Ni, 14% Cr, 1.4% Si, 0.1% Mg)	Nisil (95.5% Ni, 4.4% Si, 0.1% Mg)	26.2	0 to 1,300
B	Platinum 6% Rhodium	Platinum 30% Rhodium	1.2	0 to 1,820
R	Platinum 13% Rhodium	Platinum	5.8	−50 to 1,768
S	Platinum 10% Rhodium	Platinum	5.9	−50 to 1,768
T	Copper	Constantan	38.7	−270 to 400

In last decade, permanent energy become an area of concern in the field of energy systems for many types of applications, according on size, required power, and used materials [3]. Preceding studies showed that the system uses the theory of Seebeck effect to convert the heat to electrical energy appropriate for low voltage applications like charging a phone, LEDs and small batteries. Stecanella et al., [4] used the heat from the exhaust gases of the internal combustion engine to produce the electricity via thermoelectric generator. furthermore, a focalize reflector for establishing decay warm on thermopiles was used as a heat source to produce electricity, with Bi_2Te_3 three thermopiles which were thermally in parallel arrangement and the total generated on two junction was 8.46 V and 7.2 mA at 79 °C [5]. The thermoelectric generators system is a DC power source uses Seebeck effect, which utilizes the temperature gradient between hot and cold sides of the TEG module. The output voltage is greatly dependent on temperature difference [6]. Other researchers generated a low-cost moveable power source from a moveable thermoelectric generator, which transfers waste heat to electrical energy [7]. As a heat source for thermoelectric generator Dan Mastbergen et al., [8] used stoves to produce electricity with 4 watt and 12 V at 250 °C, with used bismuth telluride (Bi2Te3) as a thermo elements (P and N type semiconductor) which configured in series to increase voltage and power output.

In this study, the heat harvested from solar concentrator of parabolic dish used as a heat source for thermoelectric generator to produce a clean electrical energy suitable for low voltage applications.

II. Experimental and Simulation

To fabricate a thermoelectric generator (TEG), a parabolic satellite dish readymade covered in aluminum foil turned into a solar concentrator collector with three thermocouples installed on a ceramic conical cavity placed at its focal point, two thermocouples are connected in series to multimeter in order to measure the harvested electricity, and the third one is to measure temperature via a K-thermocouple instrument. The diameter of the dish is 1.8 m; surface area is 2.64 m^2 with a focal length 0.64 m, as shown in Fig .1 and Fig 2.

Fig. 1. Parabolic dish collector

Fig. 2. Experimental hardware

The output voltage and current readings are taken at 100 °C onwards for each 10 degree obtained experimentally until 190 °C, which is the maximum heat harvested from the collector, and then the resulting power energy obtained mathematically. Firstly, the experimental conducted using one-thermocouple , and then two thermocouples connected in series on 20 Jan 2022 at 1 PM, and ambient temperature was around 17 °C. Same procedure built using MATLAB for validating the obtained experimentally results, as shown in Fig. 3.

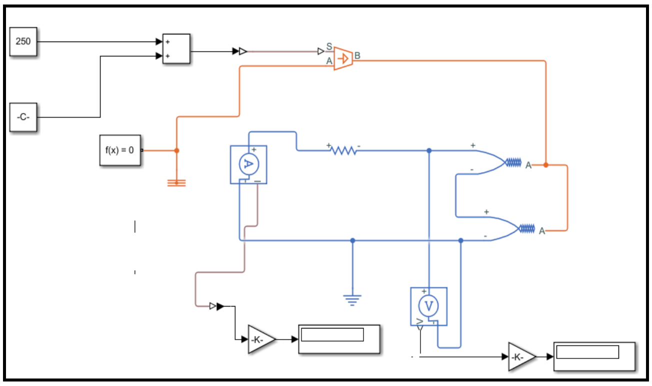

Fig. 3. Thermoelectric simulation with Matlab (two thermocouples)

III. Results and Discussion

Table 2. shows the experimental and simulation results values of voltage and current measured at different temperature readings using one thermocouple.

TABLE II. PERFORMANCE OF ONE THERMOCOUPLE (EXPERIMENT AND SIMULATION)

Temperature in ° C	Voltage in mV		Current in mA		Power in mW	
	Exp.	*Sim.*	*Exp.*	*Sim.*	*Exp.*	*Sim.*
100	4.2	4.09	0.12	0.14	0.50	0.57
110	4.6	4.5	0.12	0.15	0.55	0.68
120	4.8	4.92	0.15	0.17	0.72	0.84
130	4.6	5.32	0.15	0.18	0.76	0.96
140	5.6	5.73	0.16	0.19	0.89	1.1
150	5.7	6.13	0.18	0.21	1.02	1.3
160	6.2	6.5	0.23	0.22	1.42	1.4
170	6.3	6.9	0.24	0.23	1.51	1.6
180	6.7	7.3	0.26	0.24	1.74	1.8
190	7.1	7.7	0.3	0.26	2.13	2.0

The results show that the TEG using a single thermocouple is capable of producing power using the heat from solar collector and the amounts of voltage, current and power produced were increased as the temperature was increased as shown in Figures 4, 5 and 6 respectively. The system was able to provide maximum power of 2.13 mW, which was calculated at 7.1 mV, 0.3 mA and 190 °C. Furthermore, the results confirmed by simulation, as the maximum power was 2 mW at 7.7 mV, 0.26 mA and 190 °C maximum temperature. The rate of voltage increment was 33 µv/°C, and it has been reported that sensibility of K-thermocouple at 20 °C is 39.4 µV/°C) [3].

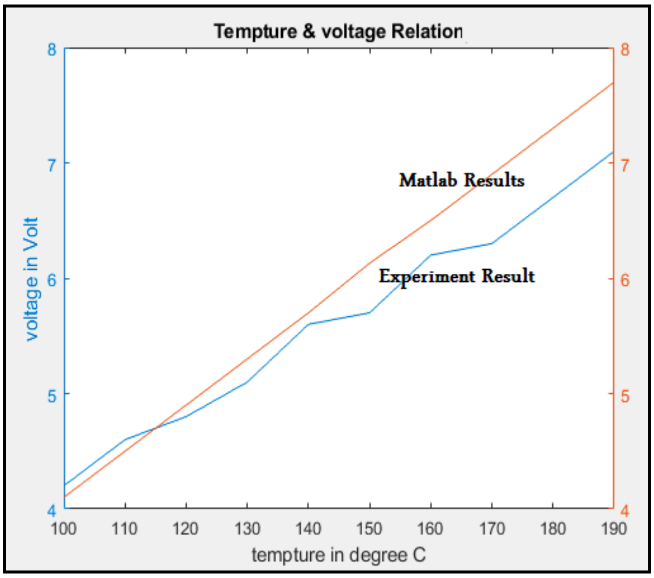

Fig. 4. Voltage vs Temperature of one thermocouple

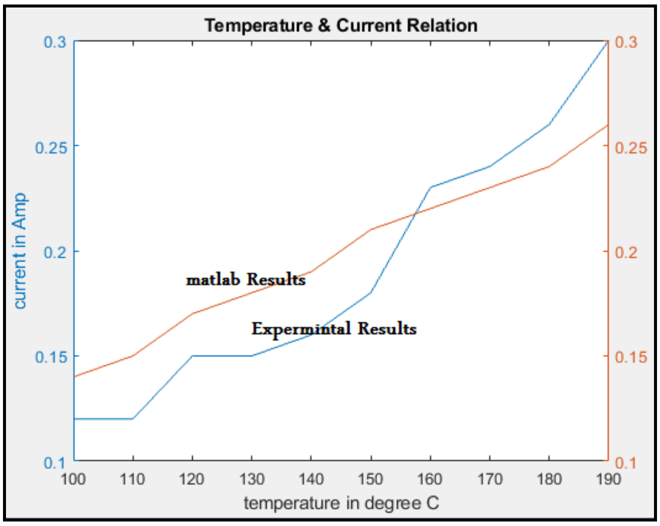

Fig. 5. Current vs Temperature of one thermocouple

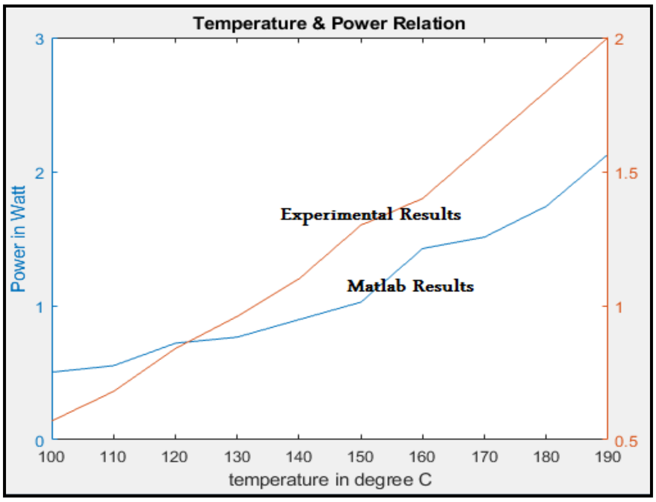

Fig. 6. Power vs Temperature of one thermocouple

The experimental and simulation results values of voltage and current measured at different temperature using two thermocouples into the system are shown in Table 3.

TABLE III. PERFORMANCE OF TWO THERMOCOUPLES (EXPERIMENT AND SIMULATION)

Temperature in ° C	Voltage in mV		Current in mA		Power in mW	
	Exp.	*Sim.*	*Exp.*	*Sim.*	*Exp.*	*Sim.*
100	5.9	8.19	0.21	0.27	1.23	2.21
110	7.2	9.01	0.24	0.3	1.72	2.70
120	8.5	9.83	0.26	0.33	2.21	3.24
130	8.5	10.65	0.32	0.35	2.72	3.72
140	10	11.45	0.34	0.38	3.40	4.35
150	11.1	12.25	0.35	0.41	3.88	5.02
160	11.7	13.04	0.40	0.44	4.68	5.73
170	15.1	13.38	0.42	0.46	6.34	6.15
180	16.4	14.6	0.43	0.49	7.05	7.15
190	17	15.37	0.46	0.51	7.82	7.83

As two thermocouples used into the system, the generator is improved, where the maximum values were obtained 17 mV, 0.46 mA and 7.82 mW. Compared with the one thermocouple system, the harvested power enhanced with about 360 %. In addition, the above results showed that the amount of power produced has proportional relationship with the temperature, and maximum temperature of our design was 190 °C, which affected by size and reflection efficiency of the dish and these parameters can be improved to get a higher temperature that can lead to improve the power of TEG system. Ready-made, old television satellite dish with a diameter of 2 m was used by O. O. Craig et al., [9], they painted it with aluminum reflector to measure thermal conductivity of ceramic wool and obtained as range from 0.07 W/m K at 200 °C to 0.22 W/mK at 600 °C. Moreover, there are high efficiency solar collectors can produce around 3200 °C with 0.1 m^2 surface area [10]. The following figures (7, 8 and 9) show the relationship between voltage, current and power with different temperature, also comparison between the experimental and simulation results.

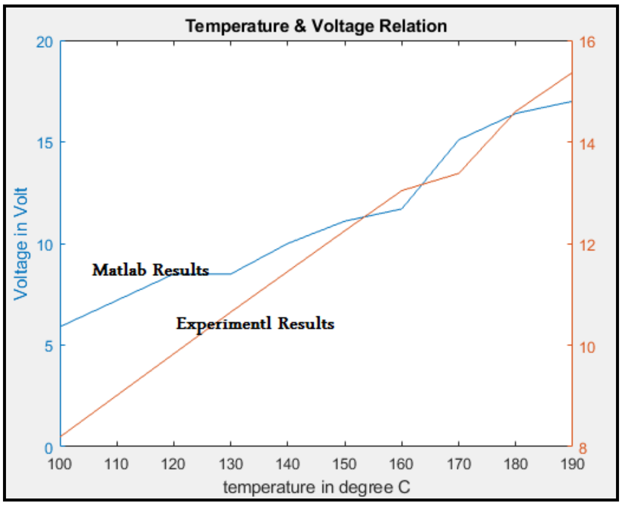

Fig. 7. Voltage vs Temperature of two thermocouples

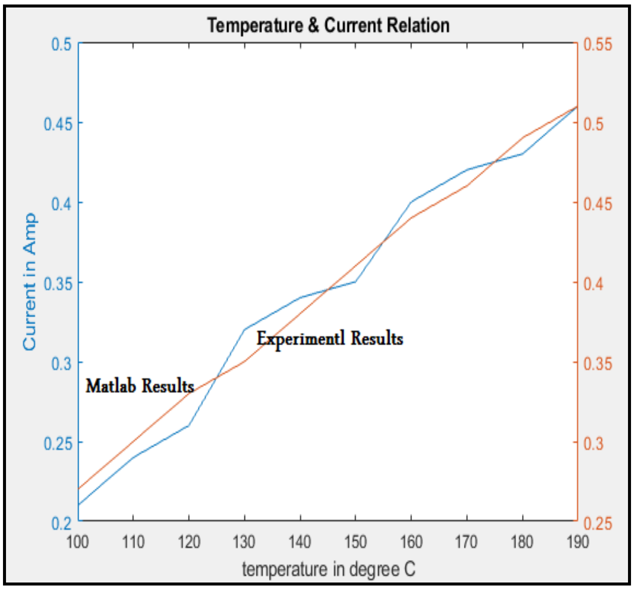

Fig. 8. Current vs Temperature of two thermocouples

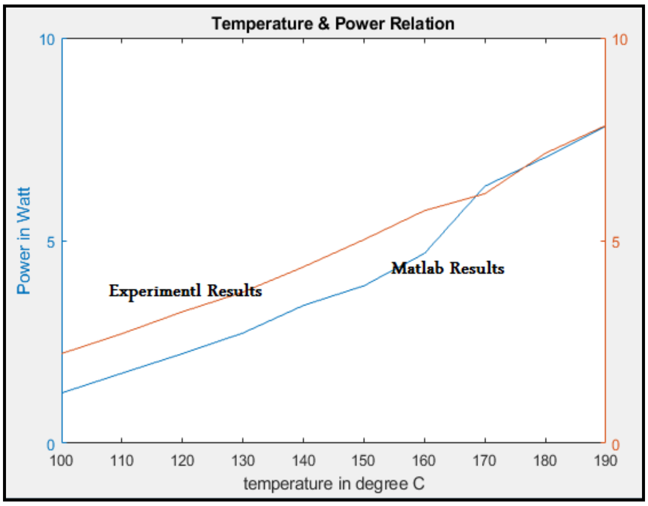

Fig. 9. Power vs Temperature of two thermocouples

The figures showed neglectable differences between experimental and simulation results. This designed experiment is able to provide maximum power of 7.82 mW, which was obtained at 17 mV and 0.46 mA when the temperature of 190 °C was maintained across two thermocouples. Adding more thermocouples into the system can increase obtained power, as the tip of thermocouple is too small, around 1 mm diameter, and with a 6 cm diameter ceramic conical cavity which used to place the thermocouples at focal point of the dish, we expected that around 200 thermocouples can be used in this design, so the system can produce more energy, furthermore, the reflection of the dish can be enhanced as well to produce more power. The generator still needs modification such as the switching and electric regulator that stabilizes the fluctuating voltage from the modules and stores the energy in a battery before using. **The efficiency concept in this study is assumed to be the practical power outcomes compared to simulated results, according to the documented readings, this ratio is evaluated to be around 80 %, as illustrated in Eq. 1. The loss is attributed to some parameters that are not considered in the simulation program, such as the cooling effect of the wind, rapid change in temperature, and the electric loss in joints, also this explains unexpected the voltage drop at 130 °C in Table 2.**

$$Eff. = \left[1 - \frac{Sim. - Exp}{Sim}\right] \times 100\ \% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

However, further experiments are necessary to study the feasibility of using another thermocouple modules and to improve the generated electrical power. This is a good objective for other research to develop these types of clean electrical power generators, which is recommended to be examined.

IV. CONCLUSION

A clean electricity generation system consisting of K-thermocouples and solar concentrator of parabolic dish was built, and its efficiency has been evaluated. The study shows that the energy produced is directly proportional to the temperature collected from the solar dish, and the energy able to be increased by using multiple thermocouples, where the amount of power produced is increased by adding more thermocouples into the system.

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