Chapter 24
Electrical and Configuration Characterization of Thermoelectric Generator Modules

M.A. Ashari, A.A. Abd. Rahman, and S. Sulaiman

Abstract Many electrical appliances and machinery emit wasted heat during their nominal functions. From heavy machinery to laptops and personal desktop computers, a significant amount of heat is dissipated during operation and even more during processing times. Thermoelectric generators (TEGs) can convert this waste heat into electricity. In order to be able to harvest energy efficiently, the need to understand the behavior of current existing thermoelectric modules is essential as it is for the implementation or application of a TEG in various scenarios. This paper describes the electrical characteristics of a typical TEG module that has undergone a series of parameter settings using an in-house and cheap solution jig. The jig evaluation was done to understand the configuration and parameters needed for the TEG module to perform at its best during applications. To obtain optimum performance from the TEG module, it is important to address several key points and identify the cause that will affect the module performance. Once the characteristic of the TEG module is analyzed and understood, it allows the design of the integration circuit to be more appropriate. Therefore this will allow a more sustainable and feasible platform of the Wireless Sensor Network when a TEG module is integrated inside the systems. The TEG module that was used in the experiments is from Hi-Z Technology Inc., model HZ-2. Among all of the Hi-Z Technology modules, this model produces the highest possible output with the lowest ΔT.

Keywords Energy harvester • Thermal equilibrium • Thermoelectric generator module • Wireless sensor networks

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Introduction

Green energy harvesting (power harvesting or energy scavenging) is a process in which energy is derived from external energy sources (such as solar power, thermal energy, wind energy, salinity gradients, and kinetic energy), captured, and stored into usable electrical energy. Nevertheless, the scope of green technology consists of using renewable energy without negative impacts on human involvements. By using green technology, the energy will be harvested and stored without the usage of hazardous materials that are either poisonous or pollute the environment. The existing green technology can provide enough power for small power consumption devices for WSN (Wireless Sensor Network) applications. For example, when using this technology the sensor node is targeted to be able to survive with very minimal maintenance with no requirement to change battery or energy storing part when integrated with any of the green technology devices such as thermoelectric or solar panels.

A thermoelectric based micro-power generator becomes an available energy supply to electronic devices that consume electrical power in the ranges of micro-watt (μW). On the other hand, it was reported that waste heat available in ambient is one of the main sources of energy harvesting and that this can be converted to electrical energy to power up the electronic circuitry [1].

Newer technology is arising whereby a thermoelectric semiconductor-based module is able to generate electricity by experiencing a significant amount of temperature difference on the opposite surface of a P-N junction semiconductor. Recent advancements of semiconductor material technology have made highly efficient thermoelectric energy harvesting a practical reality [2]. The TEG module generates relatively small power density output in comparison to other technology modules of similar size like, for example, solar panels. This paper studies the behavior of TEG modules analysing both single and multiple units connected in series or parallel to help understanding the characteristic behavior of these modules during application.

The HZ-2 module investigated here consists of 97 thermocouples arranged electrically in series and thermally in parallel. The thermocouples consist of "Hot Pressed," bismuth telluride-based semiconductors to give the highest efficiency at generally applicable waste heat temperatures as well as high strength capable of enduring rugged applications [3]. In order to obtain satisfactory performance, it is observed that certain details must be taken care of during testing and measurements of the modules. Understanding both the setup of the jig and the best method to test the module will ultimately assist in designing a more efficient apparatus.

Apparatus for Characterization

The interface between the module and the heat source and the interface between the module and the heat sink are very critical components of any thermoelectric system [2]. The TEG module needs to be compressively loaded between the heat source and

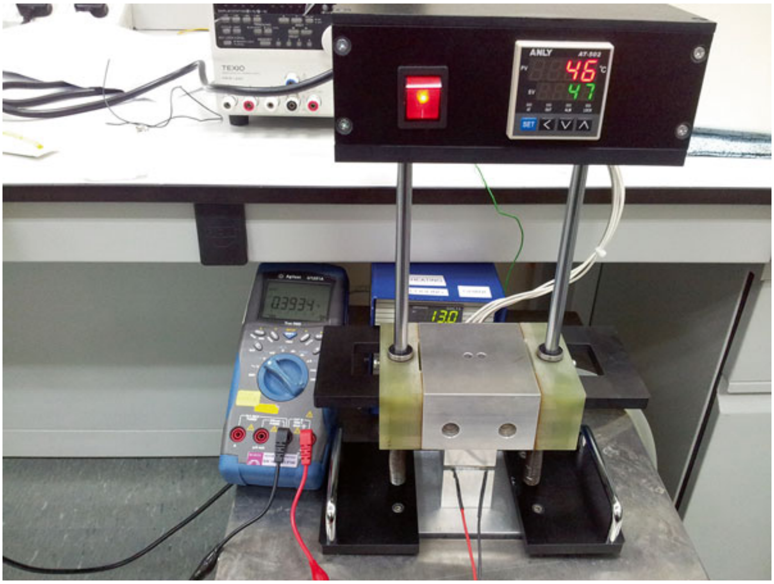

Fig. 24.1 Apparatus used to characterize TEG module using PID controller with water bath and heating element

the heat sink. This is to ensure uniform load over the surface of the module for optimum power performance and to maximize the heat transfer across the interface [4]. Figure 24.1 illustrates a low-cost thermoelectric module characterization apparatus. It consists of a PID (Proportional-Integral-Derivative) controller connected to a heating element. The DUT (device under test) is compressively loaded in between the two aluminum blocks, with a layer of thermal paste for evenly distributed thermal conductivity between the aluminum block and the DUT. The upper block is connected to a heating element, which is controlled by the PID controller. The user can monitor and control the temperature of the upper block in order to generate the intended "hot side" temperature.

The "cold side" is generated by dipping the aluminum block of the apparatus' lower part into a water bath as shown in Fig. 24.2 with the temperature setting being controlled by the water bath's PID controller. Two PID controllers are used in this test set up: one for the "hot side" and one for the "cold side" (i.e., water bath). The "thermal interface" blocks are the two smaller aluminum blocks that are in contact with the DUT. These blocks are interchangeable by the user who wishes to evaluate a single/smaller module or many/larger modules simultaneously, whichever fits the desired configuration.

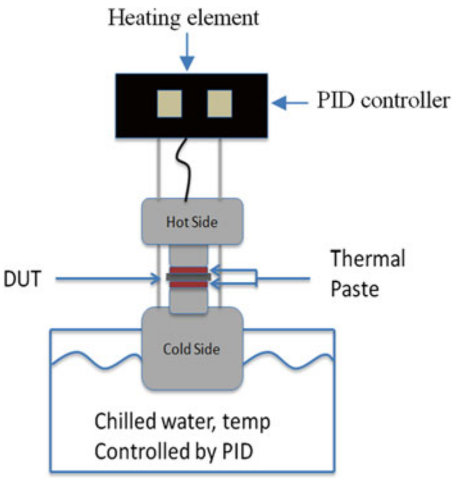

Fig. 24.2 Diagram of the TEG module characterization apparatus

Precautions and Suggested Method

The handling of this apparatus would require certain precautions in its setting up steps in order to maintain its accuracy within the desired limits. The apparatus is acknowledged for lack of vacuum in its area of experimentation. The humidity in the air also affects temperature consistency. Therefore, a vacuum chamber is planned to be installed for temperature stabilization at the cold-side area in order to avoid temperature interference and fluctuations during measurement. Precaution steps needed to be taken care of when using this apparatus are the following:

1. Use thermal insulator paste. This ensures proper contact between the aluminum block and DUT for even thermal conductivity by filling the voids in the interface that are caused by irregular surfaces. At microscopic level the surface of both materials is not totally flat.
2. Apply strong compressive load between the DUT, with the upper "hot-side" aluminum block and lower "cold-side" aluminum block. Strong contact will ensure uniform load and better thermal conductance.
3. It takes approximately 10–15 min to stabilize the temperature once the intended temperatures are reached.

Test, Results, and Measurements

Thermoelectric elements generate power when temperature gradient is available. The thermoelectric module contains thermoelectric material that makes use of the Seebeck effect to produce electricity:

$$V_{\text{Open Circuit Voltage}} = \left(\alpha_{\text{pn}}\right) \times \left(T_{\text{H}} - T_{\text{C}}\right) \tag{24.1}$$

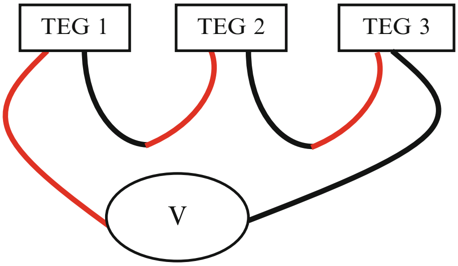

Fig. 24.3 Three TEG modules connected in series configuration

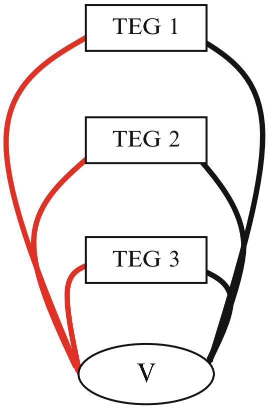

Fig. 24.4 Three TEG modules connected in parallel configuration

α_{pn} = Seebeck coefficient of thermoelectric element.
T_H = Temperature at hot junction of thermoelectric element.
T_C = Temperature at cold junction of thermoelectric element.

Maximum power is at half of the open-circuit voltage. A larger temperature difference will produce higher voltage. High voltage will result in higher maximum power and higher current at match load. When different temperature is applied between the top and bottom surfaces of the thermoelectric module, the module will generate a certain amount of electrical voltage output. The characterization of this output will enable users to design integration circuits which ultimately enable the energy harvesting at its most optimum rate.

The recorded parameters were based on the intended application of the TEG module, i.e., integrate to a WSN mote and harvest energy from ambient versus water surface. The temperature gradient was measured up to 50°, with 5° increment. After reaching the intended temperature, its stabilization must be reached first before taking any measurement. The output of the module can be measured using a voltmeter or a data logger. There are a few configurations that are taken into account to understand more of the nature of the Bi_2Te_3 based thermoelectric generator modules. Data tabulation Voc, Isc and total power output for temperature gradient of 5 until 50 °C for single TEG module, three TEG modules in series configuration (Fig. 24.3), and three TEG modules in parallel configuration (Fig. 24.4) are shown in Table 24.1.

Table 24.1 Voltage and current produced by the three thermoelectric modules connected in series and parallel configuration

			Single		Series		Parallel	
Hot side (°C)	Cold side (°C)	ΔT	Voc	Isc (mA)	Voc	Isc (mA)	Voc	Isc (mA)
30	25	5	0.056	13.3	0.1499	16.7	0.0738	24.50
30	20	10	0.1197	28.8	0.3217	37.1	0.1303	44.80
30	15	15	0.1773	42.2	0.4766	55.8	0.2004	69.80
30	10	20	0.243	71.23	0.7287	86.26	0.2724	93.70
35	10	25	0.3261	78.3	0.8818	101.3	0.3530	120.60
40	10	30	0.3913	93.22	1.1153	126.7	0.4430	150.06
45	10	35	0.4793	112.5	1.3154	148.74	0.5260	179.40
50	10	40	0.5579	132.1	1.553	172.42	0.6130	208.44
55	10	45	0.6376	149.2	1.7603	199.4	0.6995	234.00
60	10	50	0.712	165.8	1.9802	220.94	0.7869	266.20

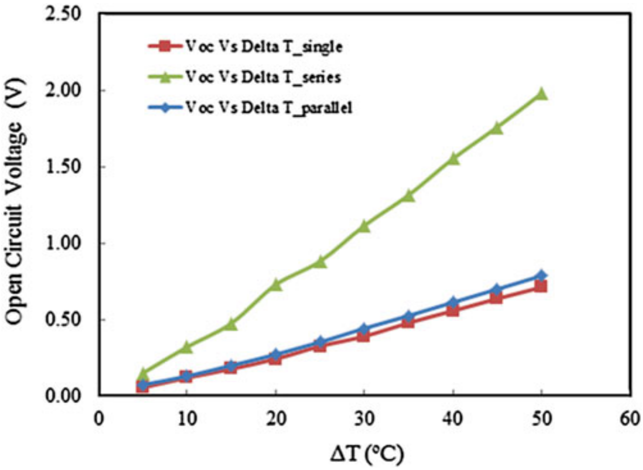

Fig. 24.5 Open-circuit voltage versus delta T of 5 until 50 °C for single TEG module, three TEG modules in series configuration, and three TEG modules in parallel configuration

First part of the experiment was to measure the output of a single TEG module. The TEG was inserted into the apparatus with the precautions taken and the reading was recorded with the lowest degree of voltage reading output fluctuation.

The results observed from testing show that output voltage is generated linearly with temperature differences between hot and cold surfaces. Based on the data taken in Table 24.1 and plotted in Figs. 24.5 and 24.6, connecting the modules in series will produce the highest open circuit voltage output compared to parallel configuration. The data also show that, as the temperature gradient increases, the open circuit voltage and the short-circuit current increase proportionally.

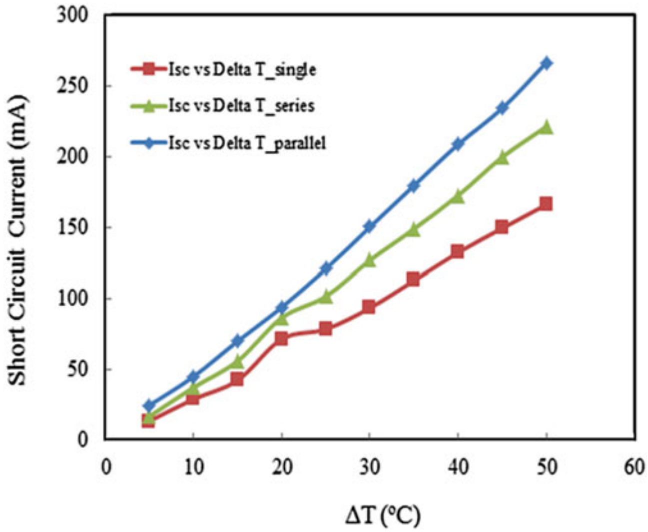

Fig. 24.6 Short-circuit current versus delta T of 5 until 50 °C for single TEG module, three TEG modules in series configuration, and three TEG modules in parallel configuration

Conclusion

This paper shows the electrical behavior of TEG modules when used singularly, in series configuration, and in parallel configuration. This paper also describes the best methods, apparatus, and precaution steps taken during data acquisition of the results.

References

1. Jin X, Chengkuo L, Hanhua F (2010) Design, fabrication and characterization of CMOS MEMS-based thermoelectric power generators. J Microelectromech Syst 19(2):317–324
2. Vining C (2001) Semiconductors are cool. Nature 413:577–578
3. Hi-Z Technology Inc. Available at http://www.hi-z.com/hz2.php
4. Leavitt FA, Elsner NB, Bass JC (1996) Use, application and testing of the HZ-14 thermoelectric module. 15th international conference on thermoelectrics. pp. 378–382. http://www.hi-z.com/uploads/2/3/0/9/23090410/hz-2.pdf