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Study of Thermoelectric Generator in different combinations of series and parallel configurations –Calculation of power and efficiency

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ABSTRACT:A thermoelectric generator system has been build up which consists of bismuth telluride module. A thermoelectric module consists of thermoelectric elements. To increase the operating voltage the thermoelectric elements are connected in series and in parallel to increase the thermal conductivity. In this paper discussing about the study of thermoelectric generator by connecting in different combinations of series and parallel configurations. When six thermoelectric generators of TEP1-1264-1.5 made of bismuth telluride material are connected in different configurations of series and parallel like six thermoelectric modules in series, six thermoelectric modules in parallel, three series and three parallel configurations, four series and two parallel etc. Moreover the figure-of-merit, output power and efficiency was calculated. The ZT value achieved was 0.273 at a temperature difference of 87^0C when six thermoelectric generators are placed in series combination. The output power was 3.62W

Index terms: Thermoelectric generator, series and parallel configurations, thermoelectric module,bismuth telluride.

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I. INTRODUCTION:

The thermoelectric module gives the transformation from heat energy to electrical energy. This transformation is performed efficiently by thermoelectric semiconductors [1]. In designing high performance thermoelectric generators the improvement of the thermoelectric material and thermo electric module and optimization of thermoelectric generators are equally important.[2,3]. Due to difference in temperature, ΔT the thermoelectric generators produces a current flow in the circuit. There are a large number of pairs of n-type and p-type legs are arranged in thermoelectric module and are connected in series and parallel combination from Seebeck effect [4] as shown in Fig:1 below. An electric current was generated when a thermoelectric module is connected to an external load resistance.The thermoelectric modules can convert heat into electrical energy due to temperature difference . Depending on the temperature, the thermoelectric device is designed with the help of p-n connection made of bismuth telluride materials. Suppose if other materials like oxy sulphides (Ni-Cr-S, Ti-S) and cobalt oxides used then a variety of problem will arise. These materials are expensive and difficult to form electrical connections.[5-8] .In thermoelectric generator the power factor was calculated by its Seebeck coefficient and its electrical conductivity under a given temperature difference was given by,

$$\text{Power factor} = \sigma S^2 \qquad [1.1]$$

Where S is the Seebeck coefficient and σ is the electrical conductivity.Commercially available thermoelectric generators are of Bi_2Te_3 , with temperature of 250^0 C tolerance and ZT is equal to one. The figure-of-merit [9], which is usually appears in dimensionless form ZT has increased from the order of 0.5 to the values of greater than one.

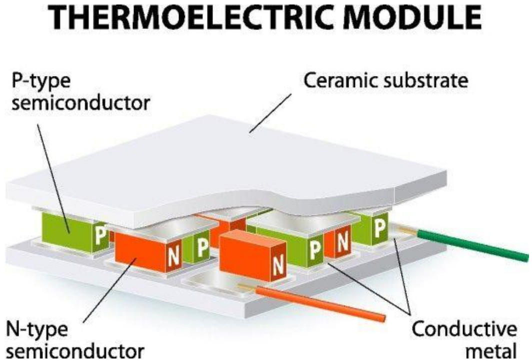


Fig:1 Thermoelectric module

The thermoelectric properties of the alloys of bismuth telluride have been recieved by several authors over the past few decades. One of the most comprehensive treatments is that of Scherrer and Scherrer[10,11]. Near room temperature, these alloys are the best available materials for power generation and refrigeration.[12].Now a days the efficiency of thermoelectric generators is improving and the cost will be decreasing[13,14].

II. THERMOELECTRIC MATERIALS:

Thermoelectric materials are playing an important role for energy conversion process between heat and electricity which means the electrical power generation and refrigeration process. For high performance of thermoelectric materials low electrical conductivity, large Seebeck coefficient and low thermal conductivity are necessary basing on figure-of-merit, ZT of given thermoelectric material and it is given by,

$$ZT = S^2\sigma\ T / K \qquad [1.2]$$

Where S is the Seebeck coefficient , σ is the electrical conductivity and K is the thermal conductivity. At room temperature, the ZT value of bismuth telluride materials have 1 and at 250^0C . Among various thermoelectric materials, bismuth telluride based alloys are the best thermoelectric materials at room temperature for electrical power generation and solid state cooling purpose.

III. ARRANGEMENT OF THE EXPERIMENT:

Fig:2 shows that the arrangement of the six TEGs, hot side used as a heat sink and cold side was fans arranged. First of all on aluminium plate, TEGs are arranged and on top of these TEGs one plate to fix the fans for cooling the system. A rheostat is connected to put the load resistance and two multimeters for measuring output current and output voltages. For the measurement of hot side temperature, temperature measurement is connected. This is the arrangement of the experiment before setting into the board arrangement. When the power is switched on, at load resistance 12Ω and at different temperatures in different combinations the output voltage , output current was measured. There by the output power , figure-of-merit , ZT and efficiency was calculated .

Fig: 2 Experimental arrangement

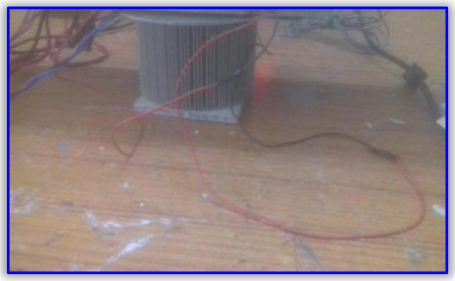


Fig: 3 Heat sink

Fig:3 Arrangement of six TEGs with cold side and hot side in a board

Fig:3 represents the arrangement of cold side was used as fans and for hot side was used as heat sink.

In thermal conductance between the hot side and cold side is influenced by the performance of the thermoelectric devices. With the increase in temeprature difference , the power and efficiency will improve. When the temeprature difference increases, the power increases slowly where as the efficiency decreases after reaching the maximum value[15] . A temperature controller is arranged to measure the temperature . The six TEGs can set in different combinations such as

(a) Six TEGs in series combination
(b) Six TEGs in parallel combination

© Three TEGs series and three TEGs parallel combination
(d) Four TEGs series and two TEGs parallel combination etc.,
(a)When six TEGs are connected in series combination:

When six TEGs are connected in series combination, the cold side temperature, hot side temperature , input voltage , output voltage, output current and efficiency was calculated at load resistance 12Ω without boost converter and are shown in table :1 below

Table:1

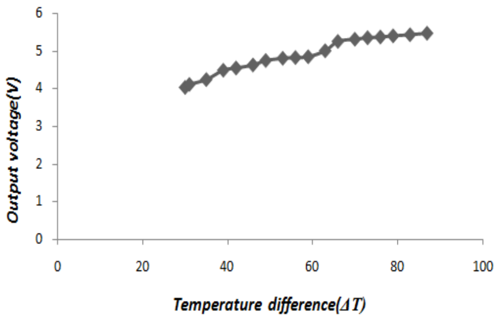
S.NO.	Cold side Temp. (^{0}C)	Hot side Temp. (^{0}C)	Temperature Difference (ΔT)	Input voltage (V)	Output voltage (V)	Output current (A)	ZT	Power (W)	Efficiency (%)
1.	45	75	30	2.5	4.02	0.42	0.140	1.68	1.63
2.	49	80	31	2.5	4.10	0.44	0.151	1.80	1.67
3.	50	85	35	2.5	4.23	0.47	0.158	1.98	1.88
4.	51	90	39	2.5	4.48	0.49	0.165	2.19	2.09
5.	53	95	42	2.5	4.54	0.51	0.173	2.31	2.24
6.	54	100	46	2.5	4.62	0.54	0.180	2.49	2.44
7.	56	105	49	2.5	4.74	0.55	0.188	2.60	2.59
8.	57	110	53	2.5	4.80	0.58	0.195	2.78	2.79
9.	59	115	56	2.5	4.82	0.59	0.204	2.84	2.95
10.	61	120	59	2.5	4.84	0.61	0.212	2.95	3.08
11.	62	125	63	2.5	5.00	0.62	0.219	3.10	3.28
12.	64	130	66	2.5	5.25	0.63	0.227	3.30	3.42
13.	65	135	70	2.5	5.31	0.64	0.234	3.39	3.61
14.	67	140	73	2.5	5.35	0.64	0.242	3.42	3.75
15.	69	145	76	2.5	5.37	0.65	0.251	3.49	3.89
16.	71	150	79	2.5	5.40	0.65	0.257	3.51	4.03
17.	72	155	83	2.5	5.43	0.66	0.266	3.58	4.22
18	73	160	87	2.5	5.47	0.66	0.273	3.61	4.40

IV. RESULTS AND DISCUSSIONS:

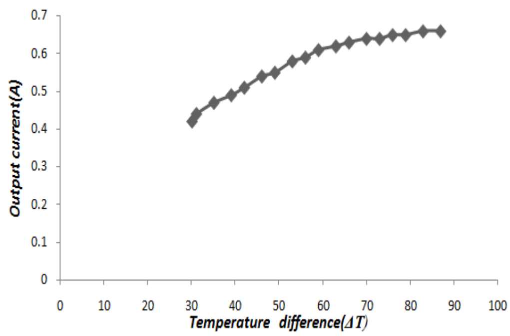
At temperature difference , ΔT = 87 ^{0}C the input voltage was 2.5V , maximum output voltage was 5.47V , output current was 0.66A . The maximum efficiency calculated was 4.40%. But at temperature difference ΔT = 30 ^{0} C , the input voltage and output voltages are 2.5V and 4.02V . The output current and the efficiency was 0.42A and 1.63% .

From graph:1, it represents graph between temperature difference as a function of output voltage . As temperature difference increases , the output voltage increases. Temperature difference , ΔT starts from 30^0 C , the output voltage was 4.02V, the output current was 0.42A. The figure-of–merit, ZT was 0.140, the output power was 1.68W and the efficiency was 1.63%.

Graph:1 Temperature difference as a function of output voltage

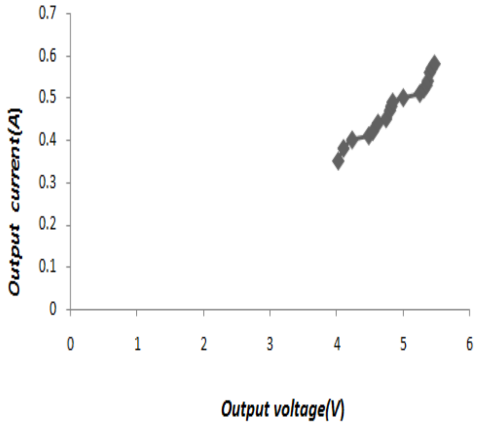


Graph:2 Temperature difference as a function of output current



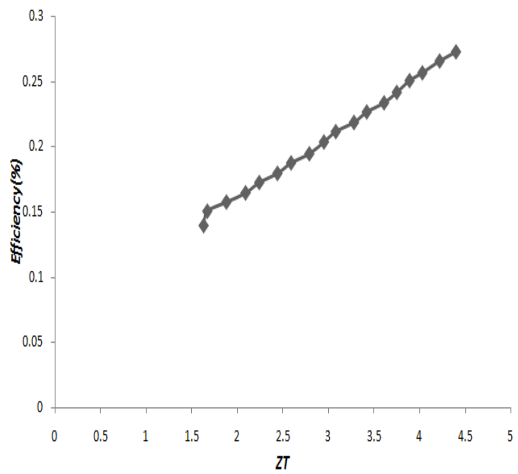
From graph:2, it is a graph with output current as a temperature difference . As temperature increases , the output current increases. The maximum current was 0.66A at a temperature difference of 87^0C .

Graph:3 Output voltage as a function of output current



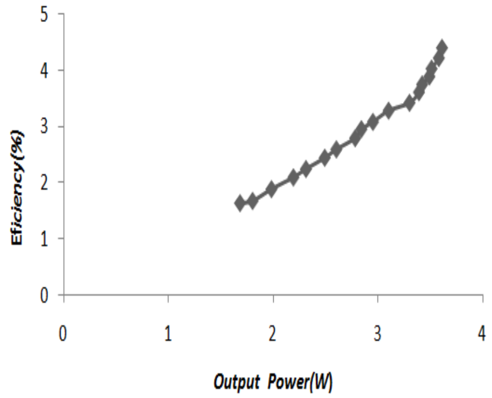
From fig:3, it represents the graph between output voltage and output current. As the voltage increases the output current also increases. The maximum voltage , 5.47V at an output current of 0.66A. The figure-of-merit , ZT was 0.273 and the output power was 3.61W.

Graph:4 Efficiency as a function of ZT(figure-of-merit).



From graph:4 , it was drawn between the figure-of-merit as a function of efficiency. As ZT increases the efficiency also increasing . The maximum efficiency was 4.40% at a temperature difference of 87^0 C . The ZT value achieved was 0.273.

Graph:5 Output power as a function of efficiency



From graph:5 it was a graph drawn between output power and efficiency. As power increasing the efficiency also increasing . The maximum power was 3.61W at an efficiency of 4.40%.

V. CONCLUSIONS

The thermoelectric module considered was the bismuth telluride . It is most suitable and reliable thermoelectric module for the generation of output voltage, current and power. In this paper six thermoelectric generators to be considered and they are connected in various combinations such as in series and parallel . when six thermo electric generators are connected in series the output current , voltage, output power was calculated . The figure-of-merit , ZT and the efficiency was calculated . The maximum power obtained was 3.61W at temperature difference of 87^0C. The efficiency was 4.40% without boost converter. The corresponding graphs was drawn . We can also connect the six thermoelectric generators in parallel combination , three TEGs series , three TEGs parallel and four TEGs series , two TEGs parallel combinations etc. The same output voltage, current, output power , figure-of -merit and efficiency can be calculated.

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