Analysis of Thermoelectric Battery Charger

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ABSTRACT--*Thermoelectric generator is a device which converts thermal energy into electrical energy. It is an alternative green technology when compared to other power generating sources, which does not need any external electrical input supply for its operation. This work focuses on two folds. Initially mathematical modelling is proved with MATLAB simulations incorporate developed thermoelectric module and finally the hardware description had been analysed, were heat is given as input to the thermoelectric module; it produces a Direct Current as output voltage. The output is given to a Boost converter, which is used for charging a battery. The novelty insists on voltage generation without an external input source.*

Keywords: Thermoelectric generator, alternative green technology, boost converter and battery charger without external input supply.

1. INTRODUCTION

Thermoelectric generator is a device which converts heat energy (thermal energy) into electrical energy through semi-conductor or conductor. The direct conversion of heat energy into electric energy (i.e. without a conventional electric generator) based on the seebeck thermoelectric effect. The Thermoelectric effect was first discovered in 1822 by Seebeck. Consider two dissimilar materials joined together in the form of a loop so that there are two junctions. If a temperature difference is maintained between these two junctions, an electric current will flow round the loop. [1] The major drawback of thermoelectric power generator is their relatively low conversion efficiency (typically ~5%). This has been a major cause in restricting their use in electrical power generation to specialized fields with extensive applications where reliability is a major consideration and cost is not. However, in recent years, an increasing concern of environmental issues of emissions, in particular global warming has resulted in extensive research into nonconventional technologies of generating electrical power and thermoelectric power generation has emerged as a promising alternative green technology. Vast quantities of waste heat are discharged into the earth's environment much of it at temperatures which are too low to recover using conventional electrical power generators. Thermoelectric power generation (also known as thermoelectricity) offers a promising technology in the direct conversion of low-grade thermal energy, such as waste-heat energy, into electrical power. Their performance and economic competiveness appear to depend on successful development of more advanced thermoelectric materials and thermoelectric power module designs.

2. SPECIFICATIONS OF THERMOELECTRIC GENERATOR

A typical multi couple thermoelectric power module is shown schematically in Figure 1: n-type and p-type semiconductor thermo elements are connected in series by highly-conducting metal strips to form a thermocouple. More than one pair of semiconductors are normally assembled together to form a thermoelectric module and within the module a pair of thermo elements is called a thermocouple. The junctions connecting the thermo elements between the hot and cold plates are interconnected using highly conducting metal (e.g. copper) strips [2]. The power output for most of the commercially-available thermoelectric power generators ranges from microwatts to multi-kilowatts. For example, a standard thermoelectric device consists of 71 thermocouples with the size of 75 mm^2 can deliver electrical power of approximately 19 W. The maximum output power from a thermoelectric power generator typically varies depending on temperature difference between hot and cold plates and module specifications, such as module geometry (i.e. cross-sectional area and thermo element length), thermoelectric materials and contact properties.

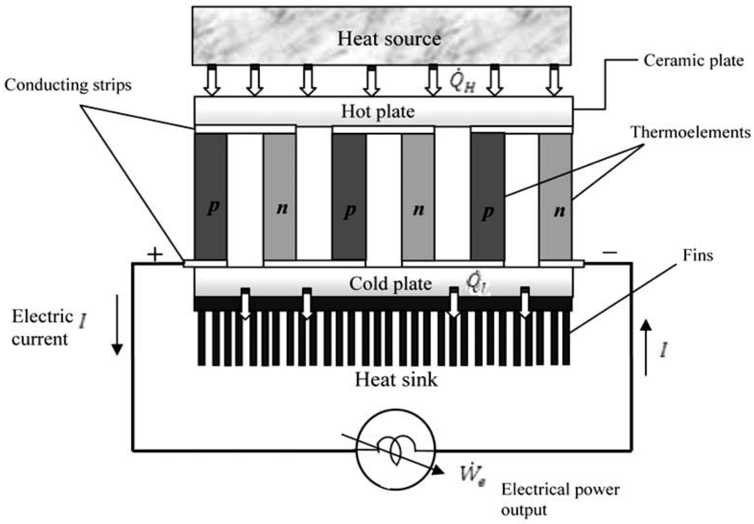

Figure 1: Schematic of a single thermoelectric-couple

3. PERFORMANCE OF THERMOELECTRIC POWER GENERATORS

The performance of thermoelectric materials can be expressed as

$$Z = \alpha^2 / kR$$

Where Z is the thermoelectric material figure-of-merit, α is the Seebeck coefficient given by

$$\alpha = -\frac{\Delta V}{\Delta T}$$

R is the electric resistivity (inverse of electric conductivity) and k is the total thermal conductivity. This figure-of-merit may be made dimensionless by multiplying by T^*(average absolute temperature of hot and cold plates of the thermoelectric module, K), i.e.,

$$ZT^* = \frac{\alpha^2 T^*}{kR}$$

And

$$T^* = \frac{T_H + T_C}{2}$$

The term α^2/R is referred to as the electrical power factor. In general, a thermoelectric power generator exhibits low efficiency due to the relatively small dimensionless figure-of-merit ($ZT^* \leq 1$) of currently available thermoelectric materials. The conversion efficiency of a thermoelectric power generator defined as the ratio of power delivered to the heat input at the hot junction of the thermoelectric device.

$$\eta = {W_e}/{Q_H}$$

Limited by the second-law of thermodynamics, the ideal (absolute maximum) efficiency of a thermoelectric power generator operating as a reversible heat engine is Carnot efficiency.

$$\eta_{carnot} = 1 - {T_C}/{T_H}$$

The maximum conversion efficiency of an irreversible thermoelectric power generator can be estimated using

$$\eta = \eta_{carnot}\left[\frac{\sqrt{1+ZT^*}-1}{\sqrt{1+ZT^*}+{T_C}/{T_H}}\right]$$

4. SYSTEM ANALYSIS

4.1 Existing System

The proposed topology is based on the external electrical input supply and in the past the work proposed by authors has been interdisciplinary focusing on electrical and mechanical nor electrical and Industrial electronics like IEEE Electron Device Letters, Vol. 33, No. 2, February 2012 233, “A Thermoelectric Energy Harvester Directly Embedded into Casted Aluminium” is based only on the TEG manufacturing. IEEE Transactions on Industrial Electronics, Vol. 61, No. 3, March 2014 1301, “Component-Oriented Modelling of Thermoelectric Devices for Energy System Design” is based on the modelling of TEG, but this work focuses purely based on Electrical sciences.

4.2 Proposed System

In this paper, the novelty insists in input supply without any external source. Heat is given as input to the Thermoelectric Generator; from that waste heat (heat energy into Electrical energy) the power is generated, also software like OrCAD PSpice 9.1 and MATLAB 2013b does not support TEG module, hence the mathematical model of TEG has been worked for authentication. The work is purely based on Energy Conservation from the waste heat.

5. MATHEMATICAL MODELLING

The Simulation of the thermoelectric generator module was done using the mathematical modelling. The thermoelectric generator operates between 1500° and 1000°K. The material properties are: α at 1250°K=0.0012 volt/°K. [1]

The constants are ρ_A=0.01 ohm cm, ρ_B=0.12 ohm cm.

For an optimum design
A_A = 43.5 cm^2;
A_B = 48.6 cm;
$L_A = L_B$ =0.49 cm
Open circuit voltage per couple:

$$V = \alpha (T_H - T_C) = 0.0012*(1500-1000) = 0.6 \text{ volt}$$

$$R = R_A + R_B$$

$$= \frac{\rho_A L_A}{A_A} + \frac{\rho_B L_B}{A_B} = \frac{0.01*0.49}{43.5} + \frac{0.012*0.49}{48.6} = 2.34*10^{-4} \text{ ohm}$$

$$V_L = V - RI$$

$$= V - (R_A + R_B) I = 0.6 - (2.34*10^{-4})(20*48.6) = 0.374 \text{ volt}$$

6. SIMULATION

Simulation of the project is done using the MATLAB/Simulink 2012 b version software. Simulink is a block diagram environment for multi domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. [7]

The output 1V DC from the thermoelectric module is given to the boost converter and the boost converter increases 1V to 12V. That 12V is used for charging the DC battery. The overall simulation of thermoelectric battery charger is shown in figure 2. The Simulation of the thermoelectric module is done using mathematical model is shown in the figure 3. The Tabulation 1 shows the Analysis of TEG module and output voltage from Boost converter.

Temperature in Celsius	Voltage from TEG	Output Voltage from Boost Converter
1400	1.04 v	12.03 v
1400	1.56 v	14.25 v
1400	2.87 v	22.19 v
1400	3.06 v	28.67 v

Table 1: Analysis of Thermoelectric generator

6.1 Simulation of Thermoelectric Battery charger

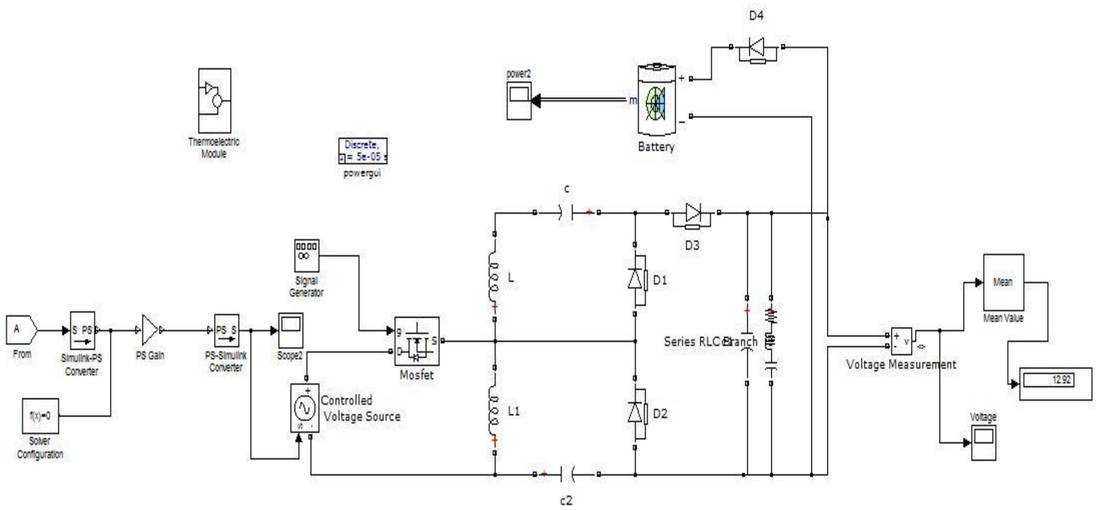

Figure 2: shows the overall simulation of thermoelectric battery charger

6.2 Mathematical model of Thermoelectric Generator

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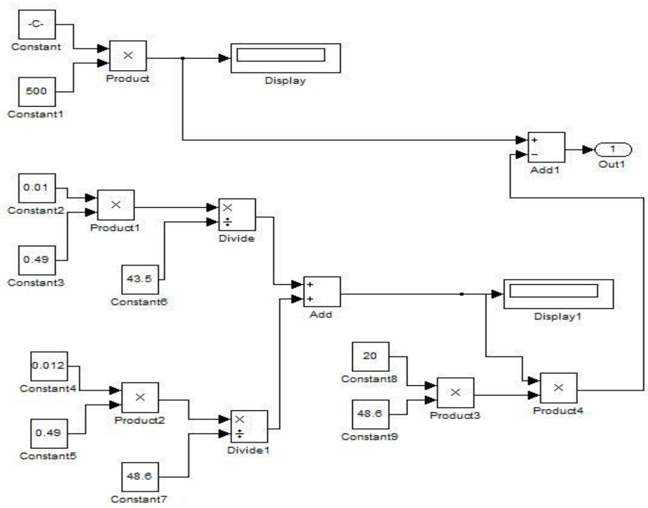

Figure 3: Mathematical model of TEG

6.3 Simulation Results:

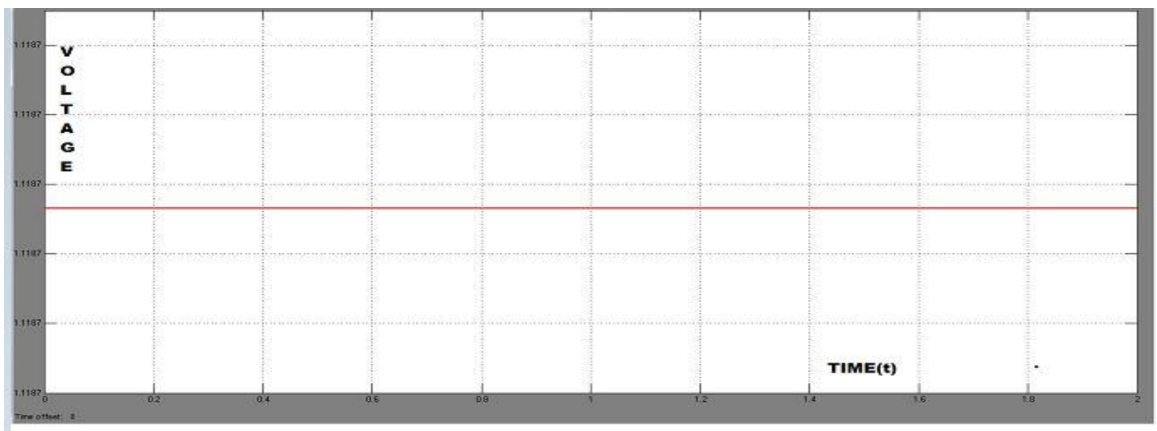

Figure 4a: The graph shows the input voltage from the TEG i.e. 1.147 v

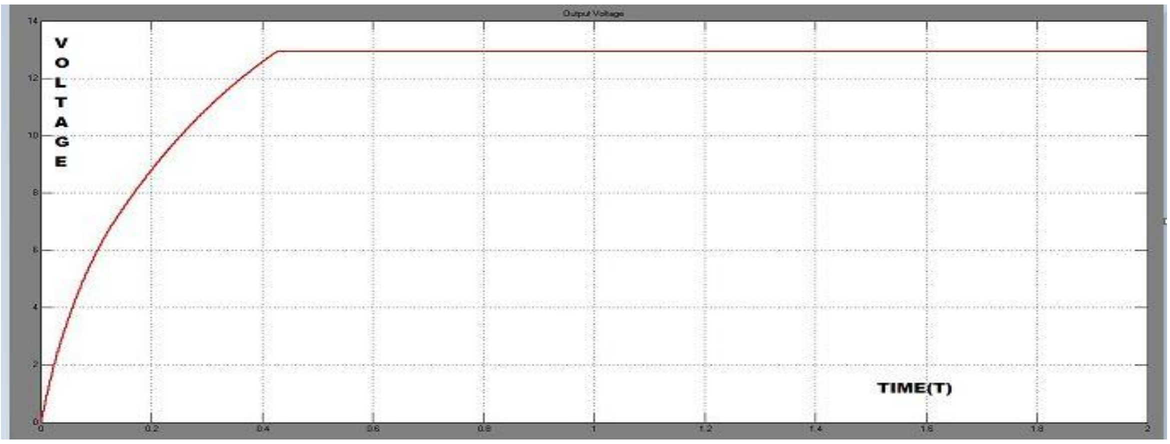

Figure 4b: The graph shows the output voltage from the Boost converter i.e. 13v

VII. CONCULSION AND FUTUREWORK

In this work the novel concept of generating power from the waste heat using Thermoelectric Generator module was proposed. The novelty insists in voltage generation without using an external input supply. It was shown with the overall analysis of thermoelectric module and its performance specifications through analytical simulation and hardware based. In future this system can be incorporated in Automobiles for utilising the waste heat and also in heat exchangers.

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