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Utilization of Human Heat to Generate Power using Thermoelectric Generator

Dr. Mrunal Deshpande[1], Parithi R[2], Mohamed Adhil A[3], Logeshwaran S[4] and Kabilan C[5]
[1-5]Dept. of EEE, SSN College of Engineering. Kalavakkam 603110, Chennai, Tamilnadu India
Email: mrunald@ssn.edu.in

***Abstract*—Mobile Energy harvesting is attracting many and is recently becoming a field of research due to the rise in the usage of wearable electronic devices. In mobile energy harvesting unused ambient energy is captured and converted into usable electrical energy. The storage and utilization of this energy is possible at the site of generation itself. The work presented in this paper focuses on one of the methods of generation of such type of energy. It is generated from human heat. Thermoelectric (generator) module is used to convert the heat from human body to electricity. Since, the generated form of electricity is not suitable for the direct use by electronic devices, a DC-DC boost converter circuit is used to convert the generated form of electricity to usable form.**

***Index Terms*— Energy harvesting, human body heat, thermoelectric generator, converter, electricity.**

I. INTRODUCTION

In recent times, the rise in wearable technology has resulted in extensive research into novel technologies of mobile energy harvesting. And also due to the increased concern of global warming, the world is now rapidly switching towards the clean and renewable energies. Generation of power from human heat is one such type which meets both the needs. This energy is clean, renewable and mobile, yet it has been remaining unexploited despite being available in abundance through our body. The energy so obtained does not cause any adverse effects on both, the human and the environment. The mobile energy harvesting technology is already used in Aerospace industry to power the Spacecrafts, Rovers and in the automobile industry to scavenge energy from the gas exhausts. But of the low power produced, it is not yet popular through it has huge potential and hence we are still scratching the surface. Here, we have focused on harvesting the power from human heat and use it for low power application.

Considering the heat loss in human being, an average human can generate roughly 3,50,000J of energy per hour. Gross caloric value of fuel gas is ~43.01 MJ/m^3 [1]. We can potentially use this heat to harvest power without wasting it.

Thermoelectric generators (TEG) [2,3] are the device which used for scavenging power from human heat. The voltage generated by the TEG is very low, which is impossible to use directly. A converter circuit is required to convert the TEG output to usable form [4-6]. Fig. 1 shows the steps to generate energy through this method.

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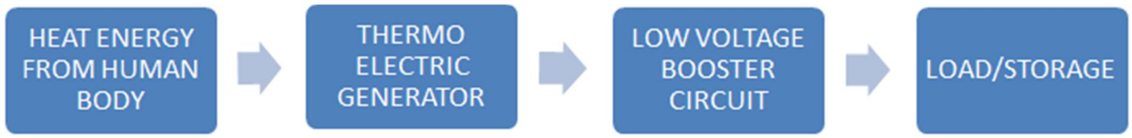

Fig.1. Flowchart

II. THERMOELECTRIC GENETRATOR

Thermoelectric Generators (TEG) is a solid-state device that converts heat flux into electrical energy through a phenomenon called Seebeck Effect. The Seebeck effect [7] is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances as shown the Fig.2 [7]. The aim of this work is to utilize this effect to generate useful power from the heat lost to environment from human body. The efficiency of the TEG can be significantly increased by the usage of heat sinks paste and heat sink plates. The average output voltage of the TEG is in the range of mV. So, several TEG modules are connected in series to increase the TEG output voltage [8]. Since, the output of the Thermoelectric generator is direct current, there is no need for rectification and this output can be directly feed to a low voltage converter.

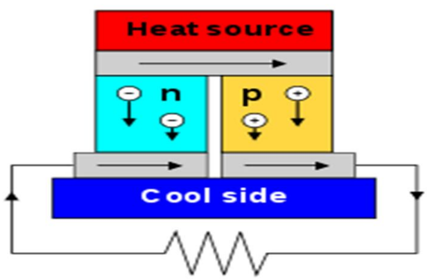

Fig.2. Thermoelectric generator (Source: Wikimedia Commons)

III. Low Voltage Converter

A Low Voltage Converter is used to boost the TEG voltage of mV range to useable voltage of 2-5V range. LTC3108 [9,10] is a 16-pin DC-DC converter manufactured by Analog Devices (Fig.3.). It is a highly integrated converter ideal for harvesting and managing surplus energy from a low or an ultra-low level input voltage sources like TEGs, thermopiles and small solar panels. The pin diagram for the converter is shown in the Fig.3 and overall low voltage converter in Fig 4. It utilizes a MOSFET switch to form a resonant step-up oscillator using an external step-up transformer and a small coupling capacitor. The frequency of oscillation is determined by the inductance of the transformer secondary winding and is typically in the range of 10kHz to 100kHz.

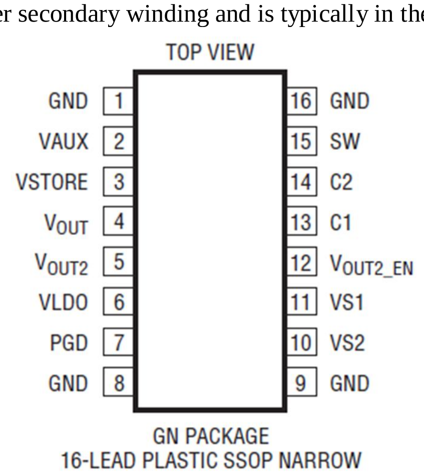

Fig.3. LTC3108

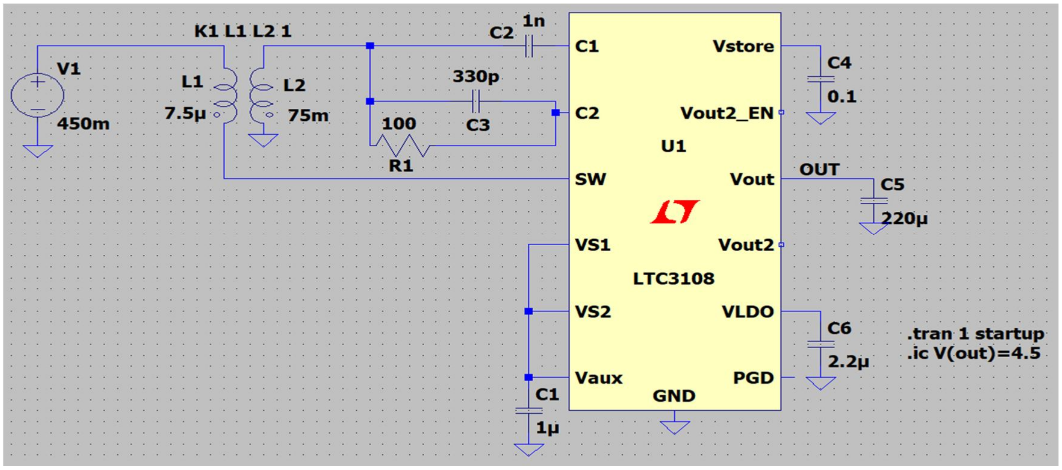

Fig.4. Low Voltage Converter

To start with the ratio of that transformer will decide how low the input voltage can be for a converter. Here, we have used a 1:100 ratio transformer, since it has a start-up voltage as low as 20mV. The step-up topology operates from input voltages as low as 20mV to 500mV [10]. Using this step-up transformer, maximum power can be drawn from V_{OUT} pin.

LTC3108 has a selectable V_{OUT} value and the user can select according to their requirement. The available output voltages are 2.35V, 3.3V, 4.1V, 5V. The pins V_{S1} and V_{S2} are used to select the output voltage and the table to select is shown in the Table 1 [10].

TABLE I. STATES OF V_{S1} AND V_{S2} PINS FOR OUTPUT VOLTAGES

V_{S1}	V_{S2}	V_{out}
GND	GND	2.35V
V_{AUX}	GND	3.3V
GND	V_{AUX}	4.1V
V_{AUX}	V_{AUX}	5V

This IC provides two output pins namely V_{OUT} and V_{OUT2}. The second output is the switched output of the converter. This pin is normally disabled until V_{OUT2_EN} is driven high.The V_{STORE} pin can be used to charge a large storage capacitor or a supercapacitor or a rechargeable Li-ion battery after V_{OUT} has reached its regulation. The stored power can be used to power the load when the input source is unavailable or unable to fulfil the current demands of the loads at V_{OUT}, V_{OUT2}. The current available to charge the storage element will depend on the input voltage and transformer turns ratio, but is limited to about 4.5mA. If V_{AUX} drops below the V_{STORE}, LTC3108 will automatically draw power from the storage element. Based on the input power available, it may take long time to charge the storage element.

IV. SIMULATION RESULTS

The low voltage converter circuit which is shown in Fig.4. is simulated by using the LTspice software. LTspice is SPICE based analog electronic circuit simulator. This computer software is produced by semiconductor manufacturer Analog Devices. The circuit is simulated and the simulated output voltage of the converter is as shown in Fig.5.

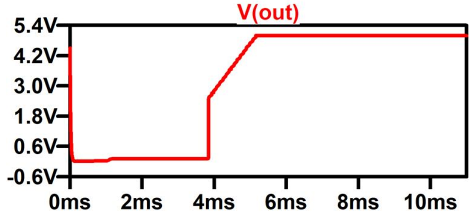

Fig.5. V_{OUT} (V) vs Time (ms)

From the graph, it can be inferred that the voltage at V_{OUT} reaches its steady state in almost 5ms for this proposed configuration.

V. Efficiency

The Efficiency of the TEG can be found using the formula given below [11]:

$$\eta = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_C}{T_H}}$$

where, T_H is the temperature on the hot side,
T_L is the temperature on the cold side,
ZT is thermoelectric figure of merit.
Thermoelectric figure of merit is the transduction efficiency value of thermoelectric materials. It is a dimensionless quantity. Here, in this work we have used the flexible TEG FTE1-01 manufactured by TEGway. The value of ZT for this TEG is 0.73. The efficiency and its variation under different temperatures is shown in Table 2, Fig 6, Table 3, Fig7, Table 4 and Fig 8.

TABLE II. Data under Air-Conditioned Environment (20℃)

	Hot Side, T_H (℃)	Cold Side, T_L (℃)	Efficiency, η (%)
Rest	36.5	20	7.64
Moderate Work	37	20	7.80
Heavy work	38	20	8.11

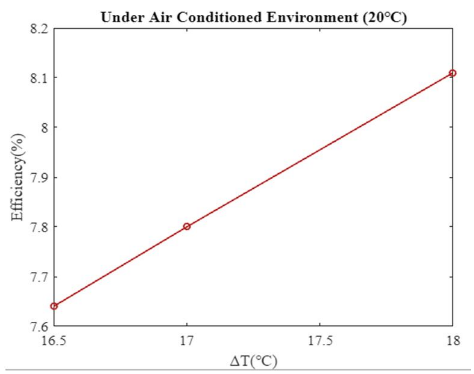

Fig.6. η (%) vs ΔT (℃) at T_C = 20℃

TABLE III. Data Under Normal Room Environment (24℃)

	Hot Side, T_H (℃)	Cold Side, T_L (℃)	Efficiency, η (%)
Rest	36.5	24	5.47
Moderate Work	37	24	5.63
Heavy work	38	24	5.96

(The mentioned Outdoor temperature is with respect to Tamilnadu, India which is obtained from online)

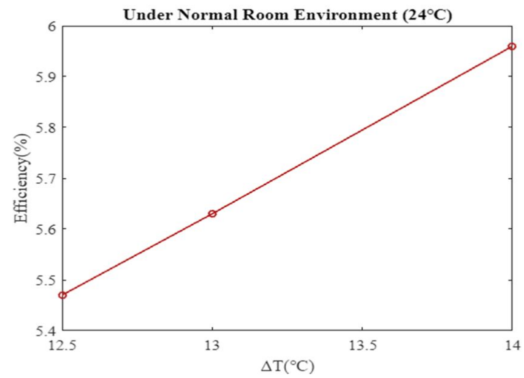

Fig.7. η (%) vs ΔT (°C) at T_C = 24°C

TABLE IV. DATA UNDER OUTDOOR ENVIRONMENT (28.8°C)

	Hot Side, T_H (°C)	Cold Side, T_L (°C)	Efficiency, η (%)
Rest	36.5	28.8	3.33
Moderate Work	37	28.8	3.51
Heavy work	38	28.8	3.85

(The above-mentioned human temperature, room temperature and outdoor temperature data are obtained from online with respect to conditions prevailing in Tamilnadu India)

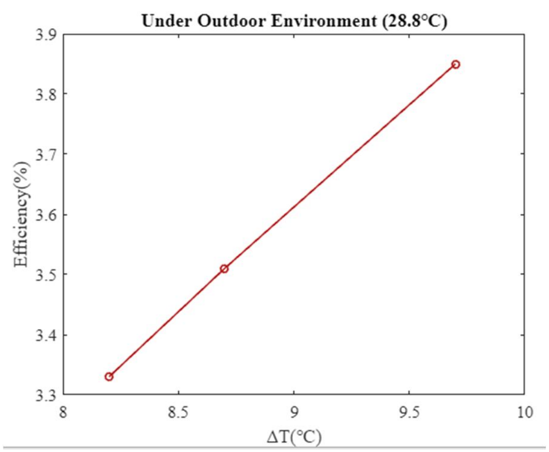

Fig.8. η (%) vs ΔT (°C) at T_C = 28.8°C

Under various temperatures, the inferences are represented in form of case study and are presented below.

VI. CASE STUDY

A.Case

Even under Air-Conditioned environment, if heavy work is done, it definitely releases lot of heat from human body. In this case the body temperature is about 38°C (Hot side) and the surrounding temperature is about 20°C (Cold side). The temperature difference is about 18°C, which is pretty higher than other cases. So, the efficiency is maximum in this case.

B. Case

In outdoor environment, at Rest Condition, the normal temperature of the human body (Hot side) is about 37°C and the surrounding temperature is about 28.8°C. The temperature difference is 8.2°C, which is lower than other cases. So, the efficiency is least.

INFERENCE:
The Efficiency of the TEG is proportional to the temperature difference between the hot and cold side.

$$\therefore \eta\ (\%) \propto T_{diff.}(°C)$$

VII. APPLICATIONS

The Applications of TEGs are vast. Starting from automobile, medical industry to space industry, wherever the heat energy is wasted and released into the environment and whenever there lies a significant temperature difference between the hot and the cold side, we can use the TEGs to harvest that energy. Some, the applications are discussed here:

A) The technology is very useful in the field of wearable electronics [12] where we have very low power consumption in the range of mW [11,13]. A flexible wristband (Fitness Tracker) powered by thermoelectric generator modules is sufficient to capture all the necessary data from the user.

Thin thermoelectric generators can be built into clothing's such as shirts [14] to harvest lower power while taking advantage of a larger surface area. The harvested energy can be stored in a flexible supercapacitor or in a Li-ion battery and used at the time of need.

B) Medical devices including, pacemakers, defibrillators, drug infusion pumps, and other implantable devices require electrical power. One of the major limitations of implantable biomedical devices is the longevity of the battery source. Currently, the longevity of pacemakers and defibrillators ranges from 5 to 10 years which is depending on the model and pacing requirements of that particular patient. After 5-10 years, the patient has to undergo surgery for the pacemaker to be removed and the old battery being replaced with a new one. A solution to this problem would be to use temperature differences, typically as low as 0.3°C to 1.50°C that can exist between the inner surface of the skin and the core body temperature to create electrical energy. A thermoelectric module generating 70μW or more from such temperature gradients can be useful in such applications. The module can be useful to supplement the battery power [2].

With the current trend in the technology, the gap between the human and the machines is becoming lesser day by day. With the current pace the evolution of human into cyborgs is not far. We are already a half cyborg [15]. We can't spend one single day without technology. The mobile phones and the internet have already become our sixth finger and the days which offer us the luxury of integrating all those into our body itself is not far. At that time the concept of mobile energy harvesting would be at its high and this TEG will surely find its place there.

The protentional which this technology poses are immense but, there are few drawbacks. The TEG does harvest all the energy that is released from our body. Most of it is lost due to the internal thermal resistance and material design. More research into the topics like flexible TEGs [16], Graphene based TEG [17] etc., are needed to increase its efficiency. And the research on the new booster circuits and storage devices like flexible supercapacitors [18] is also necessary to bring the concept of mobile generation and storage into commercial products. If all these requirements are met, the results obtained from this work suggest that this technology of energy harvesting from the human body, may evolve into a new trend for developing wearable smart devices in the future.

VIII. CONCLUSION

Implementation of thermoelectric generator to convert human body heat into usable electrical energy is presented. A converter circuit used to boost the generated energy to suitable level is also discussed. Case studies under different temperatures to present efficiency thermoelectric generator is presented. The future scope and advancements required to increase the popularity of this device are also discussed. It is concluded that harvesting of heat from human body is a green, clean, portable technology which will greatly reduce the dependency on the battery/grid power of the low-power devices in near future.

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