Thermoelectric Generator: Mobile Device Charger

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Abstract- **Energy conversion using waste heat recovering techniques especially thermo electric generator (TEG) technologies has developed during recent years. It's utilization in the alternative energy industry is attempted from many aspects. Previous research shows that TEG as a waste heat harvesting method is feasible.**

The study for the search of renewable sources of energy has been a major concern worldwide as a replacement to the high demand for fossil fuels. The researcher ventured in harvesting heat energy and converting it into electric energy. This was made possible with the use of Seebeck effect. Thermo-electric generators (TEGs) are semiconductor-based devices that harvest heat to produce electricity. The resesrchers devised a generator which uses alternative source of energy that can be used to harness and store electricity. The energy that will be stored can be used in different applications such as to power and recharge mobile devices.

The basic model of this study (prototype) as a Thermo-electric generator will consist of an aluminum heat sink and a thermo-electric cooler IC (Peltier device) that will be used as a generator. The two sides of the Peltier device is cold and hot side that will give the temperature difference which are used to generate electricity.

Keywords– **thermo-electric, heat energy, Seebeck, Peltier, electricity, generator, renewable energy, green energy**

I. INTRODUCTION

The addiction to electricity has generated a concurrent dependence to fossil fuels. However, the reserves of fossil fuels will soon be depleted since oil is a limited resource. Over the years, the cost of electricity has risen to unprecedented levels due the limited supply of oil and economic and political factors. Thus, renewable energy is a more attractive alternative to electricity generation, as it will also provide a cleaner environment for future generations. Currently, there are many great solutions to renewable energy, but some are unfeasible. In this proposed project, a device will be created to introduce a way for humans to create renewable energy using thermoelectric devices.

Thermoelectric generators are all solid-state devices that convert heat into electricity. Unlike traditional dynamic heat engines, thermoelectric generators contain no moving parts and are completely silent. Such generators have been used reliably for over 30 years of maintenance-free operation in deep space probes such as the Voyager missions of NASA. (Fisk, 2005)

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Renewable energy can be created by many methods; for example, solar energy, wind energy, hydro energy, nuclear energy, and many more. For each of these different forms of creating electricity, there are certain limitations. Solar energy is the most commonly form of renewable energy that is used in applications ranging from household power to spacecraft electrical systems. However, solar energy can only be created when there is sunlight, necessitating the use of alternate energy sources, or a method of storing energy for later use. Wind energy and hydro energy have their own limitations, making them insufficient for wider usage. Nuclear energy is used in applications such as power plants and military vehicles. Nuclear sources can supply adequate amounts of energy, but produces hazardous waste that is harmful to the environment. This project aims to provide a source of renewable energy that overcomes the limitations of current methods.

A thermoelectric device converts thermal energy to electrical energy by using an array of thermocouples. Studies have been done on improving the efficiency of thermoelectric generator by incorporating other technologies, like nanotechnology. Although these devices are used mostly in spacecraft technologies, they can be also applied to technologies on earth, which might further contribute to the advancement of technology. Some applications of this technology include automobiles, computers, household appliances, etc. For example, thermoelectric devices can enhance the energy production of hybrid automobiles by producing electricity using the waste heat of the engine. If an environment has a thermal gradient, thermoelectric devices can be applied, since they require little maintenance, and provide electricity for many years.

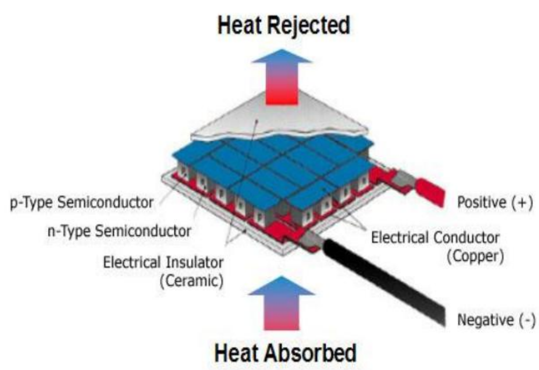

Fig. 1: Thermoelectric Generator

A thermoelectric generator is a device that consists of a p-type and n-type semiconductors connected in series, shown in Figure 1. This structure can be used to convert heat energy to electricity by using a principle known as the Seebeck effect. When heat is applied to one surface of the thermoelectric generator, the electrons in the n-type semiconductor and the holes in the p-type semiconductor will move away from the heat source. This movement of electrons and holes gives rise to an electrical current. The direction of the current is opposite to the movement of the electrons, and in the same direction as the movement of the holes. By creating the appropriate electrical connections, the current of the thermoelectric generator flows in a closed loop through the p-type and n-type semiconductors and an external load. This pair of n-type and p-type semiconductors forms a thermocouple. A thermoelectric generator can consist of multiple thermocouples connected in series, which increases the voltage output, and in parallel to increase the current output.

Objectives of the Study

The general objective of this study is to devise a generator which uses alternative source of energy that can be used to harness and store electricity. The energy that will be stored can be used in different applications such as to power mobile devices.

This research has the following specific objectives:

1. To design and construct a Thermoelectric Generator that is localized.
2. To determine the type of Thermoelectric Device to be used as an Electricity Generator.
3. To identify the electronic circuit to be used to harness usable amount of electricity.
4. To test the device and evaluate the results of the study.

Related Theories

The Thermoelectric effect was first discovered in 1822 by Seebeck, who observed an electric flow when one junction of two dissimilar metals, jointed at two places, was heated while the other junction was kept at a lower temperature. A typical multi-couple thermoelectric power module is shown schematically in Fig. 2: n-type and p-type semiconductor thermos elements are connected in series by highly-conducting metal strips to form a thermocouple (Rowe, 1995).

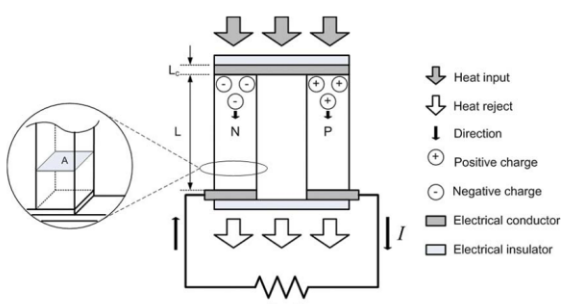

Fig. 2: Schematic of single Thermoelectric Couple

Based upon an improved theoretical model which takes into account the thermal and electrical contact resistance, the output voltage V_O, current I_O and power P_O when the module is operated with a matched load, are given by:

$$V_O = \frac{\alpha N (T_h - T_c)}{1 + 2rL_C/L},$$

$$I_O = \frac{\alpha A (T_h - T_c)}{2\rho(L+n)(1 + 2rL_C/L)},$$

$$P_O = \frac{\alpha^2}{2\rho} \cdot \frac{NA}{(L+n)(1 + 2rL_C/L)^2} \cdot (T_h - T_c)^2,$$

Where $n = 2\rho_c/\rho$, $r = \lambda / \lambda_c$, α is the Thermoelectric material Seebeck coefficient (V/K), ρ is electrical resistivity (Ω cm), ρ_c is electrical contact resistivity, N is the number of the thermoelement in the module, A is the cross-sectional area of the thermoelements $(mm)^2$, L is the length of the thermos element (mm), L_c is the thickness of the contact layer (mm), T_h is the temperature at the hot side, T_c is the temperature at the cold side, λ is the thermal conductivity of the thermoelement and λ_c is the thermal conductivity of the contact layer (Rowe & Min, 1996).

Related Literature

The researcher focuses on the literature that is related to this project, the Thermoelectric Generator. The following are some patented projects that are similar to this study:

Another published patent by Bradley J. Mitchell and William C. Sanford titled Power generation using a thermoelectric generator and a phase change material done on 2010, An energy harvesting device is disclosed that includes a thermoelectric device adapted to produce electricity according to a Seebeck effect when a thermal gradient is imposed across first and second major surfaces thereof, a housing enclosing a phase change material that is disposed for thermal communication with the first major surface of the thermoelectric device, and a radio transmitter electrically coupled to the thermoelectric device, the radio transmitter capable of transmitting wireless signals. In another aspect, the housing includes a conductive fin therein to provide more uniform distribution of heat to the phase change material (U.S. Patent No. US20120152297 A1).

Another published patent by Bjørn Erik Birkeland, Finn Erik SÅghus, Erik Rosness on 2009 titled Thermoelectric generator for battery charging and power supply, A portable device for supplying with power of at least one portable electrical load or gadget, wherein the device is adapted to be manually heated and comprises at least one thermoelectric element having one hot or warm side and one cold side, a container attached to the cold side and adapted for holding or keeping a cooling medium or fluid therein, a power converter and a set of cables coming out of the thermoelectric element and connected to the electrical load via the power converter. (U.S. Patent No. US8404962 B2).

Related Studies

According to the journal article from International Journal of Emerging Technology and Advanced Engineering titled Automobile Exhaust Thermo-Electric Generator Design & Performance Analysis, in an internal combustion engines; efficiency of engine is around 30 %, roughly 30% of the fuel energy is wasted in exhaust gases, and 30% in cooling water and 10% are unaccountable losses. Efforts are made to catch

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this 30 % energy of exhaust gases. If this waste heat energy is tapped and converted into usable energy, the overall efficiency of an engine can be improved. Thermoelectric modules which are solid state devices that are used to convert thermal energy to electrical energy from a temperature gradient and it works on principle of Seebeck effect. A hot side heat exchanger as well as cold side heat sink was designed and tested on 3 cylinder, 4 stroke, Maruti 800cc SI engine. The study showed that energy can be tapped efficiently from the engine exhaust also in near future thermoelectric generators can reduce the size of the alternator or eliminate them in automobiles improving efficiency of engine (Ramade et al., 2014).

Another study was concentrated in Thermoelectric Generator that was published in International Journal of Research in Aeronautical and Mechanical Engineering on 2014. “The thermoelectric concept is seen as a perfect solution for recovering waste heat from engine exhaust and converts in to electric energy. Since the use of semiconductor materials for thermoelectric applications, there has been a huge quest for improving its figure of merits (ZT) to make it commercially viable. The configurations of thermoelectric generator play a vital role for increasing effectiveness of the heat recovery system. Thermoelectric generator technology can be incorporated with other technologies such as PV, turbocharger or even Rankine bottoming cycle technique to maximize energy efficiency, reduce fuel consumption and greenhouse gas (GHG) emissions” (Patil & Arakerimath, 2013).

II. Project Development

The basic model of this study (prototype) as a thermoelectric generator will consist of an old PC fan heat sink and a thermoelectric cooler IC (peltier device) that will be used as a generator. There are two sides of the peltier device, cold and hot side that will harness the different temperature that are used to generate electricity.

The design of the thermoelectric charging circuit consists of three components: a thermoelectric generator, a lithium-ion battery charger, and a lithium-ion battery. Each component was tested individually to characterize their performance, and then all of the components were combined into the final circuit.

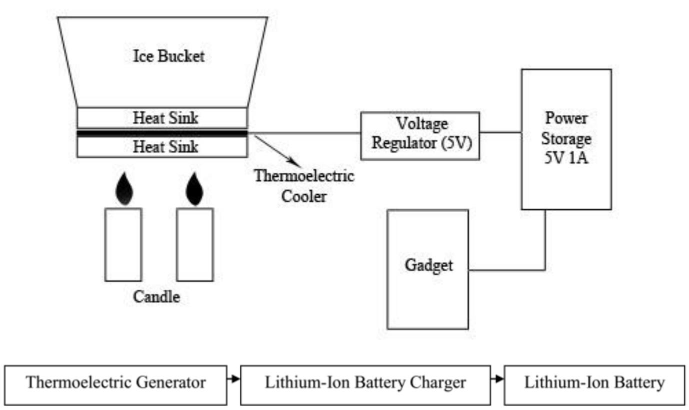


Fig. 4: Block diagram of the thermoelectric charger

A peltier device will act as a generator. The developer used a TEC-12706 (Fig. 4) peltier device because of its availability locally and affordability.

Fig. 5: TEC-12706 thermoelectric cooler IC

TABLE 1: PERFORMANCE SPECIFICATION OF TEC1-12706

Hot Side Temperature (ºC)	25 ºC	50 ºC
Qmax (Watts)	50	57
Delta Tmax (ºC)	66	75
Imax (Amps)	6.4	6.4
Vmax (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30

The thermoelectric module (TEC1-12706) was placed on a hot plate with the use of a flame source such as candle or alcohol lamp. An ice bucket is used to cool the other side of the thermoelectric module to generate electricity using the difference of temperature between the hot plate and cold bucket. As the temperature of the hotplate increased, the voltage and current from the thermoelectric module increased as well.

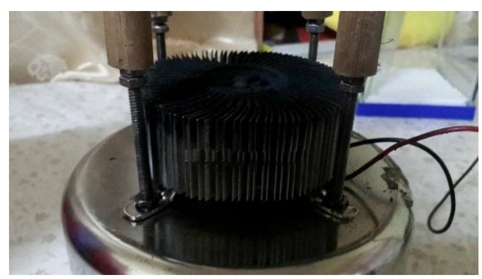


Fig. 6: Aluminum heat sink as hot side

Fig. 7: Ice bucket used as cold side

After generating the electrical current with the temperature difference, we will need to amplify the electrical energy into a usable amount of energy. A voltage booster will be used, in this study; a joule thief circuit is selected to boost the electrical energy into a usable amount. As shown on the figure below, the source will be our generator and the load will be our charging unit.

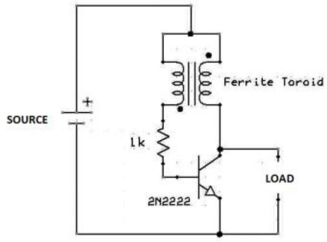


Fig. 8: Joule Thief (Voltage Booster)

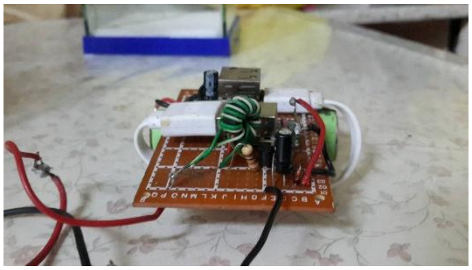


Fig. 9: Actual Joule Thief circuit

The complete setup will generate and amplify DC voltage that will be stored in the energy storage such as the battery. It will then be regulated into 5v DC voltage with 500 mA output current. The developer used the standard USB output, most of the electronic devices uses USB as their charging cable. The circuit is then connected to the output of the TEC1-12706 thermoelectric module to process the generated energy into usable energy that can be used in certain applications such as charging mobile devices.

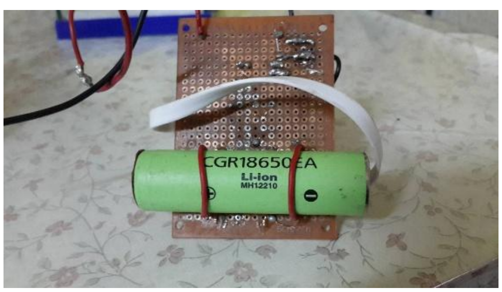


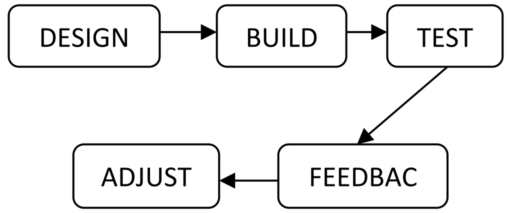
Fig. 10: MH12210 Lithium Ion battery

III. METHODOLOGY

Innovations communicated verbally are often difficult to imagine. Since they are abstract ideas, it is difficult to get a sense of what they will look and feel like. Rapid prototyping is the act of creating a low-fidelity object for the purpose of testing a concept. Through rapid prototyping, a designer is able to quickly test and adapt a design with minimum investment in time and the cost of failure. During solution design, Rapid Prototyping allows for concept testing, accelerating the innovation process.

Prototypes are built using anything at hand to mock up rough concepts, giving form to early ideas and hunches. The purpose of the building is to think, to understand existing experiences and user needs, and to move abstractions into tangible objects with a low initial production cost. Ideas are explored, and learning occurs faster by failing earlier and often. Permission is granted to experiment, try and stretch. Ideas are communicated and shared to enhance the researcher’s understanding. This method quickly moves thoughts into concrete objects for discussion.

Rapid Prototyping facilitates an interactive process:



“The purpose of rapid prototyping is to demonstrate possibilities quickly by building an inexpensive series of mock-ups so designers are able to obtain early feedback from which they may respond to user requirements. This is particularly true in the following three types of situations: (1) cases that involve complex factors, which can make predictions difficult; (2) cases already examined by conventional methods without satisfactory results; and (3) new situations, which do not offer a lot of experience to draw from (Tripp and Bichelmeyer, 1990).”

IV. PRESENTATION OF FINDINGS

Every Thermoelectric module is designed to compromise several of performance objectives. Since thermoelectric modules operate through the interplay of electrical currents and Thermal currents, the interaction with environment is as important as the electrical load. Therefore, the suggested experiments are carried out. An electrical power will be produced when the thermal reservoirs (heat sink, ice and water) can achieve and maintain the maximum temperature difference. The large number of thermoelectric elements inside thermoelectric module will produce more electric power relatively.

The thermoelectric module that is used in this study is readily available locally. TEC1-12706 can be found in electronics store or even in online shops such as OLX.com.ph, this module is selected because of its cheap price. Other components used in this study are merely recycled materials such as an old CPU heat sink and an ice bucket. The device is tested using multi-meter in measuring the output voltages.

The first test was using the human body temperature as heat source at ambient room temperature and an aluminum heat sink as its cold side. This test generates the following results.

TABLE II: HUMAN BODY (LEFT PALM) AS HEAT SOURCE

Voltage Output (mV)	Current Output (mA)	Power V * I (μW)	Inference
50	7.2	360	Body heat can generate μW range of power.
45	6.5	292.5	
60	8.4	504	
50	7.1	355	
60	8.6	516	
53	7.56	405.5	MEAN

Another test was conducted using the generated heat of refrigerator compressor. The same setup was obtained for the cooling side of the thermoelectric module. The results is shown below in Table 3.

TABLE III: REFRIGERATOR COMPRESSOR AS HEAT SOURCE

Voltage Output (V)	Current Output (A)	Power V * I (W)	Inference
0.70	0.43	0.30	Waste heat from external surface of refrigerator compressor has the potential to generate around 0.4 W
0.75	0.47	0.35	
0.87	0.40	0.35	
1	0.38	0.38	
1.25	0.28	0.35	
53	0.392	0.346	MEAN

After the testing with the TEC1-12706, proving that the peltier module can act as a generator, the developer then proceeds to the process of developing the device. The table below shows the measured outputs of the device. Energy generated are regulated in 5v as this is the voltage that are needed to charge most mobile devices.

TABLE IV: MEASURED OUTPUT FROM THE THERMOELECTRIC GENERATOR

Voltage Output (V)	Current Output (A)	Power = V * I (W)	Inference
5	0.5	2.5	Generated energy from temperature difference from the ice and the flame from alcohol lamp/candle
5	0.5	2.5	
5	0.5	2.5	
5	0.5	2.5	
5	0.5	2.5	
5	0.5	2.5	MEAN

A mobile device is then charged for 15 minutes using the device (Fig. 12). The battery charge were up to 29% for 15 minutes of charging. The figure below shows the battery discharge status of the mobile device.

V. CONCLUSION

With the completion of the study, it is clear that cogeneration power using thermoelectric modules is a promising source and presents results feasibly economical with their use, especially if implemented on a wide scale. The results were very significant, considering that only a few systems have been analyzed in this model can be applied cogeneration. It is also considered that studies and researches are made constantly to improve their efficiency and the requirements for reducing emissions of gases that cause global warming, as well as the need to use renewable sources are increasing, making the applications of thermoelectric modules become increasingly interesting and most sought after because arouses the interest of the government and industries to utilize this technology. This prototype may impact and attract future researchers to work more on the research of free energy or renewable energy. Now it is possible to get free electricity from stuffs from our home. This concept of free energy can be made using simply wasted heat from our home or even industrial sources.

VI. RECOMMENDATIONS

The researcher sees greater opportunity and applications for this study. The sought for renewable and green energy are main trends in the field of research nowadays. The prototype can be enhanced further for more efficiency and better results. Recommendations to the future researcher are as follows;

1. The use of larger thermoelectric generator to generate more energy.
2. Use commercially available DC to DC step up converter.
3. Integration of larger Power Bank as energy storage for later use.

Renewable source of energy proves to be an answer to the dwindling energy problem. The consumption of fossil fuels to produce energy also creates another problem which is global warming. Further research on these types of energy source might lead to solutions that are yet to be discovered.

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