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Research paper

Design of Optimal Thermoelectric Generator Array for Harnessing Electrical Power from Air-conditioning Unit

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Abstract

A thermoelectric generator array or TEG array was designed and tested that is capable of capturing waste heat energy and convert it into a usable electrical energy that can be used to power up electronic devices requiring low power consumption. An air conditioning unit was used as a source of waste heat energy. A cooling system was designed together with copper plate system that will eventually differentiate the cold side and the hot side of the compressor, which is the source of most of the waste heat. A DC to DC boost converter was also considered to improve the voltage and power being harnessed by the system. Lastly, a voltage monitoring unit was added to continuously monitor the output voltage of the TEG array. The converted electrical energy from waste heat energy is used and tested to check if the harnessed power is able to power up smartphone chargers and similar electronic devices. Experiment results show that the efficiency of the TEG I around 7.1768% and can be improved to 55.2889% efficiency if used together with the DC to DC boost converter.

Keywords: *Waste Heat; Seebeck Effect; Thermoelectric Generator; Air-Condition System; Alternative energy, Renewable Energy*

1. Introduction

Some experts, who specialize in utilizing renewable energy, said “There’s a gold mine in waste heat, only if we can convert it properly” [1]. They also stated that consumed energy in most electrical devices was not utilized because the energy losses, which are significantly large, and are mostly transformed into heat. This wasted heat energy can be used as an alternative source of energy for applications such as electrical power source for certain equipment.

The thermoelectric generator (TEG) is an innovative device capable of recovering wasted heat energy and transforming or converting it into electrical energy. The energy harnessed can be stored and utilized using proper power management, thus minimizing waste and conserving energy. The temperature difference in the generator may be due to the materials used in the generator [2] and the parameters used for heat transfer [3,4].

TEG is known to operate using the phenomenon called the “Seebeck Effect” or the “thermoelectric effect”. This effect is a simple and direct method of converting heat into an electrical energy by getting the temperature differences between the two sides of the generator [5]. A TEG creates a electrical voltage when there is a temperature difference between the hot and cold side of the TEG.

Waste energy such as heat was found to be a good source of alternative energy. Heat is abundant and oftentimes generated by electrical equipment that also produce waste heat. Often times, the waste heat energy from high power electrical equipment are being ignored. Thus, a great amount of electrical energy is wasted instead of potentially converting it into a usable form of renewable energy. This research proposes the use of waste heat energy as an alternative source of energy that can be used in some low power electrical purposes. Thermoelectric generator array was used on air conditioning unit, which is known to the biggest producer of waste heat in normal homes or small companies.

This proposed study used and tested a TEG array installed inside air-conditioning unit. This research also measured the highest possible output that the TEG array can produce and assessed if this system can be considered as a significant source of renewable energy.

DC to DC boost converters also play an important role in improving the output voltages of the system. Different models of this type of converters re presented in many research papers including the one in [6]. Different topologies of DC-DC converters, switching schemes and techniques [7,8,9] also play important role in choosing the model of the converted to be used. The DC-DC boost converter can also be designed to give a relatively high voltage gain as shown in [10].

2. Systems Design

The main focus of this research project is to harness power from heat coming from air conditioning unit particularly from its compressor, and convert the heat into usable electrical energy. The harnessed electrical energy will be stored into a battery using a charging/monitoring battery circuit, then harvested power will be used to power up specified loads requiring low power sources.
TEG array will gather heat from the air conditioning unit's compressor motor, and then convert this heat into usable energy using a DC/DC boost converter, which serves as the signal conditioning circuit. The conditioned signals are then fed into a battery for power storage. It can also be fed into a charging circuit for specific loads such as mobile phones, MP3 players, and rechargeable LED lamps. The battery serves as the secondary storage unit.

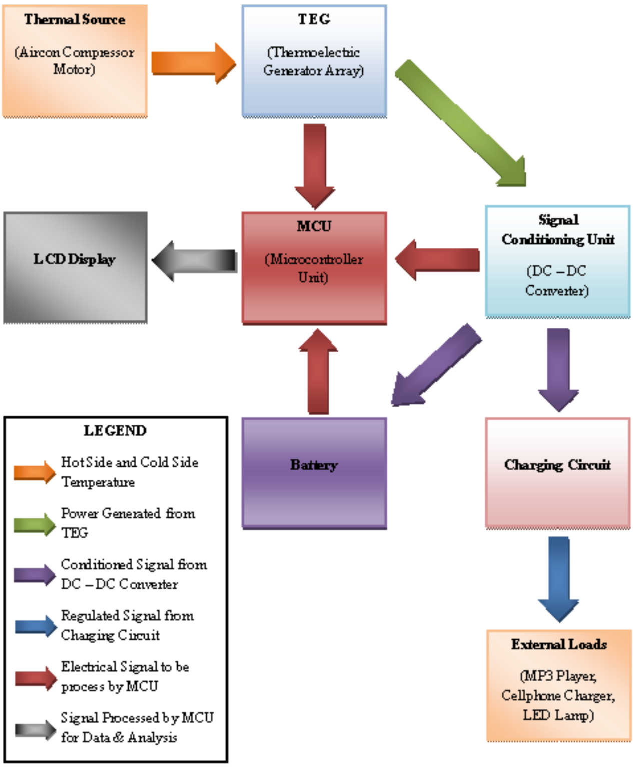

Fig.1: TEG Array in Air Conditioning System Block Diagram

Figure 1 shows the functional block diagram of the TEG array used inside an air conditioning unit. A microcontroller was used to control all the functionalities of the system. This microcontroller unit monitors the voltage in the battery and displays its value using the LCD display.

3. Systems Hardware

A thermoelectric generator module was used in this research to control the temperature. The C2-55-2812 thermoelectric module, a 241-couple, 55 mm x 55 mm, single-stage module is used for cooling and heating applications up to 180˚C. [11]. Figure 2 shows how heat is absorbed and rejected by the thermoelectric module.
Based on various experiments and tests results, the best configuration for the thermoelectric array is to connect all the modules in series. The highest output voltage range attained with this configuration through measurements was 3.9V to 4.2V, with an output current range of 312mA to 349 mA.

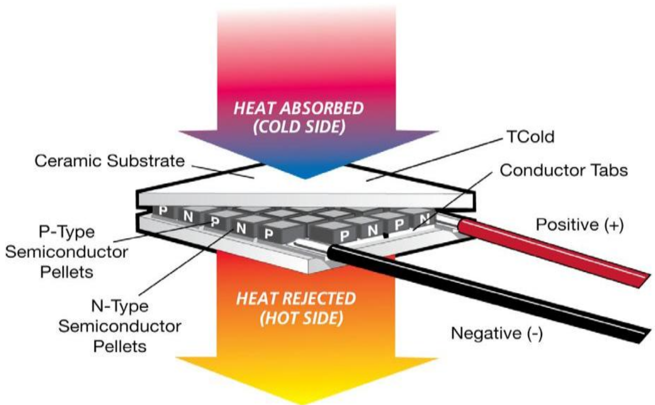

Fig.2: The C2-55-2812 Thermoelectric Module

The compressor of the air conditioning unit is found to be the hottest spot in the air conditioning unit. This location is ideal for waste heat harnessing due the constant heat dissipated by the compressor motor. Likewise. its surface area is perfectly suitable for mounting the TEG in the unit. The location is also perfect for the cooling system to be placed alongside the designed TEG array. Figure 3 shows the proposed location of the TEG in the air conditioning unit.

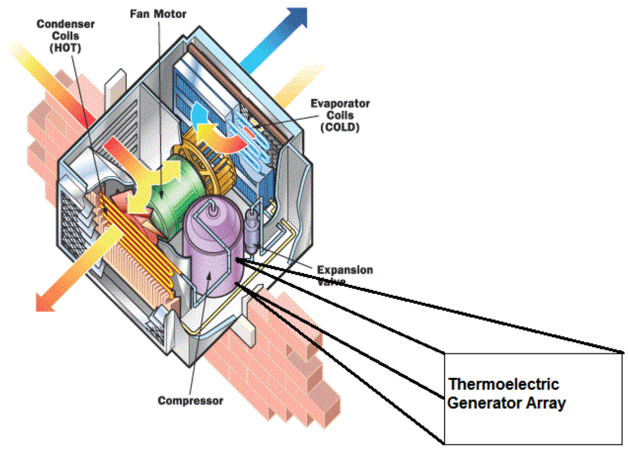

Fig. 3: Location of TEG Module Array in Air Conditioning Unit

Six thermoelectric modules were used for testing, data gathering and analysis. The proposed TEG array design maintained this number of modules and ensured that the array will fit the spaces between the compressor and other interior parts of the air conditioning unit.
The compressor shape is like a cylinder tank and its entire surface is not flat. A copper plate was needed to equally distribute the heat from the compressor to the TEG modules. Figure 4 shows how copper plate was used around the compressor to obtain a satisfactory result for power generation. The copper plate served as a thermal spreader and distributes heat equally.
One copper plate was enough to place three modules of the array on its surface. Therefore, two copper plates were needed for the six modules. An extra copper plate is also installed in case additional module is needed by the system. The hot side of the thermoelectric modules are mounted facing the copper surfaces.
In order to maintain the thermal difference between the hot and cold sides of TEG module, a heat sink was attached on the cold side of the module to ensure an optimum output. Heat sinks are also used to ensure that one side of the TEG array module is unaffected by the heat of the environment inside of the air conditioning unit. The heat sinks are made of aluminum alloy and aluminum and have a great property of capturing heat, Additionally, small holes are drilled on the point of contact of the heat sink to the TEG modules for faster cooling. The cooling system uses the 'conditioned' cold air coming from the air conditioning unit. Hollow tubes are designed for air flow coming from the 'air duct' of the unit to the heat sinks of the TEG array. Figure 5 shows the cooling system attached to the air conditioning unit.

Fig. 4: Copper Plate for TEG Array mounted on the AC Compressor

Fig. 5: Cooling System attached to Air Conditioning Unit's Air Duct and Heat Sinks

A DC/DC boost converter was connected at the output of the TEG configuration to step up the voltage harnessed and is directly connected to the battery for power storage. The boost converter used is the HZ-12-24 DC/DC converter which can handle input voltages between 1.8V and 9V. It can also give output current up to 2.5A and output voltage up to 15V. A voltage limiter was also installed prevent the battery from overcharging. The boost converter can also be used as a constant voltage source. This can be done by adjusting a limiting resistance that will maintain a certain voltage level at the output, as shown in a previous research [12].
The harvested electrical power from the thermoelectric generator can be used in charging mobiles phones and other similar devices. Normally, mobile phone batteries can give output 3.6V output voltage and rated at 1000mAH to 1300mAH. These batteries use 3 NiMh or Lithium cells that operates at 1.2V. Some battery packs require 4.5V voltage and 300mA to 500mA current for fast charging. With this, the proposed module was designed to provide 4.7V regulated voltage output and enough current suitable for slow charging of electronic devise such as mobile phones or iPods.
The Voltage Monitoring Module, which is another important part of the proposed thermoelectric generator array, is responsible for measuring, reading and displaying the voltage output produced by the TEG array module, signal conditioning circuit (DC/DC Boost Converter) and monitors the remaining charge needed by the battery.
The PIC16F877A microcontroller takes care of the data measurement, analog-to-digital conversion. It initiates the display of the 2x16 LCD and system flow of the whole Voltage Monitoring Module. It is initialized by an 8 MHz crystal resonator which gives the clock frequency needed by the microcontroller to initiate its program and make it respond faster.

4. Data and Results

Several experiments were conducted to determine the energy capacity that can be harnessed from the waste heat. Table 1 below shows the harnessed voltage and current from the proposed research setup.

Table 1: Single TEG testing at 180°C on five trials (Electric Iron)

Test Number	Voltage (V)	Current (A)
1	0.604	0.225
2	0.602	0.224
3	0.604	0.225
4	0.604	0.223
5	0.604	0.224

The data obtained from the conducted tests on both an electric iron and AC compressor at the given temperatures were based on the highest output seen using a multimeter (voltmeter and ammeter). After exposing the TEG module for a long period of time on the given temperature, voltage begins to drop due because heat begins to transfer to the cold side of the module which results to the temperature difference between the sides of the module.
Six TEG modules were used and the estimated output of the TEG module array connected in series is sum of the average output obtained from each of the six TEG modules.
An experiment was also conducted outside the room to simulate the scenario that the air conditioning placed normally on a room, with the back part of it exposed outside room. The following results are derived from experimental measurements. Figure 6 and figure 7 shows the results of these experiments.

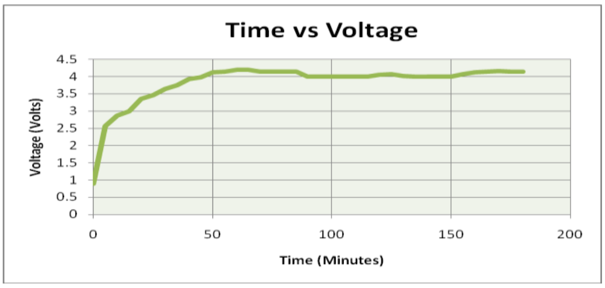

Fig. 6: Time vs. Voltage relationship

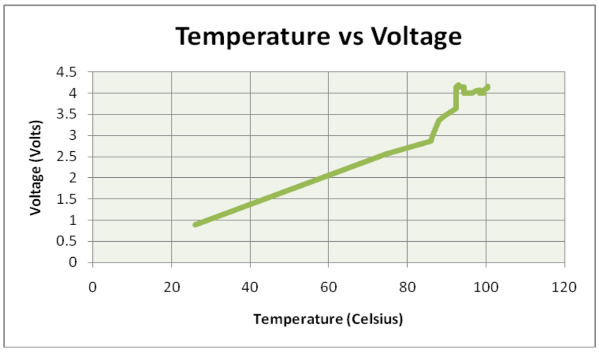

Fig. 7: Temperature vs. Voltage relationship

Based on the experiment results, the highest voltage obtained was 4.205 V. Current level is at a constant 225mA. This result yield higher output voltages compared to a test where the hole air conditioning unit is inside the room. When the whole air conditioning unit is inside the room, the cooling system from the unit also goes inside the air conditioning unit, thus, it also cools down the ambient temperature on the compressor side. The average voltage was found to be 4.1984V, current at 0.225A and power to be 1.045W.

The measured temperatures from the tests are only that of the hot side, a single test is conducted measuring also the temperature of the cool side of the TEG array to determine the temperature difference between the sides of the modules and how it affects the voltage output of the TEG modules. Figure 8 shows the relationship between the change in the temperature and its effect to the change in the output voltage of the system.

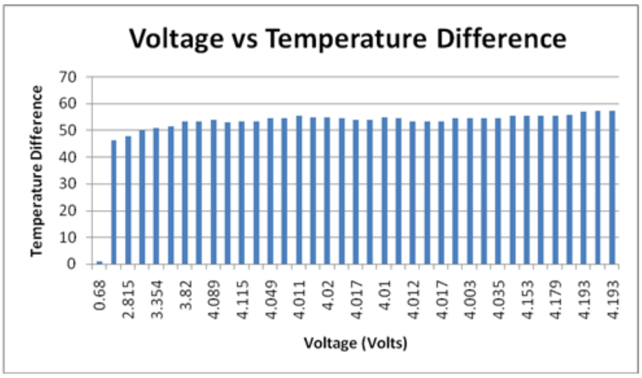

Fig. 8: Voltage Level vs. Temperature Difference

Based on the data obtained, it can be observed that at the start of the test, the voltage obtained is relatively small since the temperature difference is also small. As the operation of the system lengthens, the difference in the temperature between the sides of the TEG array increases due to the increase in temperature on the hot side of the module. The cold side of the module also experiences a small increase in temperature. It can be observed that the output voltage is directly proportional to the temperature difference between the hot side and the cold side of the TEG array module.

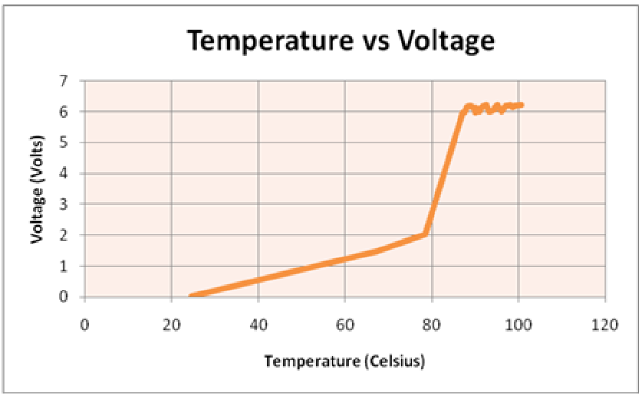

Fig. 9: Time vs. Voltage relationship for DC/DC converter testing

To improve the performance of the TEG array module, the output of the TEG array was connected to the input of the HZ-12-24 DC/DC converter to step up the voltage. The test is run for three hours. As seen in figure 9 above, the highest output obtained from the boost converter was 6.220V.

The energy harvested from the thermoelectric generator was then tested to check if the power absorbed is enough to be used in some low power applications. Table 2 below shows the result of the tests done.

All trials made for the specific loads were proven successful. In charging the nickel-metal hydride battery which has a capacity of 4.5 V, 3600mAh, the output terminals of the DC/DC converter were directly fed to the input terminals of the battery. In charging the mobile phone, the charging circuit incorporated in the proposed design was used. The charging voltage needed by lithium-ion battery used by mobile phones, iPods and MP3 players ranges from 3.9 – 4.2 V. The voltage level was set to 4.2 V by the charging circuit.

Table 2: Success rate of the trials

Trials	Pass/Fail
DC/DC only (Trial 1)	PASSED
DC/DC only (Trial 2)	PASSED
DC/DC & charging mobile phone (Trial 1)	PASSED
DC/DC & charging mobile phone (Trial 2)	PASSED
DC/DC charging a battery (Trial 1)	PASSED
DC/DC charging a battery (Trial 2)	PASSED
DC/DC & charging MP3 player and iPod (Trial 1)	PASSED
DC/DC & charging MP3 player and iPod (Trial 2)	PASSED
DC/DC & LED lamp	PASSED
DC/DC & LED lamp	PASSED
Overall Percentage	100%

5. Analysis and Conclusion

In this study, a system that harnesses power from the compressor of an air conditioning unit using thermoelectric generator modules was proposed. This system converts heat produced by the compressor of the air-conditioning unit to electrical energy through the use of thermoelectric generator modules that were attached to it. The concept behind the proposed thermoelectric generator is the Seebeck effect, wherein the difference in temperature between the two sides of a TEG module produces an electrical potential voltage. This power created by the thermoelectric generator module can be used to charge a battery. All circuits and system modules were designed to evaluate the performance of the system as well as to produce an optimal output energy.

Through several tests and experiments, it was observed that the performance of the system was greatly affected by different factors such the variations in the environment temperature and the location of the air conditioning unit. It was observed that when the system was placed inside a room with a cold temperature area, the output provided by the system is lower than when it was place outside (exposing the back side outside the room). Due to the cold temperature inside the room, the copper plate attached to the TEG experiences cooling and cannot increase the temperature high enough to produce an optimal output. Another factor was the dissipation of heat from the hot to cold side of the TEG thus lowering the output of the thermoelectric generator module. An aluminum heat sink was used and thermal paste was applied to the cold side of the module to prevent it from heating up that may result to a lower temperature difference. An airflow system that diverts some cold air to the cold side of the TEG modules to sustain a low temperature was also designed in order for the system to have an optimal output.

The TEG efficiency was found to be 7.1768% while the efficiency of the TEG with boost converter was found to be 55.2889%.

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