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Energy Harnessing System using Thermoelectric Generator with Radiation Concentrator and Solar Tracker

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Abstract: ***Harnessing systems gather the attention of many researchers today as the energy demand increase with an escalating price of fuel. Studies about renewable resources are kept being pursued by different countries to aid the deficiency of main power producers in their respective locality. Thermoelectric generators, which utilize the Seebeck effect to convert heat into usable electric energy, is the main focus of this study. It has been added with a radiation concentrator and solar tracker to maximize the heat accumulation for larger temperature difference which results to a great amount of stored energy. The energy coming from the sun is focused and concentrated using a Fresnel lens to optimize the heat and increase the output of the thermoelectric generator. The energy is then inserted in a charge controller to have a constant dc voltage output. The output voltage now will be utilized by low powered and devices and has a backup battery storage for the energy.***

Keywords: ***energy harnessing, solar tracker, charge controller, green engineering, thermoelectric energy, seebeck effect.***

I. INTRODUCTION

In the recent years, engineers and scientists have been searching for ways and methods to find an alternative source of energy because as we presently enjoy living with the advancement of the world, the demand for energy simultaneously increases with the change of our lifestyle. With the world's fossil fuel nearing its depletion, the cost of electricity has risen ton unprecedented levels due to the limited supply of oil, economic and political factors. To avoid depletion of fossil fuels and at the same time meeting the accelerating global energy demands; sustainable renewable resources must be developed (Banta, 2013).

Nowadays, the implementation of renewable resources such as solar, wind, hydroelectric, and thermal are encouraged. Also, efficient energy utilization tends to be a standard practice in all areas of the industrial society because more than 50 % of the generated energy in the world is wasted in heat. According to Korea Energy Economics Institute, the waste heat occupied 26 percent of the total national energy consumption of Korea in 2006. Thus, the thermoelectric generation plays a significant role in saving national energy as well as in reducing carbon dioxide emission by enhancing energy utilization efficiency. Thermoelectric power generators can convert heat directly into electricity and therefore can accommodate for some of this loss. The Seebeck effect was discovered in 1821, demonstrating the possibility of generating a voltage out of a temperature gradient. Thermocouples that have in Seebeck unit are junction between two different metals that produces voltage related to a temperature difference.

The proposed "Energy Harnessing System using Thermoelectric Generator with Radiation Concentrator and Solar Tracker" is capable of generating electrical energy of up to 12 watts through the utilization of solar heat which is fed to the hot-side of the thermoelectric generator, which in turn produce a potential difference between its terminals. The power extracted is filtered and regulated to achieve the desired output and it is stored in a battery.

The Specific Objectives of the researchers is:

- To develop an electronic system that can convert thermal energy to electrical energy.
- To harness wasted heat energy in the environment and make use of it in generating electricity.
- To integrate solar concentrator with thermoelectric generator in order to provide the temperature gradient needed.
- To make a portable, easy-to-install energy harnessing system that can be used to power low voltage loads.

II. FIGURES AND TABLES

In figure 1, the proponents introduced a design consisting of a system with biaxial rotation with a cylindrical base, which allows to track the sunlight efficiently, in addition to being as compact as possible to avoid a large space allotment. In figure 2 & 3, shows the placement of the electronic component under the chassis. In figure 4, shows the actual photo of the project.

Figure 5 shows the conceptual framework of the "Energy Harnessing System using Thermoelectric Generator with Radiation Concentrator and Solar Tracker". It is a project that utilizes the wasted heat from the sun and transform it into a useful energy that can be stored and, later on be used for low-powered devices. The solar tracking system focuses the heat from the sun to the Fresnel lens which is then absorbed by top side of aluminum metal plate. The temperature sensor (Thermocouple) gives signal for temperature monitoring.

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The microcontroller unit (Arduino), receives signal from LDR to trigger the tracking system and execute motor movement. Data readings from the sensors including the battery status are also processed here for Analog-to-Digital conversion. After the processing stage, the energy is stored in the battery. Upon determining the place where maximum sunlight is present, motors will react and position the exposure area of the aluminum plate where TEGs are being held. Temperature, voltage, current & battery status are displayed using an LCD module.

Figure 6 shows the block diagram of the "Energy Harnessing System using Thermoelectric Generators with Radiation Concentrator and Solar Tracker". The system is exposed to light radiation from the sun and, sunlight which is concentrated through the use of Fresnel lens is fed to the Aluminum plate from which the thermoelectric generators' (TEG) hot side is attached to accumulate maximum heat transfer. The cold side is connected to a heat sink to maintain its low temperature and to ensure that there is a temperature difference for each side of the TEG.

The TEG's output is then transferred to the surge and reverse current protection circuit which make use of high-current rating fuses and transient voltage suppressor diodes (TVS diodes) to avoid sudden overvoltage and reverse current flow. IRF9530 power MOSFET switches the charging process through the use of Arduino Mega as the microcontroller unit. Arduino Mega triggers the charge controller circuit for the charging process and, it monitors the status of the battery. The load controller circuit monitors the load output and if it is in use.

On the other hand, when the light radiation is received by the Light-dependent Resistor (LDR), analog voltage reading goes to the MCU which in turn triggers the Solar Tracker Circuit to follow the path through which maximum emission of sunlight is present. The Solar Tracker Circuit is responsible for the motor rotation adjustment with respect to the azimuthal motor and zenith motor.

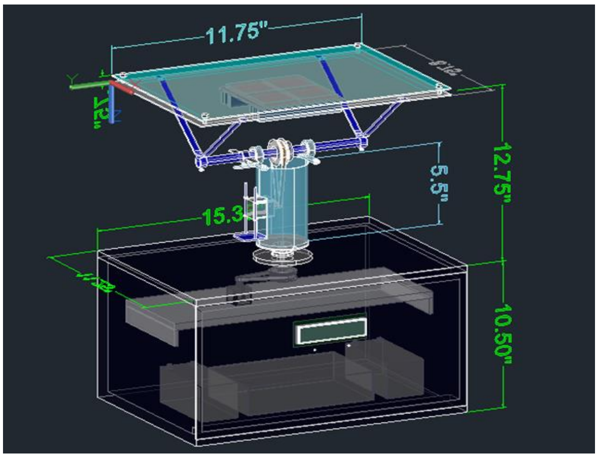


Figure 1. Initial design of the project

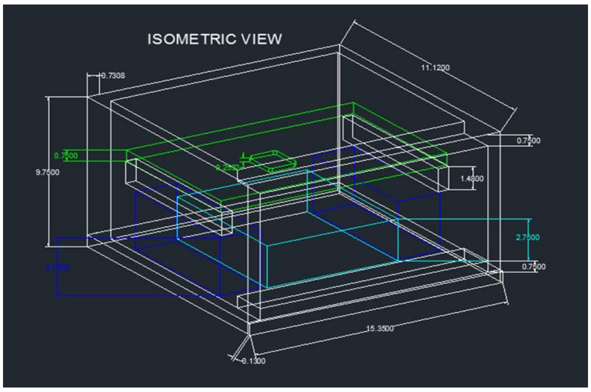


Figure 2. Isometric view of Wood Housing Case

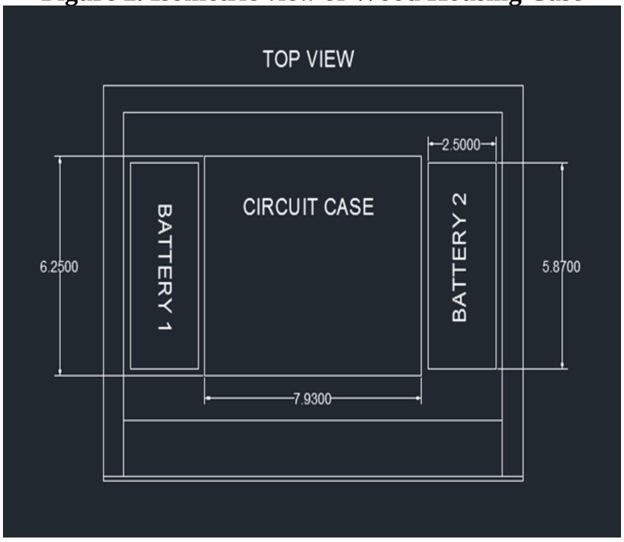


Figure 3. Placement of the circuit inside the Project Housing

Figure 4. Actual Photo of the Project

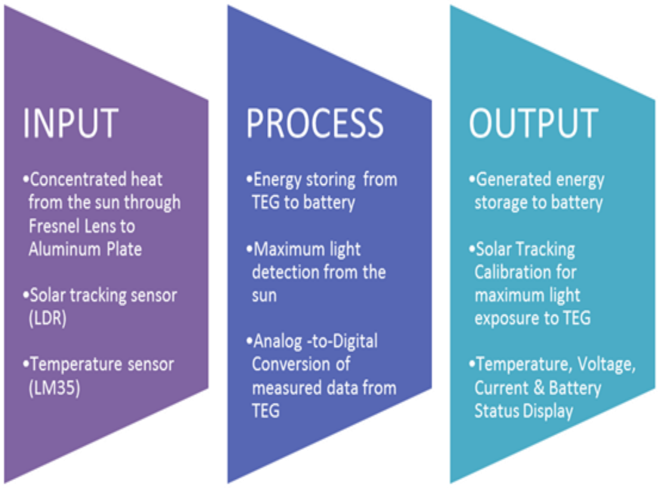


Figure 5. Conceptual Framework

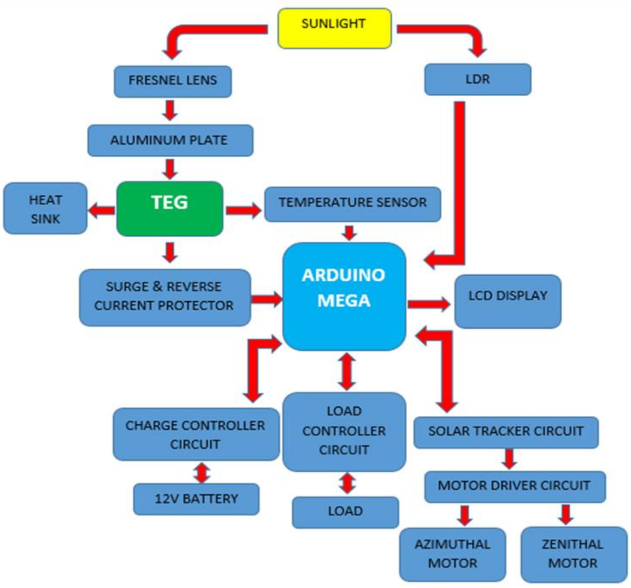


Figure 6. Block Diagram

III. MATH

To interpret the data effectively, the proponents will employ T-test of Unequal Variances in Microsoft Excel. These will help the proponents to identify the effect of the independent variable to the dependent variable.

T-Test

T-test is used to compare two different set of values. It is generally performed on a small set of data. T-test is generally applied to normal distribution which has a small set of values. This test compares the mean of two samples. T-test uses means and standard deviations of two samples to make a comparison.

IV. DATA AND RESULTS

1. Light Dependent Resistor Voltage Test

The purpose of this test is to determine if the LDR works to track the best location of sunlight. Voltage readings across the four LDRs were recorded to prove that their response with respect to light. The LDR voltage output were measured based on the intensity of light they get. There are three brightness level of the light for this test.

The graph below illustrates the response of each LDRs with a given amount of light intensity.

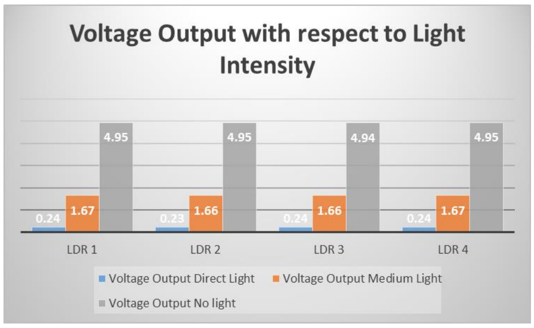


Figure 1.1: Voltage output of LDR with respect to different light intensity

Based on data above, it can be noticed that as the amount of light received by the LDR is decreased, voltage drop across it increases. Therefore, the response of the system can be adjusted based on the analog voltage readings across each LDRs. If a condition that a low voltage across a certain LDR is detected, the location of the solar tracker must adjust to that position.

2. Light Intensity Test

The purpose of this test is to identify the different light intensity with respect to time within monthly average at different temperature difference.

The test was performed to examine the actual performance of the Thermoelectric Generator array (Series-Series) exposed to the sunlight. The light intensity was measured using a smartphone application called "Light-O-Meter" and the measured value was in terms of Lux while the temperature was read using a thermal gun after the conversion in the circuit is done.

The measurement of light intensity was done using 30 minute-time interval with different temperature of hot and cold.

The graph below described the relationship between the light intensity received by the thermoelectric generator and its corresponding voltage output.

Light Intensity Test with respect to Thermoelectric Generator Voltage Output

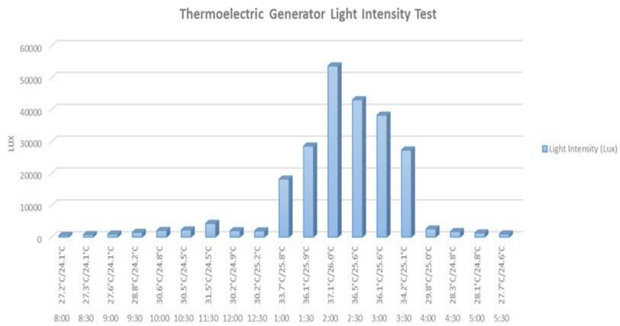


Figure 2.1: Average Monthly temperature interval versus voltage output

It can be noticed that between 1:30pm – 2:30pm is the hottest temperature on the whole day and the Light-O-meter Application recorded 53,712 (lux) light intensity. *Therefore, the greater the light intensity of the sun, the greater the temperature difference of the TEG's.*

Statistical Method
Using T-test of Unequal Variances in Microsoft Excel to arrive with one of the following hypothesis:
Null Hypothesis:
Ho: Light intensity within the day do not have significant effect on the temperature difference between the hot side and cold side.
Alternative Hypothesis:
Hi: Light intensity within the day had significant effect on the temperature difference between the hot side and cold side.

3. Motor Functionality Test
3.1 Azimuthal Motor (Vertical)
3.1.1 Axis Movement Test

Table 3.1.1: Results of testing the azimuthal motor with respect to angle of rotation

Angle of Rotation	Does the motor respond?	
	Yes	No
45°	✓	
90°	✓	
135°	✓	
180°	✓	
225°	✓	
270°	✓	
315°	✓	
360°	✓	

The results shown above determined if the azimuthal motor will rotate to its corresponding angle of rotation that being controlled by the Arduino.

3.1.2 Calibration Test

4. Table 3.1.2: Results for the calibration test of the azimuthal motor.

Steps (1.8° per Step)	Speed (RPM)	Status of Rotation
20	30	Good
40	30	No Good
60	30	No Good
80	30	No Good
100	30	No Good

Based on the results above the 20 steps was the right steps for the azimuthal motor since the azimuthal motor only needs a slowly steps for tracking the maximum light of the sun.

3.2 Zenithal Motor (Horizontal)
3.2.1 Axis Movement Test

Table 3.2.1: Results for the movement test of zenithal motor with respect to angle of rotation.

Angle of Rotation	Does the motor respond?	
	Yes	No
45°	✓	
90°	✓	
135°	✓	
180°	✓	
225°	✓	
270°	✓	
315°	✓	
360°	✓	

The results shown above determined if the zenithal motor will rotate to its corresponding angle of rotation that being controlled by the Arduino.

3.2.2 Calibration Test

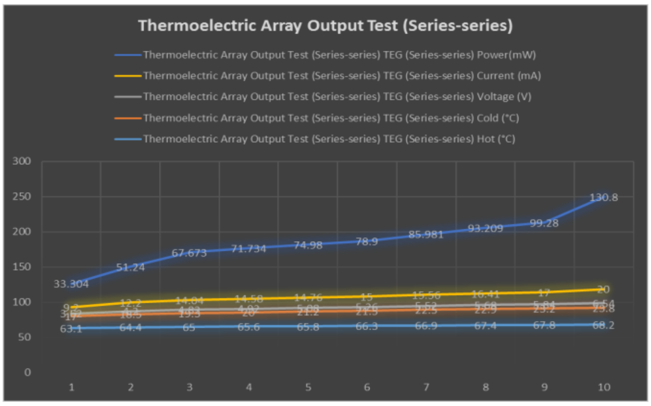
Table 3.2.2: Results for the calibration test of the zenithal motor.

Steps (1.8° per Step)	Speed (RPM)	Status of Rotation
20	30	No Good
40	30	No Good
60	30	Good
80	30	No Good
100	30	No Good

Based on the results above the 60 steps was the right steps for the zenithal motor since the zenithal motor needs a wide steps for tracking the maximum light of the sun.

5. Thermoelectric Array Output Test
The purpose of this test is to determine the voltage and current generated directly in the thermoelectric generator array in the system. This test have measured different current and voltages with different temperature.

4.1 TEG's Series-series Connection
On this setup, Thermoelectric Array's Output were connected in series-series together and, their total current and voltage output were measured.
The figure below shows the response of the TEG array with respect to different temperature difference.



6. Battery Charging Test

Computation:

For the computation of the charging time of the battery, the battery capacity is divided to the generated current. In formula:

$$T = \frac{Ah}{I}$$

Where:

T – Charging time in hours

Ah – Battery capacity in Ampere-hour

I – Generated current in mili-Ampere

5.1 TEG's Series-series Connection

Table 5.1: Results of charging duration of battery with respect to current output of figure 4.1.

Current (mA/sec)	Battery Capacity (Ah)	Charging duration of battery (Hours)
9.20	7.2	0.217
12.20	7.2	0.166
14.04	7.2	0.142
14.58	7.2	0.137
14.76	7.2	0.136
15.00	7.2	0.133
15.56	7.2	0.129
16.41	7.2	0.122
17.00	7.2	0.118
20.00	7.2	0.1

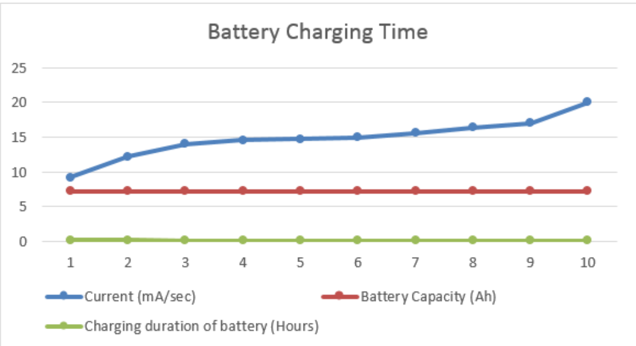


Figure 5.1: Battery charging test with respect to different current flow

Computation:

1. (7.2Ah / (9.20mA/sec) * (3600)) = **0.217 hours**
2. (7.2Ah / (12.20mA/sec) * (3600)) = **0.166 hours**
3. (7.2Ah / (14.04mA/sec) * (3600))= **0.142 hours**
4. (7.2Ah / (14.58mA/sec) * (3600)) = **0.137 hours**
5. (7.2Ah / (14.76mA/sec) * (3600)) = **0.136 hours**
6. (7.2Ah / (15.00mA/sec) * (3600)) = **0.133 hours**
7. (7.2Ah / (15.56mA/sec) * (3600)) = **0.129 hours**
8. (7.2Ah / (16.41mA/sec) * (3600)) = **0.122 hours**
9. (7.2Ah / (17.00mA/sec) * (3600)) = **0.118 hours**
10. (7.2Ah / (20.00mA/sec) * (3600)) = **0.1 hours**

The testing allows the proponent to compute for the charging duration of the battery from the harnessed energy of the Thermo-Electric Generator. It can be conclude based on the testing that the higher the value of the current, the shorter the duration of the battery to charge.

7. Load Workability Test

Table 6.1: Results of the battery duration with respect to different load at different load power.

Load	Power(W)	Battery Capacity (WH)	Working time (Hours)
Cellphone Charger	3.5	86.4	24.69
8W Light bulb	8	86.4	10.8
Table lamp	9	86.4	9.6
Portable Electric Fan	15	86.4	5.76
Laptop Charger	90	86.4	0.96

Based on the results shown, the higher the power load connected to the battery, the shorter the working duration of the battery.

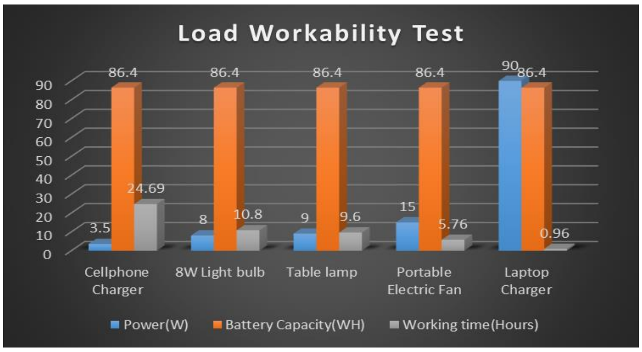


Figure 6.1: Load Workability test at different load

V. METHODOLOGY

Applied research will be used in the study. Applied research refers to research and scientific study seeking practical problems. Applied research is used not to acquire knowledge for own sake, but to find solutions to everyday problems, cure disease and create innovative technologies. Research and experiments have been carried out on different methods of generating electricity, and recently the use of TEG has been common as energy is easily harnessed from the heat that comes from the material in which the TEG was applied. The study will carry out certain tests, experiments and comparisons among the TEG's various characteristics.

VI. RECOMMENDATIONS

The "Energy Harnessing System using Thermoelectric Generator with Radiation Concentrator and Solar Tracker" project can still be improved if further research and study is conducted.

In order to upgrade the project to a higher level, the proponents would like to recommend:

a. Using other charge controller circuit like the MPPT-type (Maximum Power Point Tracking) for higher upgraded energy storing & monitoring.

b. Thermoelectric generator array should be added to increase the voltage and current output.

c. Additional LDRs ate each corner should be installed as well to increase the accuracy of solar tracking.

d. Fresnel lens should be replaced with a larger one to increase the heat concentration.

VII. CONCLUSION

The "Energy Harnessing System using Thermoelectric Generator with Radiation Concentrator and Solar Tracker" project aims to accumulate wasted heat from the sun and turn it into a usable and ecofriendly energy source.

The proponents created a device that utilizes a new technology called thermoelectric conversion which transform heat into electricity. Using a Fresnel lens to concentrate the heat to the aluminum plate through which the hot side of the TEG is placed, heat buildup is increased thus, creating a large amount of temperature difference. On the cold side, a heat sink is fixed to dissipate heat and thus, establish the Seebeck effect of generating potential difference across the TEGs terminals.

On the other hand, the solar tracker follows the direction of the sunlight through the use of Light Dependent Resistors. The charge controller provides an efficient way of monitoring the charging of the battery including its health. It also protects the battery from sudden voltage fluctuations through the use of different protective components.

Based on the results, conclusions from various experiments have been defined. In the Light Intensity Test it can be noted that between 1:30pm – 2:30pm, the hottest temperature on the whole day has been recorded and the Light-O-meter Application showed 53,712 (lux) light intensity with a maximum temperature difference of 11.1°C. Therefore, the greater the light intensity of the sun, the greater the temperature difference of the TEG's. For the Thermoelectric Generator Voltage Test, it can be noted that the modules accumulate a voltage of up to 1.2 V at 1:30pm to 2:30pm. That time of the day is therefore has the maximum light intensity and heat emission. The Thermoelectric Generator Current Test indicates that the modules accumulate a current of up to 2.1mA at 2:00pm to 2:30pm. That time of the day is therefore has the maximum light intensity and heat emission. The Thermoelectric Generator Power Test, it can be noted that the modules accumulate a power output 2.25 mW from a temperature difference of 11.1 °C.

It can be concluded based on the findings that the solar tracker is able to adjust the motion of the motors with respect to the orientation of the sunlight. The use of Fresnel lens enabled an increase in temperature difference across the thermoelectric generator because of its light concentrating properties. The output power of the system was higher compared to the study of Basilio, et.al (2015) which is also use the TEG to harvest energy from a refrigerator and use it as a source of Cellphone charging station.

Seemingly, all the objectives were met and, gathering a 12 watts power output and even higher is possible in accordance to the time it takes to generate and charge the battery.

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