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Research paper

Integrated Waste Heat Recovery System using Thermoelectric Generator (TEG)

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Abstract

To date, everyone is engaged in renewable energy. Some of the renewable sources are solar, hydro, wind and geothermal energy. An alternative source is waste thermal energy. This paper focuses on recovering waste heat of vehicles to produce electrical energy for charging purposes. The waste heat of vehicles was recovered through thermoelectric effect. According to the study about Seebeck and Peltier effects which was conducted by Pnakovich, if two junctions are made between two different conductive metals and are held at different temperatures, voltage will be created from a temperature difference between these junctions. The resulting electrical energy will be used in charging the independent battery of the vehicle. The researchers decided to integrate or combine the output voltage through the heat recovered from the exhaust pipe and radiator. The thermoelectric modules were placed in an aluminumcha plate, a group of modules is installed on top of a customize muffler which is connected in the exhaust pipe while the other group of modules is placed below the radiator. The exhaust pipe and radiator of the vehicle serves as the heat source while the circulating water is the cold side. The higher temperature difference, the higher voltage will be generated. The microcontroller has two components which are to transmit and receive part. The microcontroller measures voltage, current, temperature from hot and cold side and its temperature difference, then the data except the current is transmitted into the LCD display using Bluetooth. The combined output from the group of thermoelectric modules must have at least 12 volts to charge the independent battery. The researchers conducted an experiment in different road conditions like traveling uphill, downhill, straight and traffic situation. The maximum generated voltage is 16.22 V when conducted at uphill and the current is 12.973 mA. The maximum temperature from the hot side is 325.9 degrees Celsius. The lowest temperature from the cold side is 23.4 degrees Celsius.

Keywords: *Thermoelectric generator, Remote Battery, Charging System, Microcontroller*

1. Introduction

Combustion engine vehicles continue to increase due to demand in mobility of many people. The current designs of vehicles are inevitably inefficient in terms of energy conversion from chemical energy of its fuel to mechanical energy that runs the vehicle. Approximately, 60% of the energy from the combustion of fuel goes to waste as heat according the study of [1]. This thermal waste contributes to thermal pollution and global warming. To increase the energy utilization and address global warming, this study focused on waste heat recovery from the radiator and exhaust of the combustion engines using thermoelectric generator (TEG) [2].

In these regard, the researchers explored the recovery of waste thermal energy of combustion engine to improve fuel efficiency and lessen thermal pollution that causes global warming. So far, there are minimal practical implementations of this technology. The basic principle of TEG is generation of electricity based on temperature difference between two surfaces based on the principle of “Seebeck effect” [3-4].

2. Materials and Methods

The researchers choose the public utility jeepney (PUJ) because it dissipates more heat and approximately 60% of energy gained from burning fuel goes to waste for experimentation purposes. The seebeck principle is applied in conducting the study. The researchers agreed to install the thermoelectric modules in the exhaust pipe and radiator of the vehicle [5-6]. Then after considering the hot side of the system, however the air temperature is not sufficient to be considered as the cold side. In having a higher voltage output the temperature difference between the hot and cold side should also be higher [7]. So, to improve the cooling system of the thermoelectric modules, the researchers were interested by using water as the source of cooling. The design of the cooling system is by circulation of water through the cold side aluminum plate.

The conceptual diagram in Figure 1 shows the operation on how the heat is being recovered until it is converted into electricity for charging the remote battery. The waste heat will be recovered from the radiator and exhaust pipe of the engine of the vehicle. Then the waste heat entering the radiator and the exhaust system of the vehicle is being monitored by a wireless temperature sensor that can be seen on the dashboard of the vehicle. Then the output voltage from the thermoelectric device is being regulated for efficient charging of the remote battery.

The primary purpose of the remote battery is for charging other loads. As shown in Figure 2, parts of the vehicle are considered to acquire high temperature. The greater the temperature difference the higher the amount of voltage generated as being stated by the principle of Seebeck Effect.

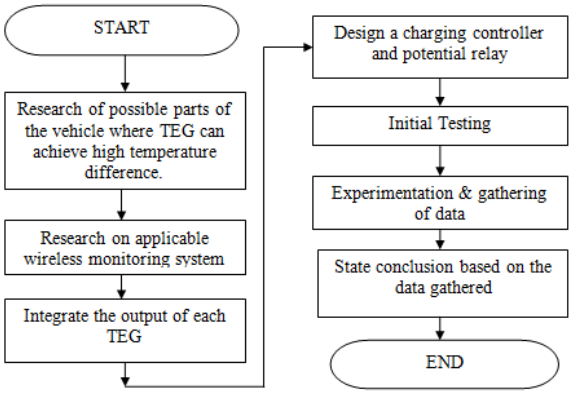

Figure 1:. Flowchart of the study

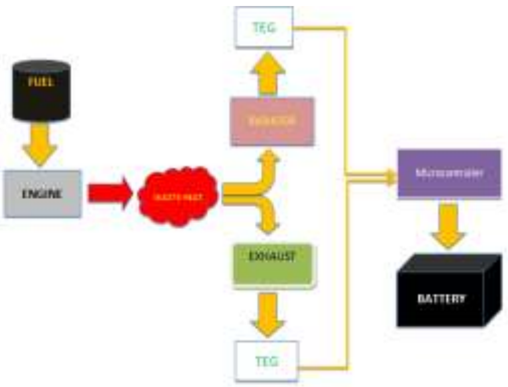

Figure 2:. Conceptual Framework

Using Bluetooth application in wireless monitoring system, the output of the two thermoelectric generators will be combined to generate higher voltage. The researchers will also design a charging controller that will monitor the charging system of the remote battery. Initial testing will follow at different road conditions and time of travel. Hence, the waste heat recovered from radiator and exhaust part of the vehicle serves as a factor for temperature difference. Then the heat recovered from the radiator and exhaust in the system is being monitored by the microcontroller to the dashboard using wireless transmission. Eventually the waste heat recovered is being converted into electricity through the use of thermoelectric module. The output of each thermoelectric module from both locations of the vehicle will be integrated to generate higher amount of voltage. Lastly, the voltage produced is used to charge the remote battery.

The researchers reversed the concept of thermoelectric cooling to power generation (thermoelectric generator). As a result, difference in temperature between the sides can generate a voltage. In the prototype, a total of 16 pieces of thermoelectric cooler was used, a group of 8 which is connected in series for the exhaust part while the remaining 8 pieces also in series-connected is installed in the radiator part of the vehicle. The thermoelectric module used was the TEC1-12706. The figure below shows the actual image of thermoelectric modules that was used in the prototype.

A microcontroller with two components which is the transmit and receive controller. In the transmit part of the microcontroller, the measured values like voltage, current, temperature and battery voltage are being sent to the receiver using Bluetooth application. Also, the transmitter automatically add up the voltage measured from both group of thermoelectric modules and monitors every 30 seconds if the total voltage is equal or greater than 12 volts and the battery voltage is less than 13.8 volts. If both conditions satisfy, the relay will automatically close and eventually the 12V independent battery is now charging.

The transmitter measures data every 15 seconds and directly sends it into the receiver which is the LCD display. In the receiver part of the microcontroller which is the LCD and has a 2GB SD card for data storage that will automatically save all data that are being displayed and will be viewed on the computer. The relay is set to 13.8V which is the maximum capacity of the battery that will trigger it to open or closed. In case the battery is fully charged, the relay will automatically open which means the battery is already isolate in the system and stops charging.

The thermoelectric modules installed above the flat surface of the muffler. The researchers used clip to ensure that the aluminum plate will not fall or move while the experiment is on process.

3. Results and Discussion

The results are shown when the test was conducted from different road conditions. When the experiment was conducted at Pililla, Rizal in an uphill condition, a lot more power required than on a smooth level road. It can be seen from the results that the hot temperature from the exhaust is rapidly increases while the hot side of the radiator is almost the same. The hot side temperature of the radiator is almost constant because the radiator fan resists the heat dissipated by the radiator. The cold side temperature of the system does not changed; the values are almost the same. Another test the researchers conducted was by traveling downhill.

The temperature from the hot side of the exhaust is increasing but later on the temperature will decrease. The hot side temperature of the radiator is constant closed to 50 degrees Celsius. The experimentation was conducted also in a straight road condition. Normally, driving in an expressway is at higher speed. So, more pressure is applied at the accelerator (gas pedal). Then more heat is dissipated at the exhaust having high temperature at the start of the test. The maximum generated voltage reached at 15.9 V. The traffic condition was conducted from Kalaw (Manila) to Project 8 (Quezon). Since it is traffic, the vehicle runs at a constant speed and stops from time to time. The exhaust and radiator will produce minimal dissipation of heat. The highest generated voltage measured was 12.3 V. There was no current reading throughout the experiment. The data plotted in the graph has a 30 second time interval. The y axis represents the generated voltage, current, temperature difference, percent voltage regulation and power versus the x axis represents the total time of experiment which is 30 minutes in every road condition.

Figures 3 to 6 represents the data plotted in the graph has a 30 second time interval. The y axis represents the generated voltage, current, temperature difference, percent voltage regulation and power versus the x axis represents the total time of experiment which is 30 minutes in every road condition. In the generated voltage, uphill condition has the highest generated voltage while in traffic condition has the lowest voltage generated. For the current, uphill condition has the highest current reading of 12.97 mA while the downhill condition considered having a low current reading. The traffic condition has no value of current because the voltages did not reach at least 13.6 V. From the temperature difference 1 which from the exhaust pipe, the uphill has the highest temperature while traffic condition is having the lowest temperature difference. At the temperature difference 2 which is from the radiator, uphill condition has the highest temperature difference while downhill condition is the lowest in temperature. In calculating for the charging time, current output and the A-h rating of the battery must be considered. The average current for uphill, downhill and straight are 8.28 mA, 5.4650 mA, and 7.6482 mA, respectively. The battery used was 12 V, with a 4 Ah specifications.

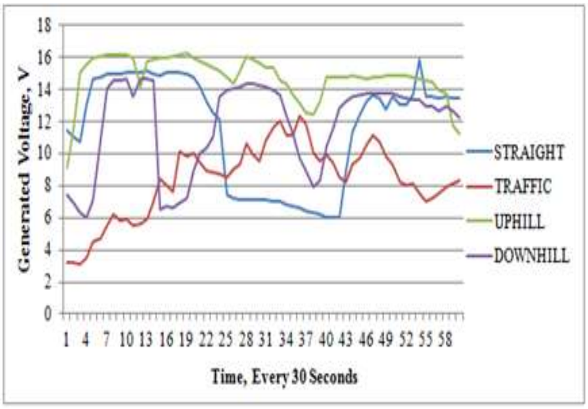

Figure 3:. Generated Voltage vs Time

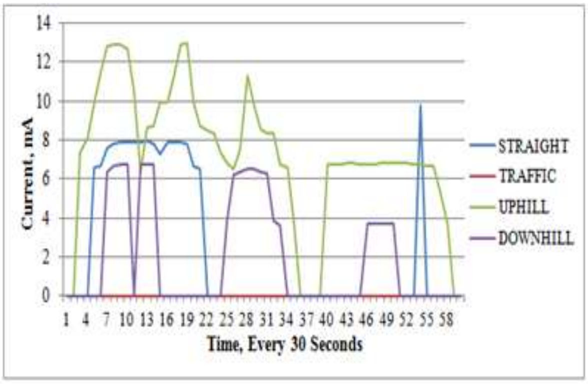

Figure 4:. Current in mA vs Time

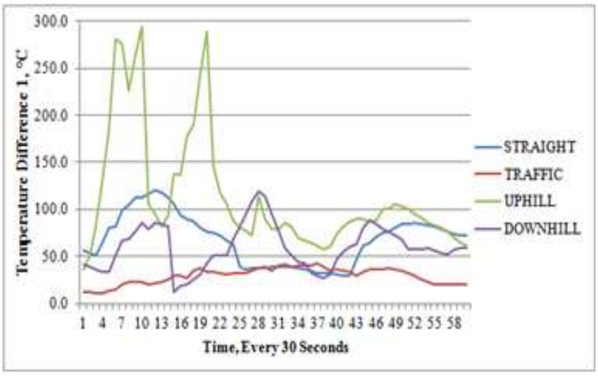

Figure 5:. Temperature diff (exhaust) vs Time

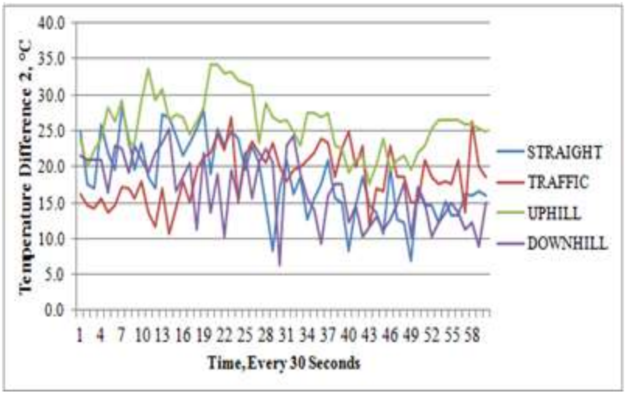

Figure 6. Temperature Diff (Exhaust) Vs Time

4. Conclusions

The researchers were able to achieve the objectives. Based on seebeck effect, the researchers verified that the generated voltage is directly proportional to the temperature difference. The system was able to generate a maximum voltage and current of 16.22V and 12.973mA in uphill condition respectively, with temperature difference of 242.8 °C from the exhaust and 28.3°C from the engine radiator. The researchers observed that the current reading from the sd card starts when the generated voltage is equal or greater than 13.6 V. When the generated voltage is less than 13.6 V, no current will be measured. It can be seen from the traffic condition that there is no current measured because the generated voltage is minimal.

5. Recommendations

In the actual application of energy harvesting through heat recovery using the exhaust and radiator of the public utility jeepney, the researchers recommend the use of higher power rating of pump for the water to circulate faster. Since the researchers only use thermoelectric cooler, it is recommend using the thermoelectric generator for higher voltage output. It is also recommended that the current reading at the display will start at 12V to become more efficient and accurate in estimating the time the battery will fully charge. Also, the researchers recommend using Zigbee, because it has dual purpose for wireless monitoring of data. The user can view the data on the computer while the experiment is on process and at the same time the data is stored on the sd card. The program and the LCD display must be modify to accurately measures and displays the current when the battery starts charging.

Acknowledgements

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