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Evaluation of Voltage Generation and Thermal Distribution from Road using Thermoelectric Technology

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***Abstract:** Road pavement is important because it is used as a mean of transportation from a place to another and also helps to connect people physically around the world. That is why road is paved all over the places as long there is land. This study conducted an analysis of the voltage generation and thermal distribution from road pavement based on thermoelectric technology. Three types of tests are done which includes effect of different number of TEG, different weather and load dependent analysis. The characteristics of temperature difference from road pavement have been studied by gathering data on-site. The analysis of these behaviours is made possible by developing a road thermoelectric generator (TEG) system that consist of TEG, temperature data logger and data acquisition device. This road thermoelectric generator system able to produce electrical power when temperature gradient is present between the pavement and ambient air. Load dependent analysis is done to obtain the optimum power generation. Result shows that 3 TEGs in cascade, sunny day with 10 Ω resistor produces the highest output voltage.*

***Keywords**: Thermoelectric, temperature difference, road pavement, vehicle loads, weather.*

I. INTRODUCTION

Energy harvesting is the process in which energy is captured from a system's environment and exploited by changing them into useable electric power. Kinetic energy, solar, wind and strain are the example of energies that can be exploited. The major energy source that has the highest possibility for being harvested is thermal energy. Asphalt pavement is one of the naturally occurring of thermal energy source. Asphalt pavement received a lot of daily solar radiation and continuously exposed to vehicle loads. This solar energy as well from vehicle loads will dissipate as thermal energy in the inner structure of the pavement.

Specific technologies that can be used to extract energy from both of them and transformed them into electrical energy are needed. Hence, thermoelectric generators (TEGs) are the most suitable device used to convert thermal energy to electricity. Thermoelectricity is defined as the direct conversion of temperature gradient to potential difference and vice-versa [1]. Besides, the effect of electricity due to heat is also known as thermos-electric effect [2]. The thermoelectric effect is classified into several phenomenons. There are Seebeck effect, Peltier effect and Thomson effect.

Yusop, A. M., et al. in it paper has conducted an analysis on energy harvesting of a thermoelectric module based on their characterization and behavior by testing two different configurations of TEM (thermoelectric module); single TEM and multi-stage TEM. Multi-stage TEM has the highest output voltage with 6 cascaded TEM compared to the other 3 tested circuit arrangement [3].Wei Jiang et al. stated that the study on energy harvesting has focused on the three aspects which are piezoelectric technology, photovoltaic technology and thermoelectric technology. However, all of them have their own difficulties or technical challenges. The thermoelectric technology problems is the low-efficiency of electrical energy production that depends on the temperature difference within road structures [4]. However, the low-efficiency of the thermoelectric technology can be enhanced by maintaining and efficiently use the temperature difference. So, it is vital to study and analyze the temperature behavior of asphalt surface and ambient air. It stated that the larger the temperature difference, the greater energy is produced. Moreover, the temperature difference also can be found from pavement materials at different depths but it is limited because the temperature difference within the pavement structure is small [5][6]. So, some methods have been done to overcome this problem. Wu et al. [7] produced a highly thermal conductive materials device to take advantage the temperature gradient meanwhile a pavement cooling system with a TEG implanted in the road was developed by Hasebe et al. [8].

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Jiang et al. then designed a road thermoelectric generator system (RTEGS) based on the following key principals. Firstly, is by collecting and storing the thermal energy from the pavement surface efficiently. Next is to use of the temperature gradient between asphalt pavement and ambient air. Lastly is by minimizing the impact of this system on asphalt pavement structure and material properties. For instance, a special designed water tank will help to enhance the output of electric energy [9].

Francisco Duarte et al. in his research mentioned that the asphalt pavement surfaces are constantly exposed to solar and vehicle loads. Energy is possible to be extracted from both of them, in which specific technologies can be used to transform into electricity [10]. This research compares the specific technologies that make used of solar energy or vehicle mechanical energy as their sources and have been tested on asphalt road. In comparison with the technologies that use solar energy, the implementation of photovoltaic system on road pavement has its own problems as glass that has been used in the system causing troubles in vehicle adherence although the system are the most efficient [11]. Meanwhile, TEG is seemed easy to install although the efficiency is reduced.

Z.B. Tang et al. stated the TEM can convert waste thermal energy from automotive exhaust into electrical energy. The advantages of TEGs are as no mechanical parts, long-lasting, silent, safe to the environment and only needed slight maintenance [12]. This research described the output power of the TEG and TEM system under mismatch conditions, which are; limited working temperature and the uneven temperature distributions among the TEM in series connection. An appropriate mechanical pressure provided on the TEM can enhance the power output. Results demonstrate that the loss of power from the TEM is significant, 11% loss of power compared to the theoretical maximum power. The system can be improved by adding thermal insulation on TEM and 2.3% reduced of power loss due to the inconsistent temperature distributions. In next experiment without thermal insulation, the power output rises maximum to 17.3 W, which is 22.5% more than the power produced by the TEG 3400 rpm when the engine operation. The thermal insulation method is suggested to trade a new effective approach to regulate the varying electrical power output of the TEM when in mismatch conditions and at the same time enhance the performance of the TEG system for greater engine speeds [13].

So, in this paper, a set of asphalt road TEG system is designed and developed in order to evaluate the voltage generation and thermal distribution of road pavement. Three sets of different number of TEGs and heatsink are used to test whether number of TEGs can affect voltage generation. From, a previous study, it is found that the output voltage generated during hot day is higher than the output voltage generated during the cold day. So, the study is proven again and with other additional conditions will also be investigated to achieve the objectives of this study. The characteristic of temperature gradient between the asphalt pavement and ambient air are analyzed by applying different weather conditions by analyzing several parameters. Apart from that, the power generation's low efficiency of TEG which depends on the temperature gradients inside road structure also will be improved in this study. Moreover, this study also investigates how much power can be generated from the road TEG system.

II. METHODOLOGY

In order to study the behaviors of voltage generation and thermal gradient of road pavement when tested with different conditions, TEGs are connected thermally in parallel as illustrated in Figure 1. Based on the illustration, the TEGs are arranged where the cold side of the bottom TEG is stacked in contacted with the hot side of the upper TEG. The positive terminal is drawn out from the most bottom TEG whereas the negative terminal is drawn out from the most upper TEG.

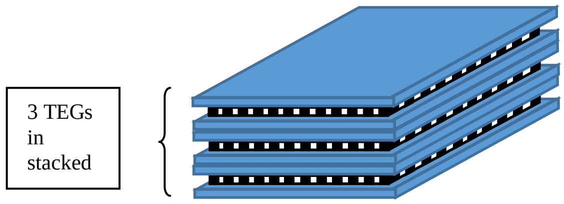

Fig. 1. Thermal parallel configuration of three TEGs.

The basic configuration in this part is as demonstrated in Figure 2. Based on the figure, the arrangement is including a set of three TEGs, a heatsink, data acquisition National Instrument USB-6211, and temperature data logger. The vehicle that used in this project is car (Perodua Kenari). An anemometer is used to record the surrounding temperature, humidity and air velocity. There are three main parts which served difference purpose throughout this study.

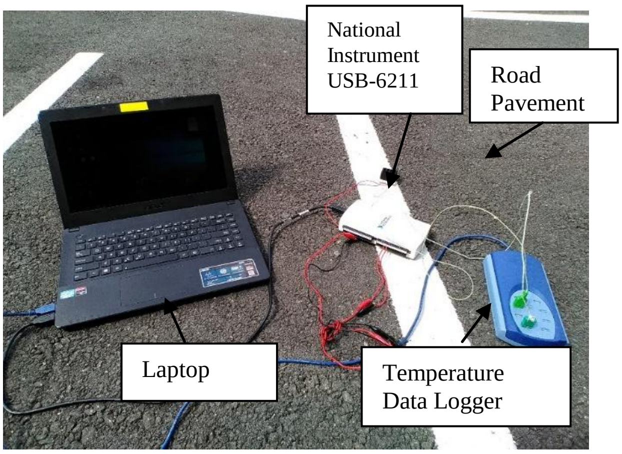

Fig. 2. Basic configuration.

A. Effect of Different Number of TEGS in Cascade

For this first part, different number of cascaded of TEGs are set in order to observe the effect of each configuration onto the voltage generation of the TEGs set. Each analysis is ran for 100 second duration. The different number of cascaded of TEGs are connected in thermal parallel. The different number of cascaded of TEGs are including 1, 2 and 3 of TEGs. The first part is conducted at the same place from 11th until 12th December 2018. All the readings are taken randomly throughout the day in range of 11.00 a.m. to 3.00 p.m. This part analysis is done as open voltage where only temperature and voltage graph will be obtained. The first part is done to proof A.M. Yusuf et al. [3] analysis where it said that the higher number of cascaded of TEGs has the highest output voltage.

Effect Different Weather

In this second part, different conditions are applied in order to observe the effect of different weather condition onto the voltage generation of the TEG's set.

Each analysis was run for 500 second duration where each condition is done for a day.

The conditions set are including sunny day, windy day and cloudy day as shown in Figure 3. The surrounding temperature, humidity and air velocity is determined by using an anemometer.

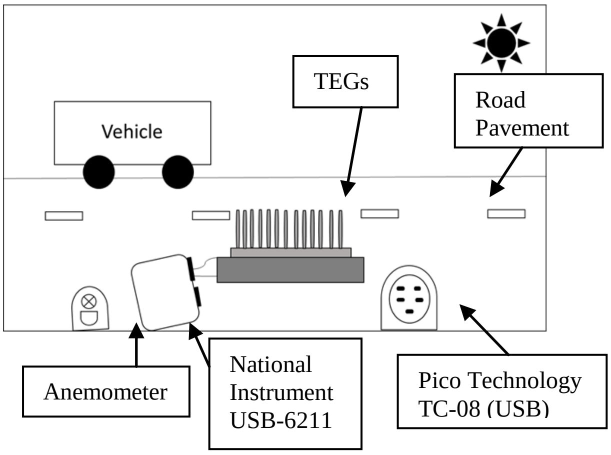

Fig. 3. Configuration for different condition.

B. Load Dependent Analysis

Load dependent analysis also had utilized the basic configuration for the data recording method. However, it is different from the previous part as a decade or known as a variable resistor which varies from 10Ω to 100kΩ is introduced as illustrated in Figure 5.

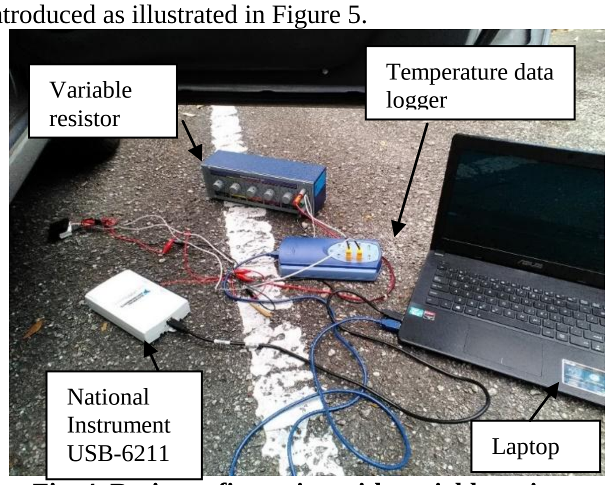

Fig. 4. Basic configuration with variable resistor included.

Total power is used to find which resistor is suitable for this power generation system. Power can be calculated using formula:

$$P = \frac{V^2}{R} \tag{1}$$

where

V is the load voltage.

R is the load or resistance value.

III. RESULTS AND DISCUSSION

A. Different Number of Cascaded of TEG

1) One TEG

Time Seconds	Channel 1 (°C)	Channel 8 (°C)
0	33.68	30.99
10	33.77	30.86
20	33.74	30.88
30	33.88	31.04
40	34.19	31.16
50	34.22	31.27
60	33.80	31.40
70	33.41	31.55
80	33.52	31.68
90	33.90	31.81
100	34.10	31.95

Fig. 5. Temperature of the hot side and cold side for 1 TEG.

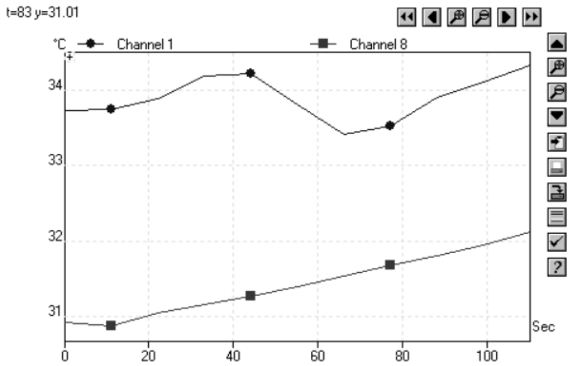

Fig. 6. Graph of hot side and cold side for 1 TEG.

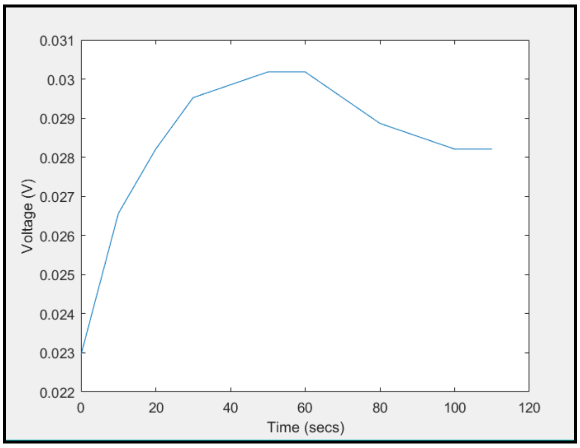

Fig. 7. Graph of voltage for 1 TEG.

For this part, only 1 TEG had been used in order to determine the output voltage. Figure 5 shows the readings of temperature of hot and cold side of TEG. From the Figure 7, it can be seen that the highest output voltage is at 50 to 60 seconds with 0.03 V where the hot side temperature is 34.22 ºC meanwhile the cold side is 31.27 ºC. Figure 6 shows that the thermal gradient between cold side and hot side becomes narrower because the heatsink cannot release the hot temperature to the environment more efficiently due to excess heat, thus, the voltage output decreases after 60 seconds as shown in Figure 7.

2) Two TEGs in cascade

2 cascaded of TEGs is used to determine the output voltage and thermal gradient. Figure 8 shows the reading of temperature for the cold and hot side of TEG. Figure 9 shows the graph of hot and cold side of 2 TEGs is more stable compared to the 1 TEG. This is due to heat need to travel longer distance from the hot side to the cold side for 2 TEGs compared to 1 TEG. Thus, heatsink can release heat efficiently because there is no excess heat. Figure 10 shows that highest voltage is produced at 100 seconds with 0.05 V from a hot side temperature of 34.45 °C and a cold side of 31.68 °C.

Time Seconds	Channel 1 (°C)	Channel 8 (°C)
0	31.48	34.61
10	31.64	34.85
20	31.57	34.90
30	31.67	33.92
40	31.86	34.09
50	31.95	34.18
60	32.03	34.35
70	31.95	34.21
80	31.63	34.22
90	31.59	34.24
100	31.68	34.45

Fig. 8. Temperature of the hot side and cold side for 2 TEGs.

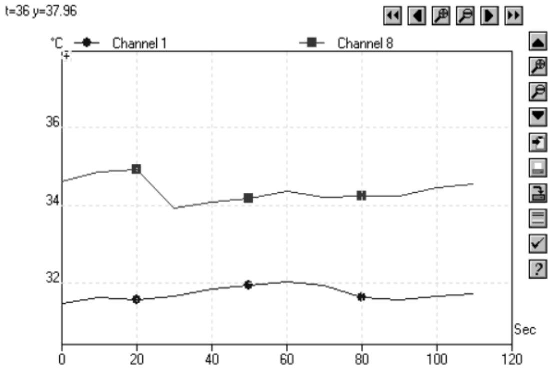

Fig. 9. Graph of hot side and cold side for 2 TEGs.

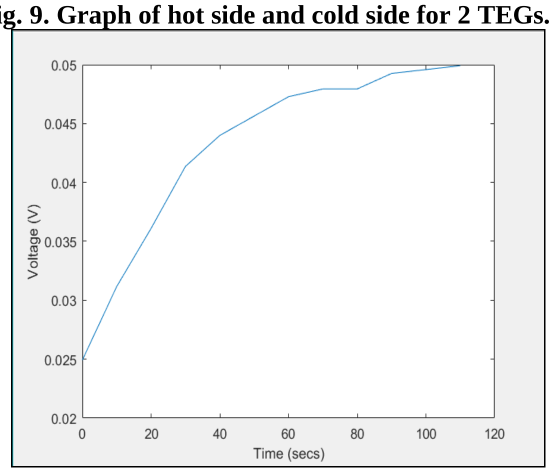

Fig. 10. Graph of voltage for 2 TEGs.

3) Three TEGs in cascade

3 cascaded of TEG is used in order to determine the output voltage and thermal gradient. Figure 11 shows the reading of temperature for the cold and hot side of TEG. In Figure 13, the highest voltage is produced at 100s when the hot side temperature is 40.11 °C and the cold side temperature is 37.62 °C with nearly 0.08 V. Figure 12 shows that the cold side temperature increases towards the end due to external temperature which is hotter, causing heatsink cannot maintain its temperature.

Time Seconds	Channel 1 (°C)	Channel 8 (°C)
0	37.02	40.08
10	36.96	40.06
20	37.21	40.06
30	37.03	40.01
40	37.30	39.97
50	36.73	40.01
60	36.50	40.04
70	37.45	40.06
80	38.03	40.07
90	38.45	40.10
100	37.62	40.11

Fig. 11. Temperature of the hot side and cold side for 3 TEGs.

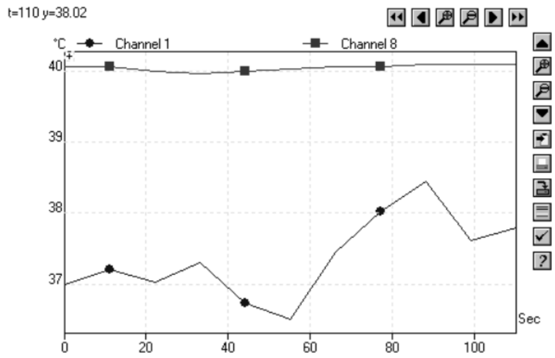

Fig. 12. Graph of hot side and cold side for 3 TEGs.

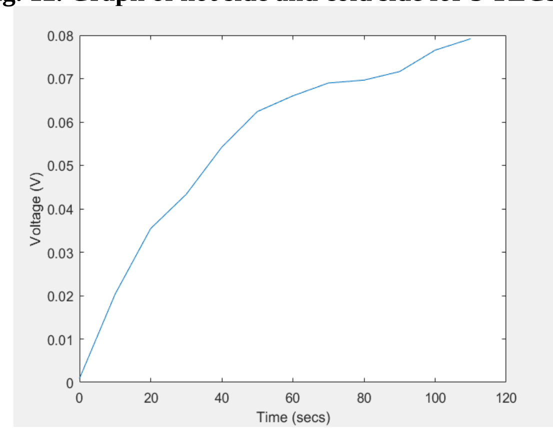

Fig. 13. Graph of voltage against time for 3 TEGs.

B. Effect of Different Weather

In this part, different conditions such as cloudy day, windy day and sunny day are applied in order to observe the effect of each onto the voltage generation and thermal distribution of the TEG's set.

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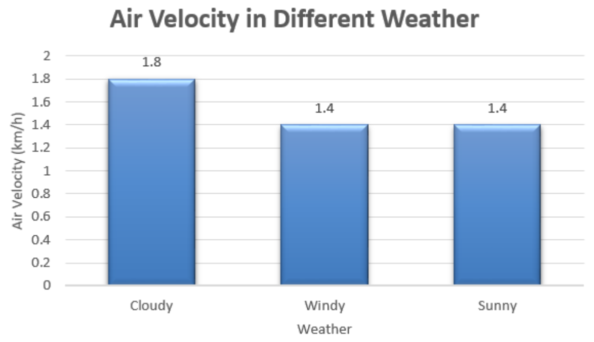

Fig. 14. Air velocity in different weather.

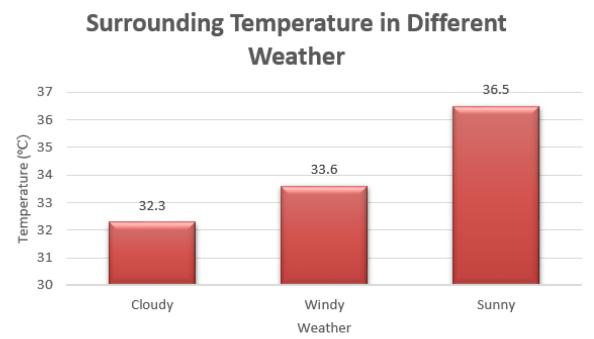

Fig. 15. Surrounding temperature in different weather.

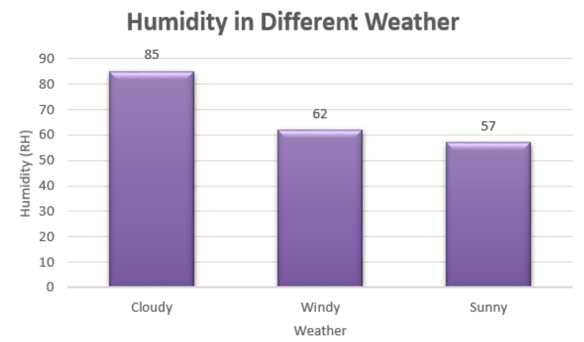

Fig. 16. Humidity in different weather.

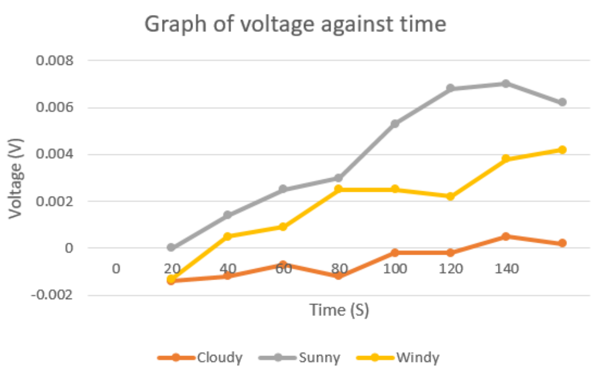

Fig. 17. Voltage generation of different conditions.

Figure 14, Figure 15 and Figure 16 show the bar chart of air velocity, surrounding temperature and humidity for different weather. From those bar chart, it can be seen that humidity and air velocity for cloudy day is the highest compared to windy and sunny day which is 85 RH and 1.8 km/h respectively. Cloud movement block solar energy from reaching road pavement meaning less heat is received. Humidity is quantity of water vapor in air. Cooler places are usually high humidity. High humidity causing surrounding temperature to become low as shown in Figure 15 and Figure 16. High air velocity due to wind and vehicle movement can cause heat stored in pavement carried away through air faster, consequently making the road pavement becomes cooler and produce less voltage as depicted in Figure 14 and Figure 17.

In Figure 17, it can be seen that the sunny day generated the highest voltage compared to windy and cloudy day. This is because the temperature gradient during a sunny day is high. Cloudy day generated smaller voltage than sunny and windy days due to TEG's temperature difference is low.

C. Load dependent analysis

In this part, load dependent analysis has utilized the basic configuration for the data recording method. However, it is different from the previous part as a decade box or known as a variable resistor which can produce resistance from 10 Ω to 100k Ω is introduced.

From Figure 18, voltage generation by 1k Ω produce the highest load voltage (0.0125 V) followed by 10k Ω (0.012 V). 10 Ω and 100k Ω generate identical voltage with both 0.0075 V. 100 Ω produce the least voltage with 0.075 V.

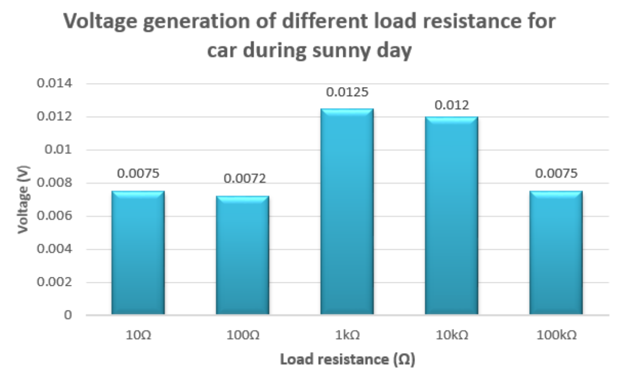

Fig. 18. Voltage generation of different load resistance for car during sunny day.

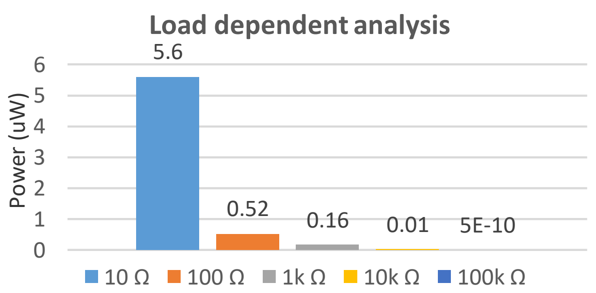

Fig. 19. Load power using different resistance for car during sunny day.

In Figure 19, the total power is calculated using equation (1). The highest power yield when using 10 Ω which is 5.6 µW, meaning the internal resistance is close to 10 Ω. 100 Ω produce 0.52 µW, followed by 1k Ω (0.16 µW) and 10k Ω (0.01 µW) respectively. 100k Ω resistance produce a significance lowest load power of 0.5 nW. In comparing both Figure 18 and Figure 19, it shows that highest load voltage does not mean it produce highest load output.

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IV. CONCLUSION

In conclusion, for the first part, three cascaded of TEG has the highest output where heat is transferred from 1st until 3rd TEG.The efficiency for three cascaded is high because less heat is wasted compared to using 1 TEG. In the second part, sunny day produce the highest voltage with 0.07 V. Low air velocity, high surrounding temperature and low air humidity can increase asphalt temperature, hence producing high voltage output. From the third part, the 10 Ω is the best resistance to match with the internal resistance of the TEGs. There are a few suggestions to be considered for further research. Since the output from TEG is too low for when the configuration is placed on the road pavement during a hot day, study on how to fully maximize the output from TEG is needed before any implementation of the result can be made into a proper system.

This may also include the study of the cooling the cold side of TEG using different method. Moreover, the use of thermoelectric generator technologies with more thermoelements can give a huge effect on the voltage generation and thermal distribution in the energy harvesting technologies. This paper is important for future and futher study on thermal energy harvesting from road pavement.

V. ACKNOWLEDGEMENT

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