Comparative Study of Thermal Energy Harvesting on Agricultural Soils using Thermoelectric Generator (TEG)

I F Saharun¹, N Saudin¹, M A Mohamed², N Jamel¹ and H Mohamed³

¹Faculty of Electric Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia
²Faculty of Electronic Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia
³Industrial Training Institute of Kuala Lumpur, Kuala Lumpur, Malaysia

Abstract. Thermal energy harvesting system using a thermoelectric generator (TEG) can operate low voltage devices up to 5 V. The TEG will act as a small electric generator from the temperature difference obtained from two different conditions. Soil is an excellent source to get a more considerable temperature difference. The ground has a much lower temperature than the ambient as the solar radiation cannot penetrate deeply into the soil. Agricultural soil with a different type of plant has been chosen as the source in this study as the different soil composition will provide a different temperature gradient. The temperature gradient was measured from the surrounding and the soil. The highest energy harvested and generated were measured and compared between different types of agricultural soil. The results lead to a finding of a lot of other factors influencing the efficiency of the energy harvesting tools and the voltage generated from different types of soil. It shows that the hot surrounding with colder soil temperature gave a promising result.

1. Introduction
The world primarily depends on conventional sources such as fossil fuels followed by coal and natural gas as sources of energy. All these shared sources formed in the earth about million years ago and the amount is decreasing from year to year because of the demand to fulfil the needs of increasing human populations. Much research has been done as a preparation to overcome the shortage of conventional sources in the future. One of the aims is to optimise the renewable sources potential to generate energy so it will be able to reduce the usage and act as a replacement for the use of conventional sources.

Thermoelectric generators applications are being developed for powering wireless sensors in factories, farming industries and poultries. Another potential for thermoelectric energy harvesting is powering devices of wearable electronic with body heat. In this study, the energy will be harvested from the temperature difference between two conditions (agricultural soil and ambient temperature) by using a TEG or Seebeck generator to generate electricity. Agricultural soil with different types of composition temperature will give influence on the amount of energy harvested along with the electricity that will be generated.

2. Literature review
2.1 Energy harvesting
power harvesting or energy scavenging is defined as Energy harvesting. The small amount of energy that naturally lost as heat, vibration, light, movement, or sound, is collected. This “ambient energy” is the source for energy harvesters, and available freely in the background [1]. There are various ways to harvest energy. Some of the methods are piezoelectricity, thermal energy and ferromagnetic.
Temperatures gradient and heat flow are omnipresent in the natural and human-made setting. Thermo-electric energy harvesting (or energy scavenging) is the best method to harvest energy offers by the environment. It may one day eliminate the need for replacing the battery application, such as remote sensor networks or mobile device [2]. Besides, the thermal energy storage system provides a potentially economical and environmentally sustainable alternative to the traditional heating system because they allow the storage of renewable energy space-efficient manner underground [3].

2.2 Thermal Energy Harvesting
Thermal energy has the most abundant source from all the energy harvesting methods mention above. Thermal power may be transformed into electric power. One technique of conversion is through a phenomenon known as the Seebeck effect. A thermoelectric generator (TEG) creates DC electricity when there's a temperature gradient between each side of the TEG. Low-powered devices can be powered by the boosted DC voltage. Figure 1 shows the generation mechanism of TEG.

\[ V_{emf} = -S \nabla T \]  

in which S is the Seebeck coefficient and \(\nabla T\) is the temperature gradient from the two faces of the TEG.

2.3 Thermal Harvesting on Soil
Soil are some of the parts of the earth. Radiation heat transfer in the soil is negligible, and the effect of heat transfer is less than 1% [6]. There will be chances to obtain a more significant temperature difference because the ambient temperature will be much higher as heat from solar radiation cannot penetrate well into the earth. Different types of soil hold different thermal properties depends on the water contents of each soil phase. Figure 2 shows the relation between water contents and soil thermal conductivity.
Figure 2 (a) shows the heat flow in dry soil. Dry soil contains plenty of water and in hard texture. The thin water film is not enough to improve contact between soil particles. In figure 2 (c) the higher water content develops the water bridges between solid particles resulting in a rapid increase of thermal conductivity [7]. The saturated soil also can act as a good heatsink by transferring the heat from the metal into the ground quickly to provide the cooler temperature at the cool side of TEG. The agricultural soil composition can change from saturated, and unsaturated depending on the types of plant and crop that grows on it with the geographical factors, including weather. Different moisture content provides a different temperature gradient. The results from this project will show the best condition of agricultural soil that can generate higher electrical output.

3. Problem statement
Soil can have a different composition based on the type and its nature, such as the condition, the type of crop, the microbial activity, or the season influence it. Soil contains more water vapours compare to the atmospheric air [2]. Higher the amount of water vapours in soil provides higher moisture and lower the temperature. Thermal power harvesting process using TEG takes place when there are temperature differences between two different conditions.

In this case, agricultural soil believed to have a cooler temperature than the environment and resulting in a more significant temperature difference. The bigger temperature differences will increase the amount of harvested energy to generate electricity. The energy harvested will be used to power up small electrical devices such as moisture sensor to be used at the agricultural site. Hence, the need to explore the viability of generating electrical energy using a thermoelectric generator from different compositions and types of agricultural soil.

4. Methodology
4.1 Project Development
The project starts by identifying the compositions of the soil, type of crop, moisture contents, and the pH value. Other than the texture and size of soil particles, identifying the pH of soil helps to identify the type of soil. The collection device developed utilising the TEG is embedded into the ground. Observation of the generated voltage at a specific time interval is recorded at a few time intervals. The ultra-low voltage step-up converter, LTC3108, needs a minimum of 20 mV before it can boost up the voltage and used for sensor centric agricultural applications.

The measurement is taken from two different agricultural locations. The vegetable farm in figure 3 has clay soil with a pH of 7. The land is wide open, exposing it to the wind and bright sunlight. The second location in figure 4 is an orchard which has silts soil with a pH of 6.5. The orchard has tall, and big trees and the wind is rarely blowing.
4.2 Circuit construction

The cold surface of the TEG attached to the rectangular shape aluminium electrode because based on the model designed in [4], rectangular shape aluminium electrode is more effective and practical to use compared to the rod type. Aluminium electrode act as a heat conductor to obtain lower temperature at the cold side of TEG.

The recorded measurement then boosted up using ultra-low voltage converter LTC3108 in LTspice simulation. The results of the harvested energy will be compared between the types of agriculture soil. LTC3108 uses a step-up transformer as an internal MOSFET to create a resonant oscillator which can operate at very low input voltages. It solves ultra-low energy input voltage by providing input voltages up to 20 mV to operate. The compact, simple, and highly integrated power solutions enable it to operate wireless sensors from TEGs, harvesting energy from temperature differences as little as 1 °C [4].
Figure 4. LTC3108 ultra-low voltage converter simulation circuit [8].

5. Results and discussions

The voltage generated by the TEG is measured for a total of 90 minutes with 15 minutes interval. Based on the measurements, the voltage generated using two TEGs connected in series gives higher voltage and current reading. These results are similar with the previous research from [4] that show a higher number of TEGs that joined in series converts more thermal energy into electrical energy.

Based on figure 7 and figure 8, most of the voltages generated are low at the beginning of the measurements because it takes time for the heat transfer to occur between the TEG, aluminium, and the soil. The soil temperature is constant all the time, especially the silt soil. The consistent temperature in silt soil at the orchard is due to high moisture content, and the shade from the tall trees that cover the ground from the sun rays.

The experiments start at noon for 90 minutes. The trend of voltages generated is expected to increase as the sunlight becomes brighter towards the afternoon, and this makes the rise in the surrounding temperature. It should be possible to generate a higher voltage output because there will be a significant temperature gradient between the ambient temperatures and the cold and moist soil. Unfortunately, as seen in figure 8, it shows the opposite results. The measurement for the single TEG keeps decreasing over time. The reading for the double TEG shows some increment, but it did not pass the minimum value of 20 mV needed by the converter. The shade from the tall trees also affected the ambient temperature, thus reducing the gradient level of the temperature.

| TIME (min) | 15   | 30   | 45   | 60   | 75   | 90   |
|------------|------|------|------|------|------|------|
| 1 TEG (mV) | 6.6  | 4.4  | 8    | 11.6 | 10   | 14   |
| 2 TEGs (mV)| 8.6  | 10.3 | 26.8 | 17.2 | 33.6 | 37.3 |
Figure 5. The comparison of voltage generated by single and double TEG for clay soil.

Table 2. Comparison between single and double TEG for silt soil.

| TIME (min) | 15  | 30  | 45  | 60  | 75  | 90  |
|------------|-----|-----|-----|-----|-----|-----|
| 1 TEG (mV) | 4.6 | 4.2 | 4.6 | 3.6 | 3.3 | 3.1 |
| 2 TEGs (mV)| 8.5 | 8.8 | 13.4| 15.6| 14.5| 15.2|

Figure 6. The comparison of voltage generated by single and double TEG for silt soil.

The experiments start at noon for 90 minutes. The trend of voltages generated is expected to increase as the sunlight becomes brighter towards the afternoon, and this makes the rise in the surrounding temperature. It should be possible to generate a higher voltage output because there will be a significant temperature gradient between the ambient temperatures and the cold and moist soil. Unfortunately, as seen in figure 8, it shows the opposite results. The measurement for the single TEG keeps decreasing over time. The reading for the double TEG shows some increment, but it did not pass the minimum value of 20 mV needed by the converter. The shade from the tall trees also affected the ambient temperature, thus reducing the gradient level of the temperature.
Table 3 shows the results from the simulation of voltage conversion of the input voltage from the measured data using LTspice for the duration of 1 second with an initial voltage of 3.3 V. Based on the results, it shows that with a higher input voltage, less time is needed to be able to achieve the desired output voltage. The values of Vin from table 3 are the voltage generated from the usage of double TEGs.

| TIME (min) | Clay     | Silt     |
|-----------|----------|----------|
|           | Vin (mV) | Vout (V) | Vin (mV) | Vout (V) |
| 15        | 8.6      | -        | 8.5      | -        |
| 30        | 10.3     | -        | 8.8      | -        |
| 45        | 26.8     | 3.3754   | 13.4     | -        |
| 60        | 17.2     | -        | 15.6     | -        |
| 75        | 33.6     | 3.4273   | 14.5     | -        |
| 90        | 37.3     | 3.5243   | 15.2     | -        |

The initial prediction is the soil with a high content of moisture can generate higher voltage because of its thermal conductivity is better than the dry soil. In this study, the tested silt soil contains more moisture while the clay is much more dehydrated, but the results show that clay soil able to generate output more than the minimum value. It shows that the amount of energy harvested from agricultural soil not only depends on the types of soil. It also depends on the surrounding temperature, the amount of sunlight, the weather, the landscape of agriculture, moisture in the ground, and seasons too.

The factors stated above are related to each other. Clay soil can generate more because the landscape of the vegetable farm does not have many trees to provide shady surroundings. With no trees, the sunlight will be able to radiate and directly heat the ground and the TEG. Even though the direct exposure of the land to sunlight lowers the soil moisture, the temperature difference keeps increasing albeit slowly because the soil still retains moisture deeper underground.

6. Conclusion
There is no fix set up to obtain the highest conversion of thermal energy from any certain types of soil. The same kinds of ground with the same soil structure but can have differing conditions. The conditions are influenced by the agricultural landscape and activities and also the weather. Higher moisture contents of soil are better as a heat sink to produce low temperature at the cold side of TEG.

The design of the harvesting tools must be able to expose the hot side of TEG to achieve the highest temperature possible. A proper connection of the cold side of the TEG to a heat sink is also a priority to ensure fast heat dissipation to the ground. Higher temperature difference without any disturbance such as wind from the surrounding or nature will produce more electrical energy from the TEG. The best conductor must fit perfectly to the size of TEG that only allowed the exposure of the hot side of TEG to the sunlight and surrounding. Even though connecting more TEGs in series will increase the generated value, an excellent open vast space without shades and well-moistened soil for the better heat sink is the critical requirement to raise the temperature gradient for better thermal to electrical energy conversion on agricultural site.

Acknowledgement
The authors would like to acknowledge the Faculty of Electric Engineering Technology, Universiti Malaysia Perlis (UniMAP) for providing research facilities and funding for the project.
References

[1] Ahmed, S., & Kakkar, V. (2017). An Electret-Based Angular Electrostatic Energy Harvester for Battery-Less Cardiac and Neural Implants. IEEE Access, 5, 19631–19643. https://doi.org/10.1109/ACCESS.2017.2739205

[2] S. Priya and D. Inman, Energy harvesting technologies. New York: Springer, 2010, pp. 335-337.

[3] Catolico, Nora & Ge, Shemin & McCartney, John. (2016). Numerical Modeling of a Soil-Borehole Thermal Energy Storage System. Vadose Zone Journal. 15. 10.2136/vzj2015.05.0078.

[4] N. Saudin, M. A. Bermawi, M. A. Mohamed, N. Jamel and C. L. Wooi, “Comparative Study of Thermal Energy Harvesting using Thermoelectric Generator (TEG) on Home Appliances,” International Conference on Economy, Education, Engineering, Business, Technology and Social Sciences (ICEBTS2019), October 5-6, 2019, Kuala Lumpur, Malaysia.

[5] Kubov, V. I., Dymytrov, Y. Y., & Kubova, R. M. (2016). LTspice-Model of Thermoelectric Peltier-Seebeck Element. 2016 IEEE 36th International Conference on Electronics and Nanotechnology (ELNANO), 47–51. https://doi.org/10.1109/ELNANO.2016.7493007

[6] Rees, S. & Adjali, Mohamed & Zhou, Zhaoyu & Davies, M. & Thomas, H. (2000). Ground heat transfer effects on the thermal performance of earth-contact structures. Renewable and Sustainable Energy Reviews. 4. 213-265. https://doi.org/10.1016/S1364-0321(99)00018-0

[7] Akrouch, Ghassan & Sánchez, Marcelo & Briaud, J. L. (2015). Effect of the Unsaturated Soil Condition on the Thermal Efficiency of Energy Piles. Geotechnical Special Publication. 1618-1627. https://doi.org/10.1061/9780784479087.146

[8] LTC3108 Datasheet and Product Info | Analog Devices”, Analog.com. Accessed on: March 21, 2020. [Online]. Available: https://www.analog.com/en/products/ltc3108.html#product-tools

[9] Biswas, A., Hamidi, S. B., Biswas, C., Roy, P., Mitra, D., & Dawn, D. (2018). A novel CMOS RF energy harvester for self-sustainable applications. IEEE 19th Wireless and Microwave Technology Conference (WAMICON). https://doi.org/10.1109/WAMICON.2018.8363908

[10] Solanki, S. S., Chavan, A. B., Tharwal, O. N., Ghadi, T. M., Sawant, S. P., & Bondre, S. S. (2018). Design and Implementation of Thermoelectric Energy Harvesting System with Thermoelectric Generator for Automobiles Battery Charging. 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT), 131–134. https://doi.org/10.1109/ICICCT.2018.8473156

[11] J. Singh, P. Kuchroo, H. Bhatia and E. Sidhu, “Floating TEG based solar energy harvesting system,” 2016 International Conference on Automatic Control and Dynamic Optimisation Techniques (ICACDOT), Pune, 2016, pp. 763-766. doi: 10.1109/ICACDOT.2016.7877689

[12] P. Ravindran, “Harvesting Thermal Energy to Power Agricultural Sensors,” thesis, North Carolina State University, 2011.