International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I8P230

Volume 70 Issue 8, 284-291, August 2022

Original Article

Development of Hybrid Photovoltaic and Thermoelectric Generator for Energy Harvesting

Norain Sahari[1], Zuraidah Ngadiron[2], Zulkifli Azman[3], Nur Basirah Mustapha[1], Noramin Ismail[4]

[1]*Power Energy Focus Group, Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Pagoh, Johor, Malaysia.*
[2]*Industry Centre of Excellence for Railway, Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Pagoh, Johor, Malaysia.*
[3]*Microelectronics and Nanotechnology-Shamsuddin Research Center (MiNT-SRC), Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.*
[4]*GSPARX Sdn. Bhd., Annexe Building, 129, Jalan Bangsar, Kuala Lumpur.*

[2]zuraidahn@uthm.edu.my

Received: 20 April 2022 Revised: 20 June 2022 Accepted: 13 August 2022 Published: 22 August 2022

Abstract - *Solar cells are devices that generate energy from the sun. Solar radiation strikes a photovoltaic (PV) panel capable of collecting and converting the light it receives into electrical energy. In this study, the hybrid's output power equals the total maximum output power produced by the PV module and the thermoelectric (TE) generator devices. It has been researched that there will be an unusable waste of energy from the heat. Furthermore, the solar radiation can also cause the PV panel to warm up, reducing its production efficiency. Hence, to improve the effectiveness of the system's energy harvesting, this heat production was utilised using a TE generator. This study aims to develop a hybrid PV-TE generator for electrical energy harvesting and compare the efficiency of energy harvesting by individual solar panels and hybrid PV-TE generators. Three types of PV modules are used: PV Standalone, PV-TE Generator and PV-TE Generator with the heat sink. When the thermoelectric generator's body reacts with heat, it generates current and voltage, as shown on the digital multimeter and the digital temperature sensor. The output voltage and current are measured based on the total output of the solar panel and TEG module. In this study, the TEG produced more voltages as the temperature rose. Compared to stand-alone solar PV, the total efficiency of combining TEG with solar PV is improved.*

Keywords *- Solar panel, TEG module, Heat sink, Energy Harvesting.*

I. Introduction

The majority of countries are currently undergoing fast urbanization and population growth. The emerging world is seeing rapid expansion [1]. Over the last few decades, the use of solar power in residential buildings has increased dramatically following the developing world. Due to rising energy demand, fossil fuels are being replaced by renewable energy sources such as solar energy [2-4]. Solar cells are solar energy-generating devices. The solar radiations fall on a photovoltaic (PV) panel capable of collecting and converting the light radiations that fall on it into electrical energy [5].

The possibility of merging a photovoltaic (PV) system with a thermoelectric (TE) generator to boost power generation is investigated in this study. To capture electrical energy from both light and heat, this invention combines a PV panel and a TE generator [6]. In this study, the hybrid's output power is equal to the total maximum output power generated by the PV module and the TE generator devices individually. In each case, the maximum output power that could be generated was 90 watts. Overall, the output provided by a hybrid PV-TE generator system is better than the single system.

This study combines a PV panel and a TE generator to utilize light and heat to harvest electrical energy. In this study, the hybrid's output power is equal to the total maximum output power produced by the PV module and the TE generator devices individually. It has been investigated that there will be an unusable waste of energy from the heat. Furthermore, the solar radiation can also cause the PV panel to warm up, reducing its production efficiency [7]. This project will solve all the problems by inventing a new device that will consume all the waste energy released. Hence, to improve the effectiveness of the system's energy harvesting, this heat production is utilised using a TE generator.

This project aims to develop a hybrid photovoltaic and thermoelectric (PV-TE) generator for electrical energy harvesting. By developing the Hybrid PV-TE system, the relationship between temperature gradient and efficiency of output energy on hybrid PV-TE generator can be analysed. This project compares energy harvesting efficiency by individual solar panels and hybrid PV-TE generators.

This project focuses on developing and building a hybrid solar panel and thermoelectric to harvest the solar energy the electrical energy. Firstly, the solar panel used in this project has rated power and voltage of 10 W and 16 V, respectively. TEC1-12706 Thermoelectric Peltier will be used as a thermoelectric (TE) generator. Then, the output voltage and current will be measured based on the total output of the solar panel and Peltier module.

2. Materials and Methods

The project design development depends on the knowledge received throughout the execution phase. All necessary operations were examined and recorded. The project's final phase is the project closure, which tests and debugs all issues to ensure the goals are met.

2.1. Design Phase

The hybrid system combines a solar PV system with a TE generator's reliability and heating capacity [8,9]. The block diagram of a hybrid system combining TE and PV power generation is shown in Fig. 1. The energy deficit is defined as the TE and PV module's inability to supply electricity to the load at a certain time. Meanwhile, Fig. 2 shows the process of this project from the start to the end. Three types of PV modules are used: PV Standalone, PV-TE Generator and PV-TE Generator with Heat Sink. Firstly, as stated, all types of PV modules are placed under sunlight at a specific time. The thermoelectric generator then got heat energy from the solar panel. When the thermoelectric generator's body reacts with heat, it generates current and voltage, as shown on the digital multimeter and the digital temperature sensor. The output voltage and current are measured based on the solar panel's total output and TEG. All connections for this project are connected in series for voltage measurement and parallel for the current measurement. The energy harvesting efficiency of individual solar panels and hybrid PV-TE generators are compared to all the data collected.

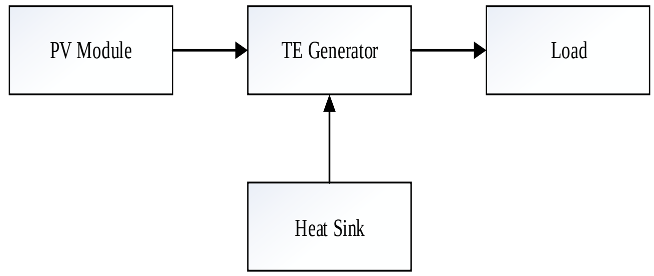

Fig. 1 Block Diagram of Hybrid Photovoltaic and Thermoelectric (PV-TE) Generator for electrical energy harvesting

Fig. 2 shows the process of this project from the start to the end. Three types of PV modules are used: PV Standalone, PV-TE Generator and PV-TE Generator with Heat Sink. Firstly, as stated, all types of PV modules are placed under sunlight at a specific time. The thermoelectric generator then got heat energy from the solar panel. When the thermoelectric generator's body reacts with heat, it generates current and voltage, as shown on the digital multimeter and the digital temperature sensor. The output voltage and current are measured based on the solar panel's total output and TEG. All connections for this project are connected in series for voltage measurement and parallel for the current measurement. The energy harvesting efficiency of individual solar panels and hybrid PV-TE generators is compared to all the data collected.

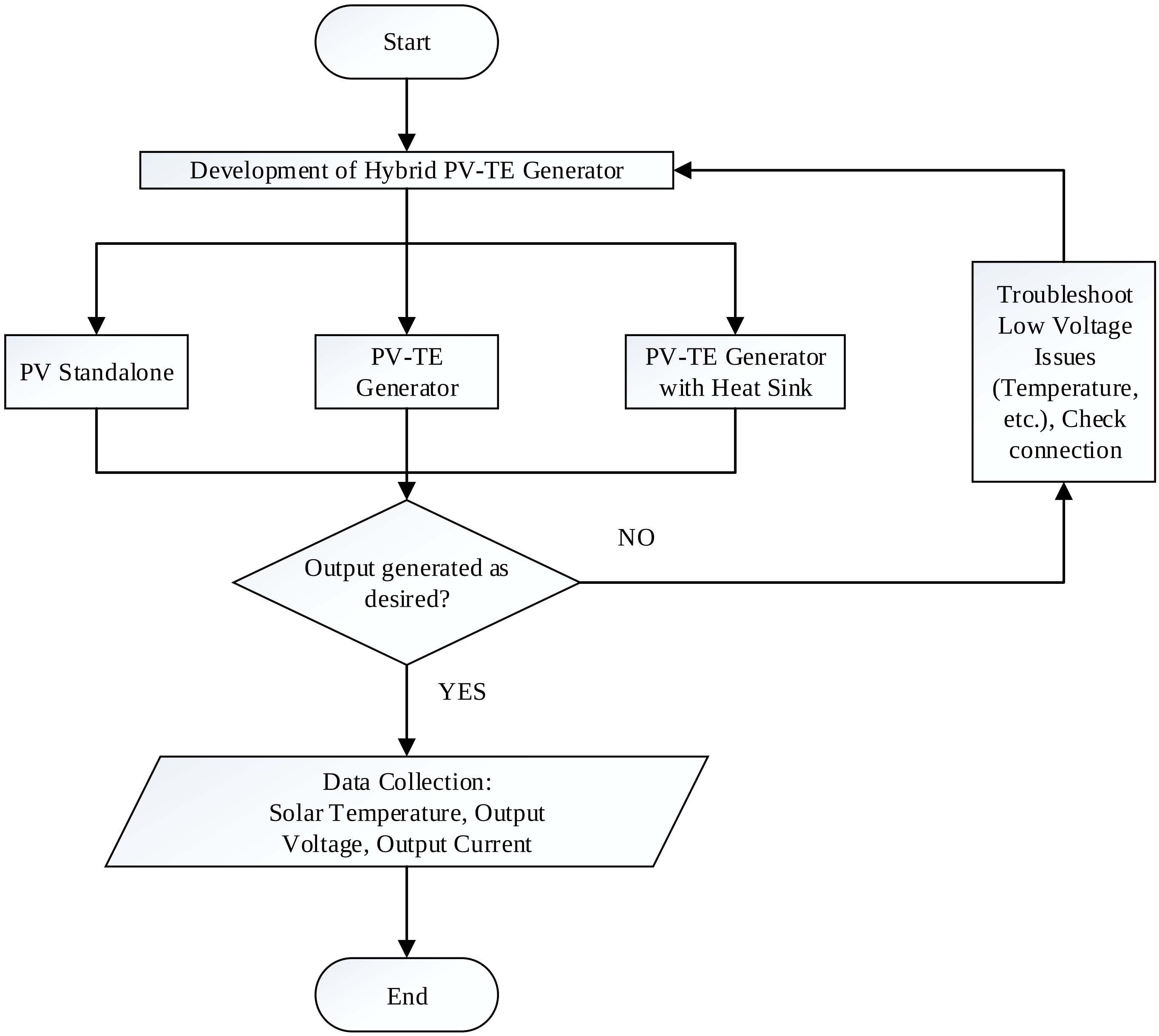

Fig. 2 Flowchart of the Project

This project setup consists of PV Standalone, PV-TE Generator and PV-TE Generator with heat sink, respectively. This setup aims to analyse the relationship between temperature gradient and output energy efficiency on hybrid PV-TE generators and compare energy harvesting efficiency by individual solar panels and hybrid PV-TE generators.

2.2. Placement and Concept of TEG

The TEG is located in the middle of the back of the solar panel. As for the PV-TE generator without a heat sink, the placement of TEG for a PV-TE generator with a heat sink acts as a cooler to reduce the temperature of the solar panel and TEG. Even for small changes, the average temperature of the PV panel decreases when a heat sink is used. For the development of this project, this placement configuration is tested to decide the perfect position for the TEG to be placed.

One of the most significant aspects of the TE module design is determining the ideal geometry module to get the best performance out of the TEG. The major indications of a TE module's generating performance are the conversion efficiency and power per unit area. The thermo-element length influences these performance indications of a TE module for a certain figure of merit, contact characteristics, and operating temperature differential. Thermoelectric materials convert temperature differences into electric voltage, allowing power to be generated directly from heat. Good thermoelectric materials must have high electrical conductivity and low heat conductivity. Low thermal conductivity ensures that one side remains cool. At the same time, the other is heated, creating a significant voltage in a temperature gradient, as shown in Fig. 3.

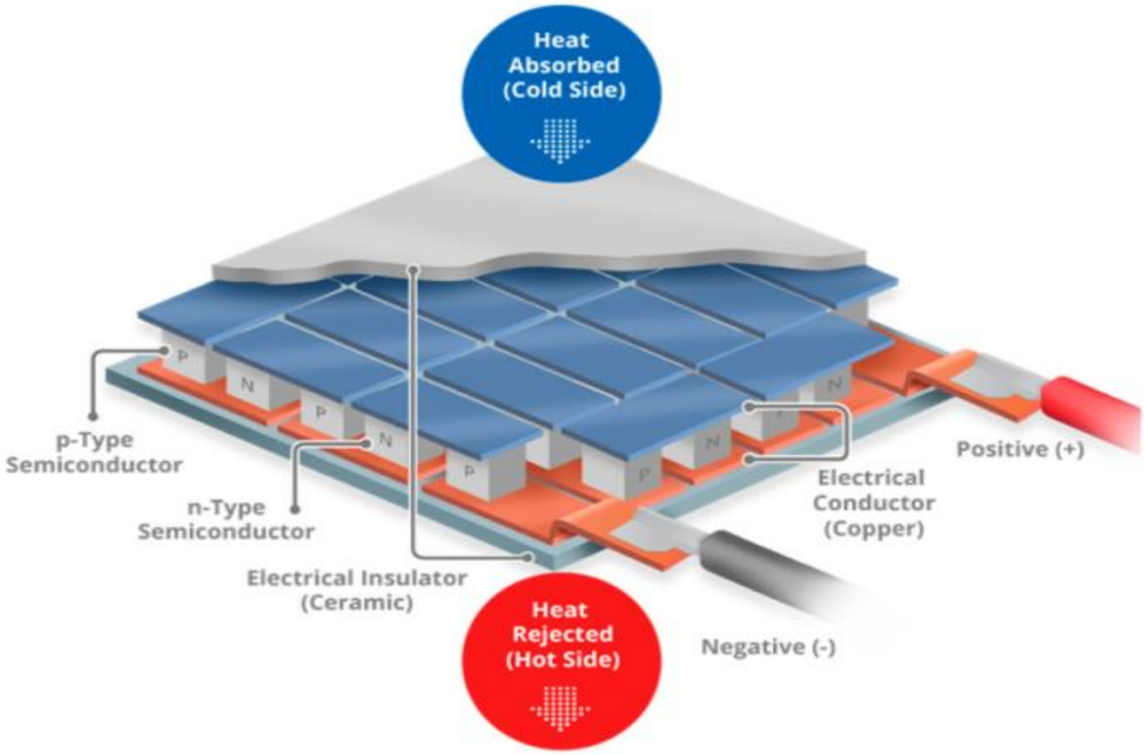

Fig. 3 Design of Thermoelectric Generator[6]

2.3. Complete setup of the proposed development of hybrid PV-TE generator for energy harvesting

Fig. 4 shows the complete setup of experiment rigs for this study and how the data is taken. All three types of PV cells are placed under the sunlight at 45°, leaning to the back and supported by the solar panel stand. The temperature LCDs are attached to the PV-TE generator's solar panels and the TEG module except PV stand-alone. All the data are recorded simultaneously to ensure that the outputs comparisons are valid as the solar panel temperature is the same by the time the experiment starts. All connections for this project are connected in parallel for voltage measurement and series for the current measurement. In this study, the TEG harvested more voltages as the temperature rises.

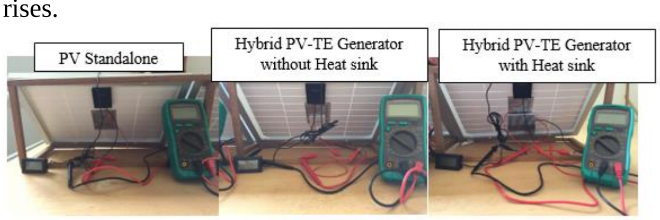

Fig. 4 Completed setup for experiment rigs

3. Results and Discussion

The relationship between temperature gradient and output energy efficiency on the hybrid PV-TE generator is discussed. The analysis of each solar panel will be presented to compare the energy harvesting efficiency of individual solar panels and hybrid PV-TE generators.

3.1. Analysis of PV Standalone

PV cell is employed without using the TEG module and the heat sink. The results are shown in Table 1. The voltage and current generated at 0900 hours is 20.6 V and 10.8 mA with a temperature of 28.5 °C after half an hour of operation. It shows that the voltage and current outputs produced by the solar panel are directly proportional to the temperature. The power out was computed from the corresponding voltage and current outputs, as shown in Table 1 and Fig. 5.

Table 1. Outputs for PV stand-alone

Time (Hours)	Temperature (°C)	Output Voltage (V)	Output Current (mA)	Output Power (W)
0900	28.5	20.6	10.8	0.22
0930	31.9	21.2	11.7	0.25
1000	51.6	21.3	11.6	0.25
1030	54.7	21.1	11.5	0.24
1100	49.9	21.4	11.8	0.25
1130	57.8	21.3	11.7	0.25
1200	54.7	21.2	11.6	0.25
1230	47.5	20.5	10.9	0.22
1300	53.3	20.5	10.9	0.22
1330	48.1	20.7	11.1	0.23

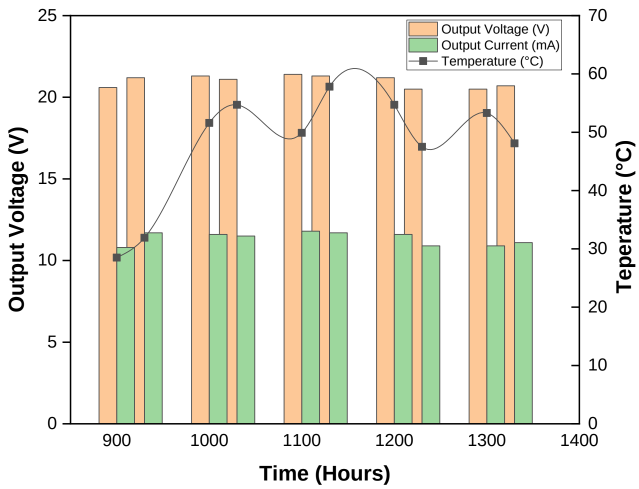

Fig. 5 Graph analysis of the outputs and temperature versus time of PV stand-alone with the time interval of 30 minutes

3.2. Analysis for Hybrid PV-TEG without the Heat sink

The same data collection method is applied for this configuration except for adding a TEG module at the back of the solar panel. The results as shown in Table 2. After half an hour of operation, the voltage output is 20.8 V, with the temperature of the solar panel (T_1), 28.5 °C while the temperature of the TEG module (T_2) is 27.8 °C. The produced current is 12.0 mA. However, there is considerable variation in the findings due to the wind and overcast season. The function of the TEG module in operation is to increase the efficiency of the solar panel and the output generated. The power was determined after measuring the hot and cold junction temperatures. Table 2 and Fig. 6 shows the result of the analysis.

Table 2. Outputs for PV-TE without the Heat sink

Time	Tem p.$\boldsymbol{T_1}$ (°C)	Temp .$\boldsymbol{T_2}$ (°C)	Temp. $\boldsymbol{\Delta T}$ (°C)	Output Voltag e (V)	Output Curren t (mA)	Outpu t Powe r (W)
0900	28.5	27.8	0.7	20.8	12.0	0.23
0930	32.4	31.7	0.7	21.9	13.1	0.29
1000	54.9	53.7	1.2	21.4	12.6	0.27
1030	55.1	53.6	1.5	21.4	12.6	0.27
1100	52.5	51.5	1.0	21.6	12.8	0.28
1130	55.1	54.3	0.8	21.3	12.5	0.27
1200	58.1	56.9	1.2	21.3	12.5	0.27
1230	49.6	48.9	0.7	20.7	11.9	0.25
1300	55.6	54.8	0.8	21.2	12.4	0.26
1330	48.8	48.1	0.7	20.6	11.8	0.24

The temperature gradient at 0930 hours is slightly lower than the gradient at 1030 hours. The highest output voltage was observed at 0930 hours, producing 13.1 mA output current. The result shows that the PV-TE generator combination is valid when the temperature gradient and output voltage are larger, as the total summation reading can affect the output generated by the PV.

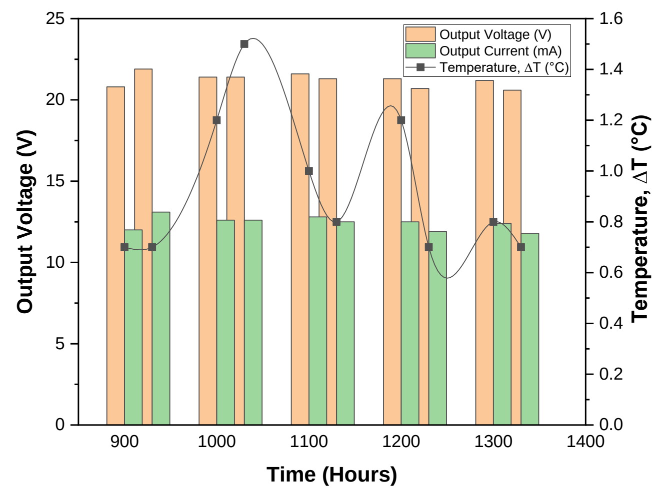

Fig. 6 Graph analysis of the outputs and temperature versus time of PV-TE generator without heat sink with the time interval of 30 minutes

3.3. Analysis for Hybrid PV-TEG with Heat sink

The third configuration adds and positions the heat sink beneath the TEG module. The outputs' results are shown in Table 3. After half an hour of operation, the output voltage is 21.0 V, with the solar panel temperature (T_1) at 28.7 °C while the TEG module (T_2) temperature is at 24.0 °C. The current produced is 13.3 mA. When the temperature gradient increases, the solar panels' outputs increase, which will cause the total summation increases. Due to the wind and overcast season, the findings have significant variance. The heat sink will help the TEG module improve the solar panel's efficiency while increasing the output generated. It is because the TEG with heat sink produces higher output voltage due to the higher temperature gradient of the thermoelectric. The power was determined after measuring the hot and cold junction temperatures. The results are depicted in Table 3 and Fig. 7.

Table 3. Outputs for PV-TE with Heat sink

Time	Temp. T_1 (°C)	Temp. T_2 (°C)	Temp. ΔT (°C)	Output Voltage (V)	Output Current (mA)	Output Power (W)
0900	28.7	24.0	4.7	21.0	13.3	0.27
0930	32.8	27.8	5.0	21.6	13.9	0.30
1000	54.2	49.2	5.0	21.6	13.9	0.30
1030	57.6	52.9	4.7	21.5	13.8	0.30
1100	54.3	49.2	5.1	21.6	14.0	0.30
1130	56.8	52.2	4.6	21.5	13.8	0.29
1200	60.0	55.3	4.7	21.5	13.8	0.30
1230	51.7	47.5	4.2	21.0	13.4	0.28
1300	56.6	52.0	4.6	21.1	13.5	0.28
1330	50.4	46.1	4.3	21.0	13.3	0.28

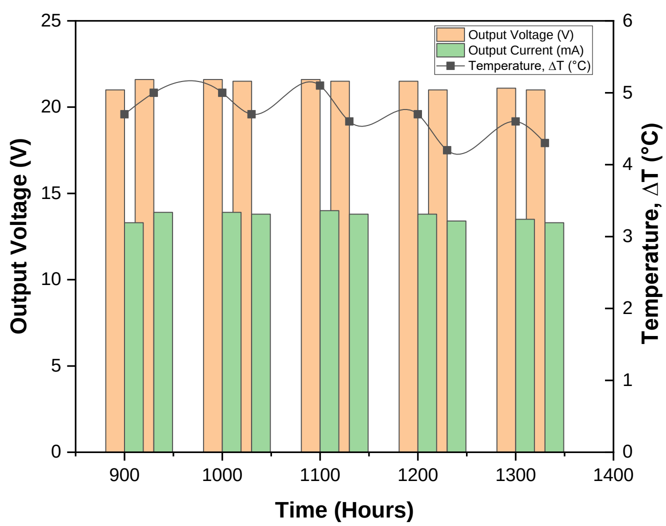

Fig. 7 Graph analysis of the outputs and temperature versus time of PV-TE generator with a heat sink with the time interval of 30 minutes

3.4. Comparisons Analysis of PV Standalone, Hybrid PV-TE generator without a Heat sink and Hybrid PV-TE generator with the Heat sink.

Figures 8 and 9 show the output voltage and current comparison between the hybrid PV-TE generator and the PV stand-alone. It shows that the operating temperature is directly proportional to the output. As the temperature rise, the voltage and current output will increase. As a result, the efficiency of the solar panel decreased. Theoretically, as the sun irradiation increases, the output will increase. However, in real situations, a PV cell's power is occasionally affected by temperature and solar radiation levels. PV cells convert energy directly into electricity based on solar radiation and temperature, resulting in both I-V and P-V output characteristics. Overall, the output generated utilising a hybrid PV-TE generating system is higher than the output power of the individual experiment

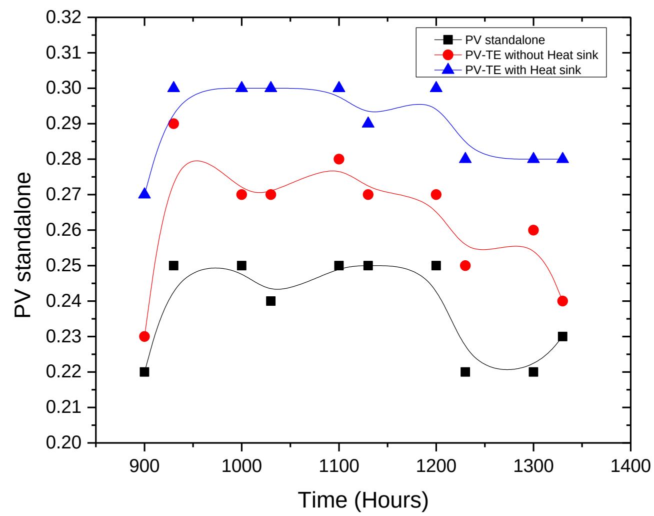

Fig. 8 The output voltage comparison

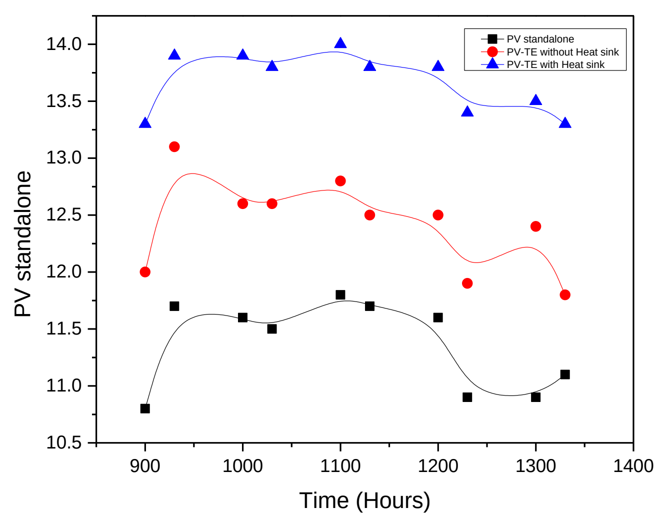

Fig. 9 The output current comparison

Based on Fig. 10, the experiment shows that the output generated by utilising a hybrid PV-TE generating system is higher than the output power of PV stand-alone. However, the output produced by PV-TE generator with heat sink is the highest as the system efficiency increases. It indicates that when there is a temperature difference between hot and cold sides, the TEG system increases, and the output also rises.

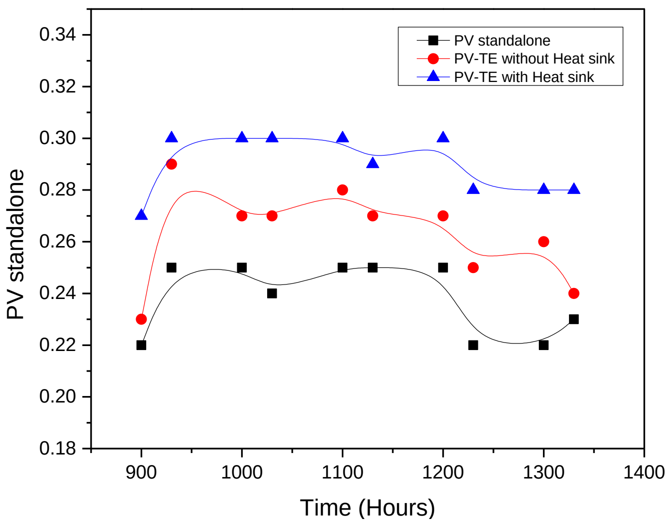

Fig. 10 The output power comparison

A thermoelectric device is a solid-state semiconductor component that may generate electricity when a temperature differential exists between its connections and vice versa. They were invented from many thermocouples that are thermally and electrically coupled in series. The temperature gradient affected the energy produced by TEG. When a temperature difference arises across a thermoelectric device, electrons transfer from the low-temperature to the high-temperature side owing to density differences, resulting in a potential difference that generates the current. Furthermore, two sources of energy are used to convert solar and heat energy into electricity. PV turns sunshine (solar radiation) directly into electricity, whereas TE generator generates electricity when a temperature difference develops at the junction of two conductors due to the Seebeck effect. Using a TE generator to gather diverse waste heat sources and convert them to electricity has a large potential.

4. Conclusion

Based on the findings and analysis of the hybrid system's development between PV and TE power generation, it was discovered that the system is the potential to generate more electricity. It was stated that when the temperature difference between the hot and cold sides of the TE generating system increased, the output would grow. The results illustrate the system's capacity to deliver required output under specific testing conditions, demonstrating its reliability. However, more testing is required to demonstrate the system's potential to generate sufficient electricity in real-world weather situations. Several parameters, such as ambient temperature and sun irradiation, change with the weather throughout the year, resulting in an output that differs from the expected results. By developing the Hybrid PV-TE system, the study of the relationship between temperature gradient and efficiency of output energy on hybrid PV-TE generator is analyzed as when the temperature gradient increases, output energy efficiency also increases.

In comparison to stand-alone solar PV, the total efficiency of combining TEG with solar PV is improved. According to the findings, the thermoelectric generator might be used to charge the battery. By finishing this project, a new method of energy harvesting based on waste heat energy from the photovoltaic cell will be developed, which will benefit customers by cutting their current utility expenditures.

Acknowledgment

The authors gratefully appreciate the Universiti Tun Hussein Onn Malaysia (UTHM) for supporting this research work under TIER 1 grant vot H803.

References

[1] Pradeep, J., Krishnakumar, S., & Sowmiya, M, “Hybrid energy harvesting system using IOT,” *IOP Conference Series: Materials Science and Engineering*, vol.923, no.1, 2020.. https://doi.org/10.1088/1757-899X/923/1/012077

[2] Popovici, C. G., Hudişteanu, S. V., Mateescu, T. D., & Cherecheş, N. C, “Efficiency Improvement of Photovoltaic Panels by Using Air Cooled Heat Sinks,” *Energy Procedia*, vol.85, pp.425–432, 2016. https://doi.org/10.1016/j.egypro.2015.12.223

[3] Li, G., Shittu, S., Diallo, T. M. O., Yu, M., Zhao, X., & Ji, J, “ A review of solar photovoltaic-thermoelectric hybrid system for electricity generation,” *Energy*, vol.158, pp. 41–58, 2018. https://doi.org/10.1016/j.energy.2018.06.021

[4] Vijayalakshmi, R., Pratheeba, C., Sathyasree, K., Ravichandran, V, “ Challenges, Issues and Solution for Hybrid Solar Pv and Wind Power Generation With Off-Grid Integration,” *International Journal of Engineering Trends and Technology*, vol.68, no.3, pp.18-21, 2020.

[5] Jadin, M. S., Setapa, N. A., & Mohamed, A. I, “ Development of Hybrid Thermoelectric and Photovoltaic Power Generation,” *ARPN Journal of Engineering and Applied Sciences*, vol.10, no.22, 2015.

[6] Jeyashree, Y., Hepsiba, P. B., Indirani, S., Savio, A. D., & Sukhi, Y, “Solar Energy Harvesting using Hybrid Photovoltaic and Thermoelectric Generating System. *Global Journal of Pure and Applied Mathematics*, vol.13, no.9, pp. 5935–5944, 2017.

[7] Sahin, A. Z., Ismaila, K. G., Yilbas, B. S., & Al-Sharafi, A, “A Review on the Performance of Photovoltaic/Thermoelectric Hybrid Generators,” *International Journal Of Energy Research*, vol.44, no.5, pp.3365–3394, 2020. https://doi.org/10.1002/er.5139

[8] Ruzaimi, A., Shafie, S., Hassan, W. Z. W., Azis, N., Ya’Acob, M. E., & Supeni, E. E, “Photovoltaic Panel Temperature and Heat Distribution Analysis for Thermoelectric Generator Application,” 2018 IEEE 5th *International Conference on Smart Instrumentation, Measurement and Application*, ICSIMA 2018, pp. 28–30, 2019. https://doi.org/10.1109/ICSIMA.2018.8688801

[9] Rodrigo, P. M., Valera, A., Fernandez, E. F., & Almonacid, F. M, “Annual Energy Harvesting of Passively Cooled Hybrid Thermoelectric Generator-Concentrator Photovoltaic Modules,” *IEEE Journal of Photovoltaics*, vol.9, no.6, pp.1652–1660, 2019. https://doi.org/10.1109/JPHOTOV.2019.2939878

[10] Hafez Fouad , "A Highly Efficient 0.18um CMOS Rectifier For Vibrational Energy Harvesting System in Embedded Electronics Design" *SSRG International Journal of Electrical and Electronics Engineering*, vol. 7, no. 8 pp. 4-10, 2020. *Crossref*, https://doi.org/10.14445/23488379/IJEEE-V7I8P102.

[11] T.Ajay Sairam, Mr. T. Vino, T.M.K Rajasekhar, "Power Management Techniques for A Solar-Powered Embedded Device," *SSRG International Journal of Electronics and Communication Engineering*, vol. 6, no. 4, pp. 1-5, 2019. *Crossref*, https://doi.org/10.14445/23488549/IJECE-V6I4P101

[12] Hafez Fouad, et al. "Voltage-Booster for CMOS Wide-Band High-Precision Rectifier of Energy Harvesting for Implantable Medical Devices in Internet of Bodies (IOB) Telemedicine Embedded System" *SSRG International Journal of Electrical and Electronics Engineering*, vol. 9, no. 4, Apr. 2022, pp. 19-30. *Crossref*, https://doi.org/10.14445/23488379/IJEEE-V9I4P103

[13] Mr. Abhinav V. Deshpande, "Energy Harvesting from Piezoelectric Material using Human Motion," *SSRG International Journal of VLSI & Signal Processing*, vol. 6, no. 2, pp. 5-8, 2019. *Crossref*, https://doi.org/10.14445/23942584/IJVSP-V6I2P102

[14] Vipin Mehta, Sanjay Kateray, P L Verma, "Calculation Analysis of Heat Transfer on the Surface of Engine Cylinders with Unequal Size of Material and Expanded Surfaces," *SSRG International Journal of Mechanical Engineering*, vol. 9, no. 2, pp. 1-8, 2022. *Crossref*, https://doi.org/10.14445/23488360/IJME-V9I2P101