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An Experimental and Comparative Performance Evaluation of a Hybrid PV-TEG System of Energy Harvesting

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Abstract

Rising energy demand encourages a shift away from fossil fuels and towards renewable alternatives such as solar energy. Solar cells are devices that convert sunlight that strikes photovoltaic (PV) panels into electricity. However, the sunshine not only generates electricity, but it also heats the PV panels, making them less efficient. This research intends to address these issues by developing a novel gadget that collects and utilises extra heat energy. The project's goal is to increase the system's energy harvesting efficiency by utilising TE generators to harness this excess heat. Three different types of PV modules were used: PV Standalone, PV-TE Generator, and PV-TE Generator with heat sink. When subjected to heat, the thermoelectric generator produces current and voltage, which are displayed on the digital multimeter and digital temperature sensor. The voltage and current measurements are based on both the solar panel and the TEG module. The investigation discovered that the TEG produced more voltage as the temperature rose. Compared to using only the solar PV system, integrating the TEG with solar PV increased overall efficiency.

1. Introduction

Hybrid Photovoltaic and thermoelectric systems convert solar energy into electrical energy more efficiently. There are two types of energy used. One type of energy is solar, which turns radiant light into electrical energy, and another is thermal energy, which converts heat into electricity. To capture and convert energy into electricity, photovoltaic cells and thermoelectric modules are utilised. Furthermore, the solar thermoelectric hybrid system is eco-friendly and emits no hazardous emissions. The solar thermoelectric hybrid system improves overall reliability without losing power quality.

Solar energy is the world's greatest and most abundant renewable energy supply, and it is also environmentally beneficial. Researchers and engineers have paid close attention to hybrid systems for solar energy utilisation over the last decade due to their superior efficiency and stability of performance when compared to individual solar devices. The photovoltaic technology directly transforms sunlight into electricity. A photovoltaic cell is made up of two or more thin layers of semiconducting material, the most common of which is silicon. When silicon is exposed to light, electrical charges are created, which can be carried away as direct current by metal contacts. The PV panel is the primary component of a PV system, and any number of panels can be linked together to produce the appropriate electrical output.

Combining PV with TEG raises the PV working temperature due to the new thermal resistance produced by the TEG; hence, optimisation of the integrated PV-TEG system is critical, as is an interchange of waste heat from the PV and energy gained from the TEG. Numerous theoretical and practical studies have been undertaken to improve PV-TEG, including optimising TEG engineering for a specific section of the PV The results demonstrated that the size of the TEG is critical in hybrid systems since it can raise or reduce the total power generated by the hybrid system and render integration worthless.

2. Materials and Method

2.1 Materials

The main materials that are used in this project is solar cells. Other than that, to make a new system of this project, the solar cells will be combined with thermoelectric generator (TEG). The using of TEG is to investigate how the temperature gradient influences the efficiency of energy output in the hybrid PV-TE generator. The others materials being used are heat sink and mini USB rechargeable fan.

The block diagram of a hybrid system combining TE and PV power generation is shown in Figure 1. The energy deficit is defined as the TE's and PV modules' inability to supply electricity to the load at a specific moment

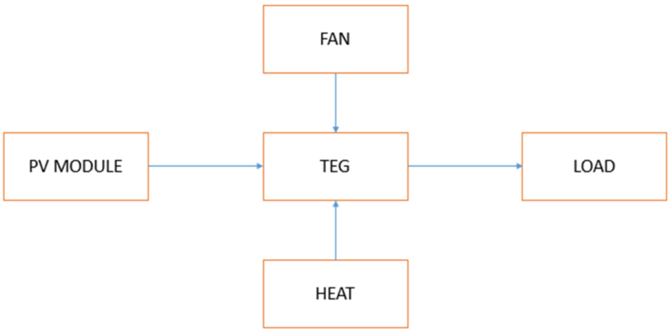

Fig.1 *Block diagram of hybrid system*

2.2 Methods

Three solar panels with different system was used in this experiment which are PV standalone, hybrid PV-TEG and hybrid PV-TEG with heat sink and fan, The data of the experiment were collect from 1030 a.m until 1600 p.m. The data were collected half an hour between 1030 a.m to 1600 p.m. From the experiment, temperature of PV and TEG, voltage of PV and TEG also current of PV and TEG were collected.

Figure 1 shows the experimental setup for PV standalone, hyrid PV-TEG without heat sink and hybrid PV-TEG with heat sink and fan. These all configuration were experimental simultaneously in the same day and same time to ensure the data were valid.

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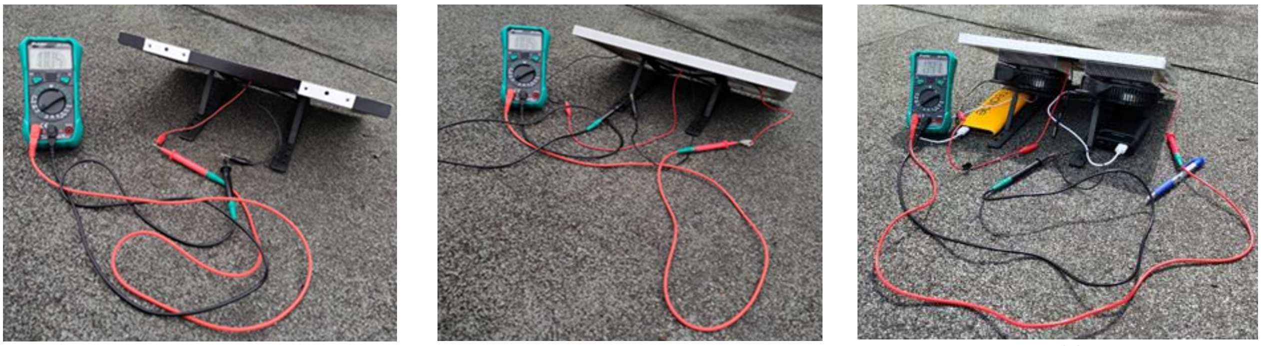

(a) (b) (c)

Fig. 2 *a, b, and c show the experiment that will be done using three different case studies (a) PV standalone, (b) Hybrid PV-TEG, (c) Hybrid PV-TEG using heat sink and fan*

Figure 3 shows the flowchart of the project. The study started with the development of PV-TEG generator which consist of three configurations namely PV standalone, hybrid PV-TEG without heat sink and hybrid PV-TEG with heat sink and fan. The data was collected simultaneously by using multimeter for output voltage and current and infrared thermometer for temperature.

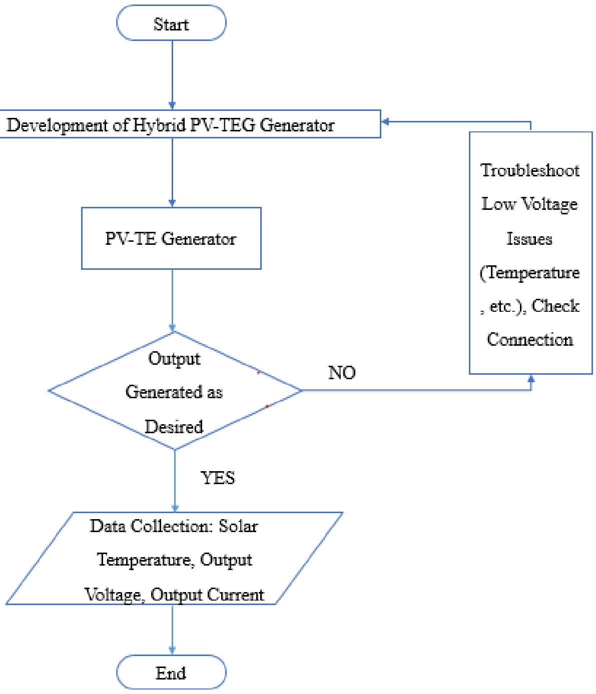

Fig.3 Flowchart of the project

3. Result and discussion

The experiment included three different configurations: solar PV standalone, PV-TEG without a heatsink, and PV-TEG with a heat sink and fan. The talk begins with an explanation of the data obtained from the PV standalone. Next, the performance of PV-TEG without a heatsink and PV-TEG with a superior cooling system is discussed. The next part compares the data results for all three situations in terms of overall performance in voltage, current, and power. Finally, this part looks at the link between the temperature gradient and the voltage generated by TEG in PV-TEG without a heatsink and PV-TEG with a heatsink and cooler.

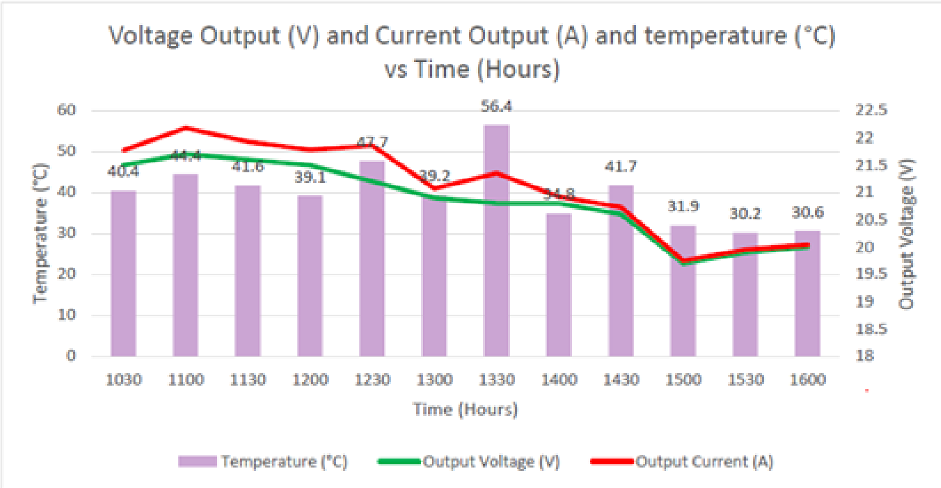

Fig. 4 *Graph analysis of the outputs and temperature versus time of PV standalone with the time interval of 30 minutes*

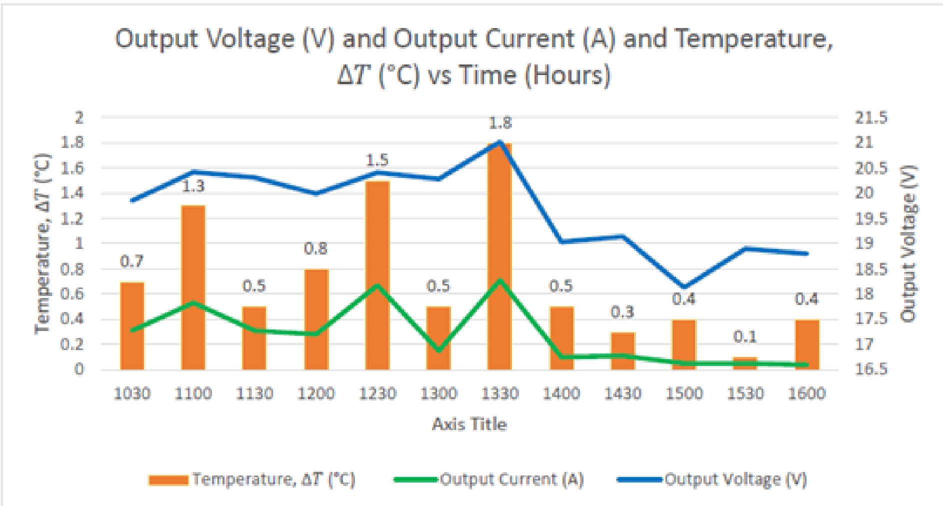

Fig. 5 *Graph analysis of the output and temperature versus time of hybrid PV-TEG with a time interval of 30 minutes*

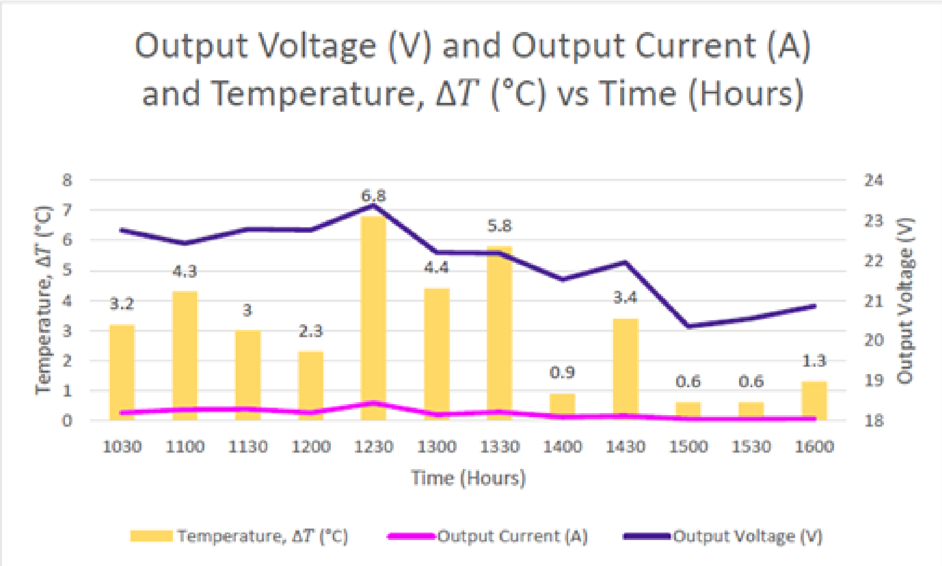

Fig. 6 *Graph analysis of the output and temperature versus time of hybrid PV-TEG with heat sink and fan with the time interval of 30 minutes.*

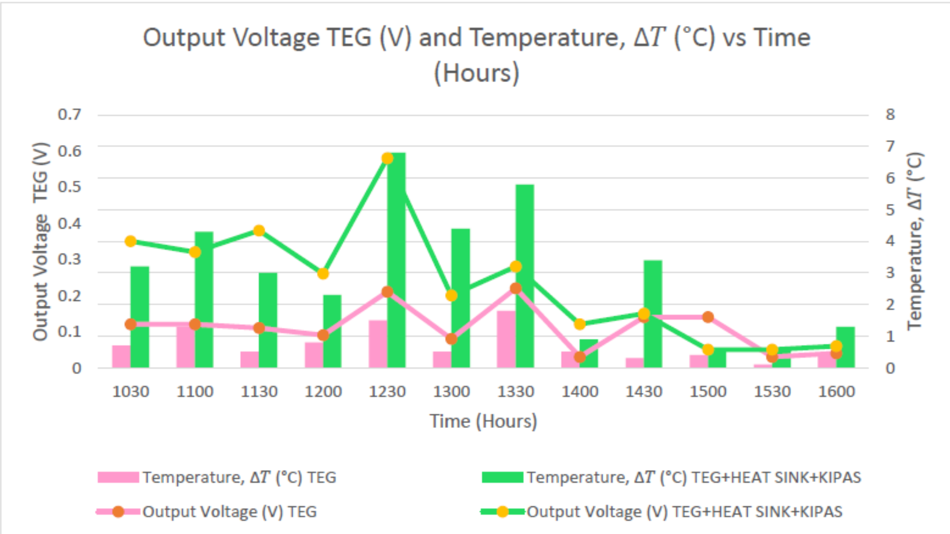

Fig. 7 *Graph comparison between the temperature gradient and TEG output voltage for hybrid PV-TEG and hybrid PV-TEG with heat sink and fan.*

Figure 4 shows the temperature, output voltage and current vurses time of PV standalone with time interval 30 minutes. The temperature is higher at 1330, and the voltage drops at this hour. The variation in PV standalone panel output voltage and current, with greater values in the morning and lower values in the evening, can be related to the basic actions taken of photovoltaic cells in response to changing sunlight intensity. As the sun rises in the morning, the intensity of the sunlight progressively increases, peaking about midday. The PV panels receive more sunlight energy during this time, resulting in higher voltage and current output. As the day changes into the afternoon and evening, the intensity of the sunlight decreases, resulting in a decrease in the PV panel's output voltage and current. This pattern corresponds to PV panels' typical response to switching sunlight levels throughout the day, pointing out their sensitivity to changes in incident solar radiation.

Figure 5 shows graph analysis of the output and temperature versus time of hybrid PV-TEG with the time interval of 30 minutes. At 1330 hours, the temperature gradients produce a 15 A output current for the hybrid PV-TEG. According to the data, the temperature gradient across the thermoelectric generator (TEG) impacts hybrid PV-TEG system's output voltage and current. The voltage produced increases due to the temperature difference between the hot and cold sides of the TEG, according to the Seebeck effect, a fundamental thermoelectric phenomenon. The thermoelectric generator gets more efficient as the temperature gradient increases, indicating a greater temperature differential between the

PV and TEG components. The output voltage and current increase as more electrical energy generated by the temperature difference between the hot and cold zones. As a result, the finding is consistent with the expected behaviour of a thermoelectric system, in which a higher temperature gradient leads to higher electrical output in a hybrid PV-TEG system.

Figure 6 shows the graph analysis of the output and temperature versus hybrid PV-TEG with heat sink and fan with a time interval of 30 minutes. The more significant temperature gradient recorded at 1230. The temperature gradient across the thermoelectric generator (TEG) influences the output voltage and current in a hybrid PV-TEG system with a heat sink and fan for active cooling. The Peltier effect, a fundamental principle of thermoelectricity, states that the voltage produced is directly proportional to the temperature difference between the hot and cold sides of the TEG. When a cooling system, such as a heat sink and fan, is used, the temperature differential between the PV and TEG components is efficiently maintained. This improved temperature gradient positively affects the thermoelectric conversion process, resulting in increased efficiency. As a result, output voltage and current increase as the cooling system optimizes the conditions for thermoelectric generation by successfully regulating the temperature difference. As a result, your data indicates that the active cooling system contributes to higher electrical output in the hybrid PV-TEG setup.

Figure 7 the output voltage difference under high-temperature gradients in the experimental investigation of two hybrid solar thermoelectric configurations - the Hybrid PV-TEG and the Hybrid PV-TEG with a heat sink and fan - provide important details into the system's performance. The Hybrid PV-TEG first proved the proof of concept for the thermoelectric generator (TEG) operating at high temperature gradients, where the TEG effectively converts the temperature differential into electrical power. As a result of the excellent thermal management systems at work, the observed greater temperature gradient in the Hybrid PV-TEG with a heat sink and fan can be contributed.

4. Conclusion

In the end, an experimental and comparative performance evaluation of a hybrid PV-TEG system for energy harvesting has been completed, which aligns with the project's primary goal. The combination of photovoltaic and thermoelectric devices provides a flexible option for harvesting energy from both sunshine and temperature differences. This novel hybrid system takes use of the complementing nature of these two energy sources, producing a more robust and efficient source of electricity than isolated solar panels.

The investigation of the effect of temperature gradients on the energy output efficiency of the Hybrid PV-TEG revealed useful results. The experiments indicated a direct relationship between temperature differentials and the electrical output of the system. The detailed examination of these temperature-dependent effects improves our understanding of the behaviour of the Hybrid PV-TEG under diverse environmental circumstances, hence helping to the improvement of thermoelectric energy harvesting systems.

Furthermore, the comparison between the energy harvesting efficiency of individual solar panels and that of the Hybrid PV-TEG establishes the superior performance of the hybrid configuration. The project's final objective aimed at quantifying the advantages of the integrated system over conventional photovoltaic setups. The results highlight the potential for enhanced energy harvesting capabilities when leveraging the synergistic effects of both photovoltaic and thermoelectric technologies. This outcome not only validates the viability of the Hybrid PV-TEG concept but also underscores its potential as a promising solution for sustainable and efficient energy generation in diverse environmental contexts.

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