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Efficiency Improvement of PV Panel using Series-Parallel Combination of Thermoelectric Generator

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Abstract

The concept of combined heat and power (CHP) is a rapidly developing technology due to various material innovations in the field of Thermoelectric Generators (TEGs). The efficiency of a solar panel degrades with the increase in temperature. In this study the efficiency of solar PV panel is increased by using Peltier TEC1-12706 model TEG. Thermoelectric generator (TEG) converts temperature difference into electrical energy and also by applying voltage it can create temperature difference which is known as Peltier effect. Top surface of the Peltier module is attached with the panel and bottom surface with the heat sink to validate the statement mentioned above. To conduct this study 10W power rating panel is used. Three arrangements have been considered in this thesis to make a comparative study: First, alone solar panel; Second, combination of Photovoltaic – Thermoelectric Generator without power supply and Third, combinations of Photovoltaic – Thermoelectric Generator with power supply. The output of these arrangements is calculated by measuring variables including – ambient temperature, solar irradiance, solar panel surface temperature, voltage, current, solar panel output power, and efficiency. The data is collected at a height of approximately 12 meters in an outdoor rooftop, The measurements are collected between approximately 8 am to 3 pm local time. The research results reveal that the monocrystalline PV panel efficiencies are – 13.47% for alone PV Panel, 13.83% for PV-TEG without power supply, and 14.30% for PV-TEG with power supply. Also, the power outputs are – 10.81W. 11.22W, and 11.53W for alone PV panel, PV-TEG without power supply and PV-TEG with power supply respectively. The combined PV-TEG efficiency is found 23.52%. The proposed configuration results in increased in production of overall efficiency with an average of 10%.

Keywords: Photovoltaic (PV), Thermoelectric Generator (TEG), PV-TEG, Overall Efficiency.

1. Introduction

Solar energy is among the most advantageous kinds of renewable energy that humans may use for a variety of uses. Solar energy is known as green and clean renewable energy source. No greenhouse gas emissions are released into the environment when solar panels are producing electricity. According to the International Energy Agency, solar energy will be the most common source of power worldwide by 2050. This is due to how swiftly the solar energy sector has expanded [1]. The PV module is one of the several forms of solar technology that were developed as a result. While a PV module may convert 4–17% of the sun's irradiated energy into electrical energy, 50% of it is converted to heat. The temperature of the PV modules is also raised by the strong light, which lowers their efficiency [2]. For 1K (kelvin) increase of PV module causes 0.65% output power loss and 0.08% conversion efficiency loss [3].

PV systems may be cooled using a variety of technologies, including liquid-based, air-based, heat pipe-based, PCM-based (phase change materials), Nano Fluid-based, Thermo-Electric Generator based technologies. However, the cooling method depends on a number of things [4] such as the kind of photovoltaic technology employed, the kinds of photovoltaic shapes, and the environment (location) where the system is located. The cooling methods used in cooling systems can be categorized as follows: (1) Passive cooling system, (2) Active cooling system.

Active cooling systems need external or self-generated electricity to run components like fans and pumps that remove heat from the surface of the cells. In addition to the employment of active components (such as fans and pumps), active cooling has been proven to be more efficient than passive cooling at removing heat from solar panels, leading to better electrical efficiency of PV cells. On the other side, passive cooling, sometimes referred to as a hybrid PV/T system, cools the PV panels while also producing thermal energy. Additionally, it should be highlighted that CPV/T systems have substantially better energy generation efficiency than a typical PV/T system.

Out of all cooling systems, the PV coupled with Thermoelectric Generator (TEG) has recently received increasing attention [5]. Recent advancements in TEG materials have been made possible by co-generating low-

grade thermal energy sources with a PV system [6]. The efficiency of the PV system is increased by removing heat and the correct placement and quantity of TEGs will enable the TEG modules to generate their maximum energy [7]. Thermoelectric Generator (TEG) plays a vital role in this paper to enhance the overall efficiency of PV-TEG system.

Numerous deterioration processes have an impact on PV panels – Cell cracks, moisture induced degradation, potential induced degradation. Irradiance, temperature, and humidity are a few examples of the external environmental factors that have an impact on these degradation processes [8].

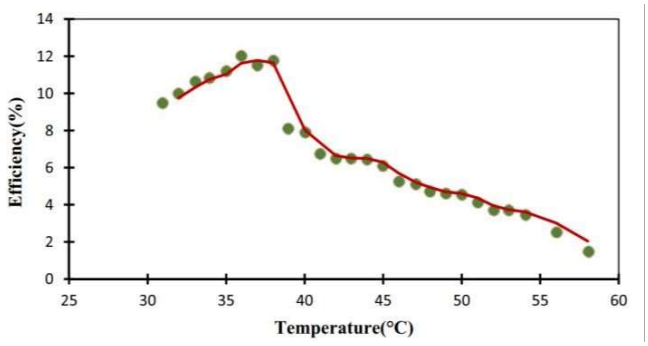


Fig 1.1: Temperature effect on PV Solar Cell [8]

The high temperature is the main obstacle for manufacturers of PV cells, as it reduces the efficiency of PV panel also shown in Fig. 1.1. It is the common element that influences the different forms of deterioration [9]. The spectrum response of the solar cell is discovered to rely on temperature as the cell temperature rises, and it changes the solar cell's spectral response [10]. Studies have shown that photovoltaic cell efficiency declines as the temperature of the sun plate rises. Because of this, adding a cooling system is necessary to reduce the temperature of a photovoltaic (PV) cell. The performance of solar photovoltaic modules has reportedly been greater in cold climates than in hot climates. According to reports, crystalline cells have a loss in output efficiency of 0.4%–0.5% for every 25 °C rise in temperature whereas amorphous cells experience a drop of 0.25–0.25% [11]. The precise statistical society given in Figure 1.2 is a good indicator of the relevance of the topic among researchers and dependent on industry to solar photovoltaic technology after examining and reviewing all published papers in the field of cooling of PV cells since 1995.

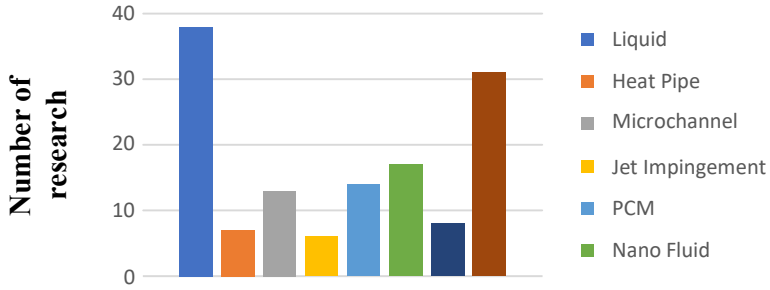


Fig 1.2: Cooling Methods Statistics

The concentrated type PV-TEG combination is frequently utilized to get the most energy possible from both PV and TEG systems [12, 13]. However, concentrated systems raise the bar for installation and upkeep in terms of complexity. As a commercial product for household customers, research on flat plate PV systems using TEG is now in the development stage. PV-thermal systems may be constructed in a variety of hybrid designs, such as hybrid PV with phase change materials (PCM) [14], PV-Thermal systems based on nano-fluids [15], and PV-TEG (thermoelectric generator) [16]. The PV coupled with TEG system has received the more attention recently compared to all those systems [6].

In this paper, the efficiency improvement of PV panel by attaching thermo electric generation (TEG) is investigated. Here the peltier effect of the TEG is utilized to increase the PV panel efficiency. Three different combinations of PV cell and TEG are considered in this investigation. First, conventional PV panel, secondly PV and TEG with passive cooling and thirdly PV and TEG with active cooling are considered, and the measured data are compared.

2. Performance Analysis of Proposed PV-TEG model

Two identical solar panels of 10W were used primarily for the experiment, one coupled with peltier modules to form a PV-TEG system, the other for obtaining standard testing result. We also used a 5W and a 10W solar panel for collecting further reference data for temperature and output. TEC1- 12706 model thermoelectric module is used which is mostly available. Heat sink is used to dissipate hot side temperature of thermoelectric module and provide temperature difference naturally.

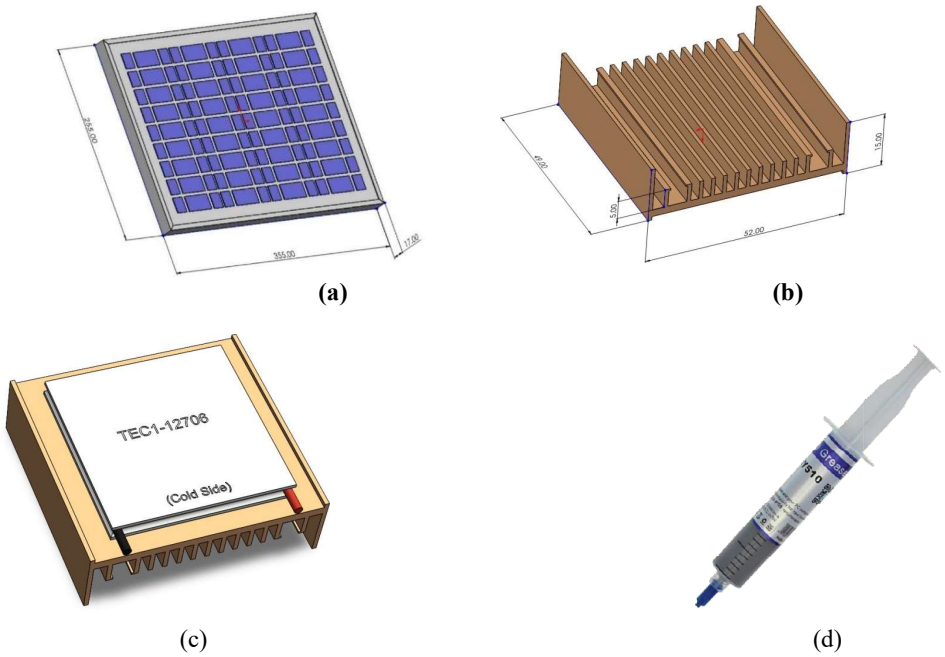


Fig 2.1: (a) 10W Solar Panel, (b) Heat Sink, (c) TEG-Heat Sink Assembly, (d) Thermal Paste

Top side of heat sink was attached with the thermoelectric module with thermally conductive paste. Bottom side was exposed to ambient air for heat dissipation. Heat sink helps maintaining the temperature difference between top and bottom side of TEG module and thus takes part in power generation. In order to ensure proper heat conduction between bottom surface of PV panel to the thermoelectric module, and thermoelectric module to the heatsink, thermal paste (HY510) was used in between the two attaching surfaces. These grease materials are commonly used for heat conduction between CPU and cooling fans.

Series-Parallel Connection of PV-TEG

17 peltier modules with 17 heat sinks were attached to the back of the primary 10W PV panel. Glue and thermal paste were used in between surfaces to attach them together. The TEG modules were connected with series and series-parallel connections.

Mode 1: Solar Panel Only

The second primary solar panel was used without any peltier module or external components to measure the standalone panel output and efficiency.

Mode 2: PV-TEG with Waste Heat Recovery

The first primary solar panel attached with TEG modules and heat sinks are used without any external power source to measure panel output and TEG output as shown in Fig. 2.2. Heat sinks exposed to ambient air provided passive cooling and helped dissipate back surface temperature, while the TEG module generated small amount of electric voltage due to the difference in temperature on its top and bottom surface.

Mode 3: PV-TEG with External Power for Active Cooling

Here, the PV-TEG system was supplied with external power source through the 12V 30A power supply as shown in Fig. 2.3. External power provided additional cooling for peltier module, which helped cool the PV panel further to increase efficiency. In this setup, TEG modules are connected such that each module gets 12V

and 5A supply. Series connection or parallel connection wasn't used because one provides too low voltage to run the TEG modules, the other provides too high current of 30A that can damage the TEG modules. With this configuration, we got both voltage and current at the best operating ranges.

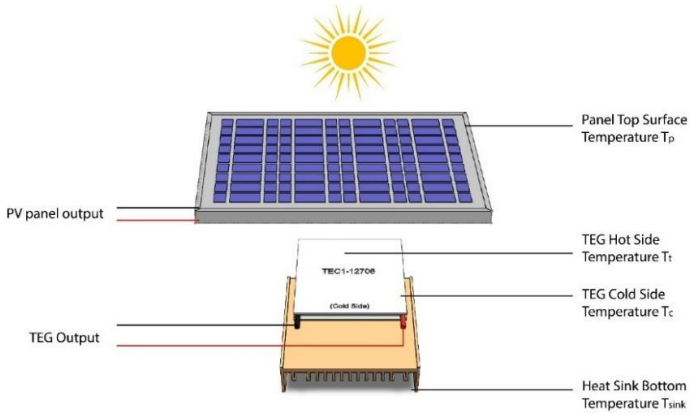


Fig 2.2: PV-TEG Setup (Mode 2)

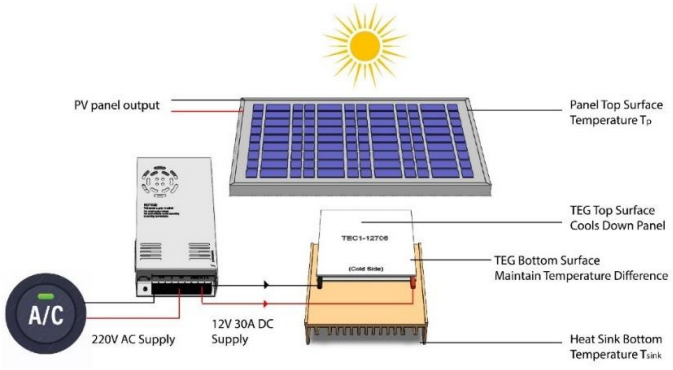


Fig 2.3: PV-TEG Setup (Mode 3)

3. Results and Discussions

Power Output vs Irradiance Curve

The increase in power output when TEG is coupled with the PV panels is shown in Figure 3.1. Here, power output is taken from PV-TEG system in Mode 2 and PV only in Mode 1. In maximum cases, the PV panel power output is slightly larger in PV-TEG system, than alone PV panel.

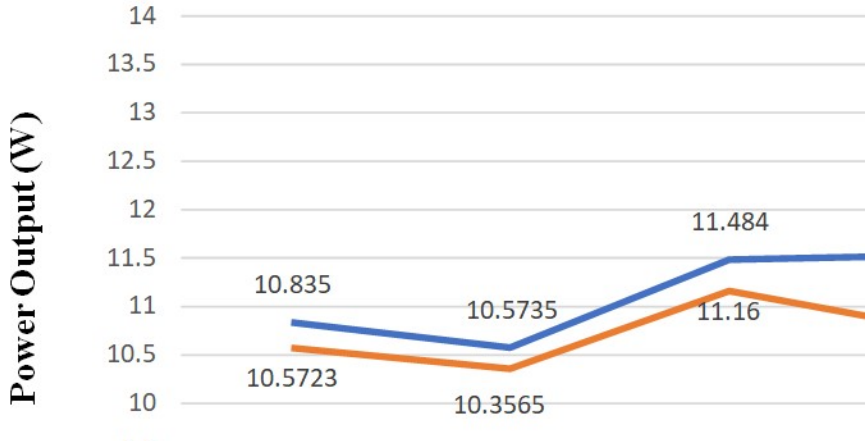


Fig 3.1: Comparison of Power Output of PV-TEG to PV Only

TEG power output is excluded here, only PV panel output is taken. This means that Mode 2 has higher power output than Mode 1, having 11.0909W average power and 10.81096W average power without any external source needed. This effect increases with the increased size of solar panels and number of TEG-heatsink modules.

Efficiency vs Irradiance Curve

Here, efficiency of PV-TEG system in Mode 2 and PV only in Mode 1 is experimented in Figure 3.2. It is seen that for the same irradiation, efficiency rises for PV-TEG system due to better heat dissipation by the heat sink, with respect to only bottom surface of PV panel exposed. Average efficiency for solar panel in PV-TEG system is 13.825%, while standalone solar panel efficiency is 13.4774% which is lower.

Efficiency curve of PV-TEG with PSU, PV-TEG without PSU and alone solar panel

The efficiency of PV panel is determined for all 3 modes of arrangement is shown in Figure 3.3. We can see that in Mode 1, PV efficiency without power supply or TEG is overall the lowest for 4 out of 5 cases. In Mode 2, PV-TEG without power supply has efficiency in the mid-range. And for Mode 3, when cooling is done using external power on TEG modules, efficiency is highest overall. Average efficiency for solar panel in PV-TEG with external power for cooling (Mode 3) is 14.3%, which is better than the 13.825% in Mode 2 and 13.4774% in Mode 1.

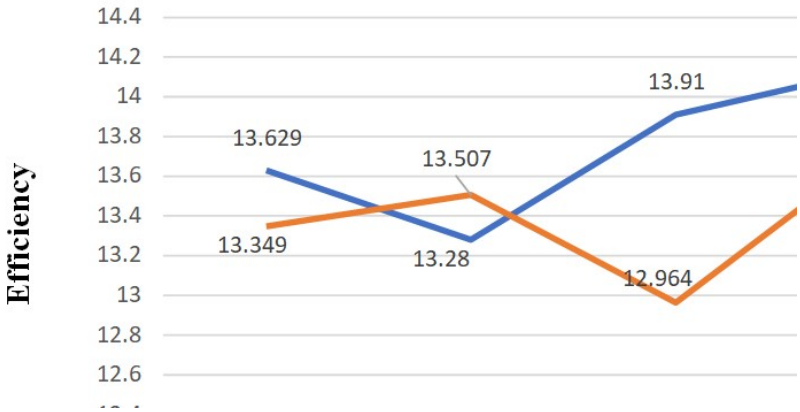


Fig 3.2: Efficiency of PV-TEG system to PV Only

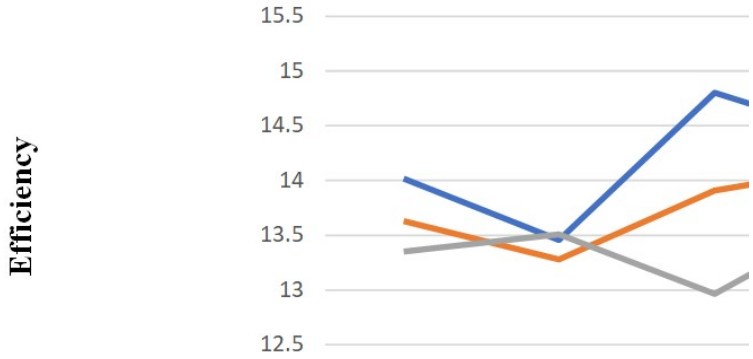


Fig 3.3: PV Panel Efficiency with and without External TEG Power

4. Conclusions

In this thesis, several parameters regarding solar PV panel performance and thermoelectric generator performance were examined individually and combine in order to find out the feasibility of PV-TEG systems. Mathematical modeling of these systems had been examined. Multiple PV panel data were taken throughout a long period of time to get a good overall insight into what parameters affect the performance of such systems. By designing and constructing a model with the developed 3 different modes of experiment, the respective results are compared and understand the best configuration that improves PV panel efficiency. The active

cooling is done with 12V 30A input to the peltier devices in series-parallel connection; efficiency throughout the period was observed and measured with a maximum value of 14.873% just after 2 minutes of cooling. It is noticed that the without active cooling, PV panel efficiency slightly decreased 14.16% but was still higher than the standalone PV panel due to better heat dissipation to ambient through the heat sink. The combined efficiency increased drastically for the case of both PV and peltier effects applied together. Throughout the time period, it is noticed 6 to 14% efficiency increased. In fact, the PV panel power output was increased with increase in irradiation, whereas thermoelectric module power output was increased with the increase in temperature difference between top surface and bottom surface.

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