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Heat Energy Utilisation on Solar Panels Through Electric Thermal Generators

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Abstract- Solar energy is clean and renewable, making it a viable option for those seeking to reduce their carbon footprint. These electrons are then converted into electricity, which can be used to power homes, offices, and factories. In this study, heat generated by solar panels will generate electricity by using 10 thermoelectric generators (TEG) type SP1848 27145 arranged in parallel series and attached at the bottom of the panels. A study carried out by the Sun Energy Foundation found that the average power generated by solar panels without TEG is 9.4 W, with an average efficiency of 12.12%, while solar panels with TEG produce 9.22 W, with a potential efficiency of 11.98%. An average TEG produces 23.41 mW of power with a 0.00878% efficiency. As a result of the relatively small temperature difference between the hot and cold sides of the TEG, the efficiency produced is very small. The temperature difference between the hot and cold sides of the TEG averages 4.35°c. A heatsink is the only heat dissipator on the cold side of the TEG, and airflow is the only natural coolant, resulting in insufficient heat dissipation by the heatsink. The temperature that occurs on the hot side of the TEG depends solely on solar radiation for the heat to be generated, so the temperature on the hot side of the TEG is not too high. The solar energy is a clean and renewable source of power, which is essential for reducing our carbon footprint. This study investigated the use of thermoelectric generators (TEG) to harness additional electricity from solar panels. While the TEG system showed promise, it had relatively low efficiency due to the limited temperature difference between the hot and cold sides of the TEG. The study highlighted the importance of efficient heat dissipation and the need for further research to optimize TEG performance in solar energy applications.

Keywords: Temperature, Thermoelectric Generator, Solar Panel, Solar Radiation, Efficiency, Power

1. Introduction

As the population continues to grow, the need for electricity also increases. New technologies that require electricity, such as computers, cell phones, and other electronic devices, are becoming more common, and this increases the electricity demand. Additionally, the development of renewable energy sources, such as solar and wind power, requires a large amount of electricity to power the technology needed to generate the energy [1]. It is also an environmentally friendly energy source because it does not emit any harmful gases or pollutants into the atmosphere, making it a much more sustainable energy source than traditional fossil fuels [2]. Additionally, solar energy is relatively inexpensive to produce, making it a viable option for many households and businesses. Solar energy is also a renewable resource and does not produce any harmful emissions, making it an environmentally friendly energy source [3]. Additionally, it is becoming more cost-effective due to advancements in technology, making it easier and cheaper to install and maintain solar panels. Thermoelectric generators can use the heat generated by solar panels to produce electricity, which can then be used to power various devices. To replicate the conditions of a real-world environment, the research team used a combination of real-world solar radiation and electricity generated by the solar panels to create a realistic environment for testing the TEG technology [4]. The results of the experiment showed that the TEG technology was able to effectively convert the excess heat generated by the solar panels into usable energy. The average efficiency of 0.095% is achieved by arranging S P1848 27145SA TEGs in series [5]. This indicates that the TEG technology is a viable way of converting the waste heat from solar panels into useful energy. The results show that the TEGs arranged in series were able to produce a significant amount of power with an impressive efficiency rate [6]. The use of a critic learning method for obtaining optimal admittance parameters, based on interaction force and trajectory tracking without prior knowledge of environmental dynamics, is a key innovation. Additionally, our neural-network-based adaptive controller with dynamic learning capabilities effectively addresses dynamic uncertainties, guaranteeing reliable trajectory tracking performance [7]. The authors introduce the MBOA-MPPT, a novel optimization-based MPPT control technique for grid-connected PV systems. This research aims to improve both MPPT and power flow control for solar PV systems, addressing the energy demands of grid-PV setups. To enhance PV system performance, the paper employs an interleaved Luo DC-DC converter, which effectively reduces switching losses and frequencies, leading to improved power quality. The MBOA-MPPT technique offers several key advantages, including faster convergence, reduced time consumption, decreased total harmonic distortion (THD), and high power tracking efficiency. Extensive simulation analysis validates the effectiveness of the technique by examining IV and PV characteristics, voltage gain, duty cycle, and more [8]. A predictive current control approach for a multifunction grid-connected PV generator, incorporating an integrated active power filter system, is presented. The system effectively compensates reactive power, mitigates harmonic currents generated by nonlinear loads, and injects surplus active power into the grid. The control strategy utilizes a discrete-time model for the active power filter, enabling real-time prediction of filter currents. To maximize the power output from the PV array and regulate the DC-DC boost converter's duty cycle, a Perturb and Observe (P&O) based MPPT algorithm is employed. The system uses the Modified Virtual Flux (MVF) based P-Q theory to accurately extract reference filter currents, even in distorted distribution systems. These reference currents are then used by the proposed predictive current control to generate switching signals for the grid-connected Voltage Source Inverter (SVI). Extensive simulation results demonstrate the superior performance of the system under dynamic and steady-state conditions. The proposed algorithms consistently maintain the Total Harmonic Distortion (THD) of grid currents below 5% and effectively restore the sinusoidal waveform of the grid currents. This research showcases the robustness and effectiveness of the proposed approach in enhancing the performance of multifunction grid-connected PV systems with integrated active power filtering, particularly in the presence of nonlinear loads and solar irradiance fluctuations [9]. This study assesses the efficiency of solar panel absorption of direct solar radiation and suggests a novel approach. It aims to convert the heat generated within solar panels into electrical energy using ten SP 1848 27145SA thermoelectric generators in a series-parallel setup. The study anticipates higher power generation than prior research. It relies on the temperature differential caused by solar radiation to enhance thermoelectric electricity production. Furthermore, the research explores the potential use of thermoelectric generators as an alternative power source when solar panels alone prove insufficient. This work has implications for improving solar energy utilization and offers a more sustainable energy solution.

2. Basic Theory

2.1 Heat Transfer

Heat transfer occurs through three main methods: conduction, convection, and radiation. Conduction is the transfer of heat between two objects that are in direct contact with each other, while convection is the transfer of heat due to the circulation of fluids, such as air or water. Radiation is the transfer of heat through electromagnetic waves. In conduction, heat is transferred through direct contact between two objects. In convection, heat is transferred through the movement of fluids such as air or water. In radiation, heat is transferred by electromagnetic waves.

2.2 Conduction

This type of heat transfer occurs when two objects of different temperatures come into contact with each other. Heat will transfer from the hotter object to the colder object until they both reach the same temperature. This is why a cold drink warms up in your hand when you hold it. Steady-state conduction occurs when the temperature of the object remains constant, while unsteady-state conduction occurs when the temperature of the object changes over time. Heat transfer through conduction can be further classified as either direct or indirect. Direct conduction occurs when the heat transfer is between two objects that are in direct contact with each other, while indirect conduction involves a medium such as air or water to transfer heat between the two objects. In steady conduction, the temperature gradient remains constant throughout the material, so the amount of heat transferred through the material is constant. In unsteady state conduction, the temperature gradient changes over time, resulting in a varying amount of heat being transferred through the material.

2.3 Convection

The transfer of heat between a solid surface and a fluid around it using a conducting medium (liquid/gas). This type of heat transfer is known as convection, and it occurs when the fluid is heated due to contact with a solid surface. The heat is then transferred through the medium of the fluid, either through convection currents or radiation. A convection heat transfer process can be divided into two categories based on the flow state, namely free convection and forced convection. When it comes to forced convection, various outside factors are used, such as a fan, a pump, or a breeze.

2.4 Radiation

Radiation heat transfer is the fastest way to transfer heat because the energy is transferred at the speed of light. This makes it especially useful in applications where time is a factor, such as space exploration and cooking heat will still move through electromagnetic wave emission despite a vacuum separating the two objects. Radiation heat transfer is evident in the sun's heat reaching the Earth.

2.5 Solar Panel

Solar panels are made up of photovoltaic cells which contain a semiconductor material like silicon [7]. When light hits the cell, it creates an electric field which causes electrons to flow through the material, generating an electric current. This current is then used to generate electricity. A few of the factors that affect it include temperature, sunlight intensity, solar radiation, direction, and spectrum. Temperature and sunlight intensity, for example, can cause a decrease in the efficiency of the solar cells which in turn reduces the amount of power generated [8]. Additionally, the angle of the sun's rays relative to the panel and the spectrum of the light can also impact the amount of power produced. The maximum output efficiency (η) of a solar panel is defined as the percentage of optimum output power to the light energy used, which is written as:

$$\eta = \frac{P_{in}}{P_{out}} \text{ X } 100 \text{ ----- (1)}$$

Where:

η = Efficiency of solar panels

P_{out} = Power output from solar panels

P_{in} = Power input from solar panels

P in can be calculated by using the following equation to find the efficiency of solar panels

$$FF = \frac{I_{mpp}.V_{mpp}}{V_{OC} \cdot I_{SC}} \text{ ------ (2)}$$

$$P_{out} = V_{OC} \cdot I_{SC} \cdot FF \text{ ----- (3)}$$

Where :

FF = Factor of fill

$Vmpp$ = Power at its maximum

$Impp$ = Current maximum

Voc = Voltage across an open circuit

Isc = Current in a short circuit

$Pout$ = Power output of solar panels

Equation (2) to obtain FF requires Vmpp, Impp, Voc, and Isc which are obtained from the solar panel data sheet used. Whereas in equation (3) Voc, and Isc are obtained from the results output of the solar panels used [11]. To find the efficiency of solar panels, Pin is needed which is obtained by using the equation as follows [11]:

$$P_{in} = G.A \text{ ------ (4)}$$

Where :

Pin = Power input from solar panels

G = Radiation from the sun

A = Surface area of solar panels

2.6 Thermoelectric Generator

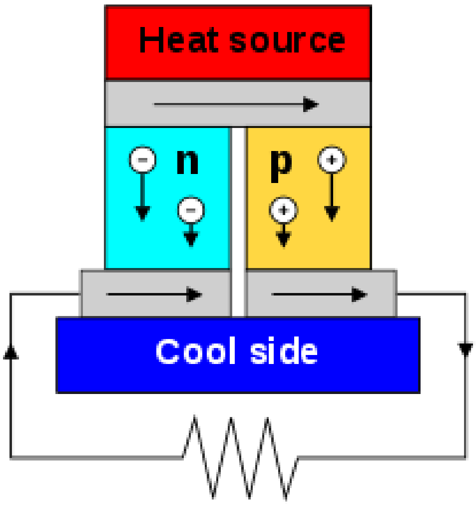

Fig 1. Workings of thermoelectric generators

A thermoelectric generator is a device that can convert directly from a temperature difference into an electric voltage. Conversely, when given an electric voltage will produce a temperature difference [12]. Thermoelectric are made of semiconductor materials that are arranged in such a way with n-type components (electron-plus materials) and p-type (electron-deficient materials). Thermoelectric can convert heat into electricity based on the Seebeck effect. Figure 1 is the working principle of a thermoelectric generator which consists of one hot side (Th) and one cold side (Tc). On the hot side of the thermoelectric with a higher temperature, it will move electrons on the rod with type -n semiconductor material (material that is excess electrons) to the cold side with a lower temperature and enter the rod with type -p material (material that lacks electrons) through the metal connection [13]. So that an electric current will arise from the movement of these electrons [14].

$$\alpha = \frac{V}{\Delta T} \text{ ------ (5)}$$

Where :

α = Seebeck coefficient

V = Voltage generated by TEG

ΔT = Cold side and hot side TEG temperature differences

TEG can generate a maximum voltage of Kelvin [15]

$$Z = \frac{a^2\theta}{R} \text{ --------- (6)}$$

Where :

Z = Merit Figure
α = Coefficient of Seebeck
θ = Temperature resistance
R = Resistance to electricity

Equation (6) shows how the Seebeck coefficient, the heat resistance, and the electrical resistance affect thermoelectric performance. The following equation can be used to calculate obstacle heat and electrical resistance [16]:

$$\mathrm{R} = \frac{V}{I}\frac{(T_h-\Delta T)}{T_h} \text{ --------- (7)}$$

$$\theta = \frac{\Delta T}{I.V}\frac{2T_h}{(T_h-\Delta T)} \text{ --------- (8)}$$

Where:
R = Resistance to electricity
θ = Resistance to heat
I = Current generated TEG
V = Voltage generated TEG
Th = On the hot side of the temperature TEG
ΔT = TEG temperature difference between cold and hot sides

$$\eta_{max} = \frac{\Delta T}{T_h}\frac{\sqrt{1+\frac{Z}{2}(T_h+T_c)-1}}{\sqrt{1+\frac{Z}{2}(T_h+T_c)-\frac{T_c}{T_h}}} \text{ ------ (9)}$$

Where :
ηmax = TEG's maximum efficiency
ΔT = TEG temperature difference between cold and hot sides
z = Figure of Merit
Tc = TEG temperature on the cold side
Th = An equation for calculating the efficiency of a TEG is the temperature on the hot side (K)
ηmax (%)

2.7 System Design

This study aims to design and construct a system that consists of several components, namely the solar panels that will act as the voltage generators in the system. In this system, the SP1848 thermoelectric generator is used to produce electrical energy from the temperature difference between the inside and outside of the system [17].

Fig 2. The solar panel model

A solar panel with and without TEGs is placed side by side with a 60 cm high solar panel holder at a 15o tilt in Figure 2. 10 TEG SP1848 27145 SA are attached to the bottom of the solar panel with the position of the hot part of the TEG attached to the solar panel using thermal paste, it is intended that the hot side of the TEG can receive heat on the solar panel as a result of solar radiation [18]. After that, a heatsink is attached to the cold side of the TEG which functions to dissipate heat so that the cold side of the TEG can be maintained. The solar panel on the left is a solar panel system with TEG while on the right is a solar panel without TEG which is used as a comparison measurement scheme. In this study, the system to be made consists of several components, namely, solar panels as voltage generators. SP1848 thermoelectric generator in this system is used to produce electrical energy from the temperature difference that occurs. Measurements are made in the following way

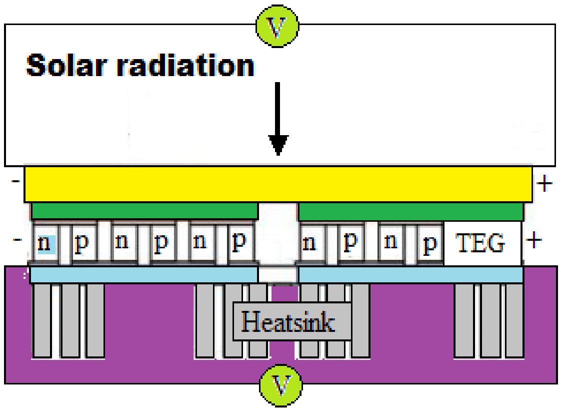

Fig 3. Current measurement diagram for solar panels and TEGs

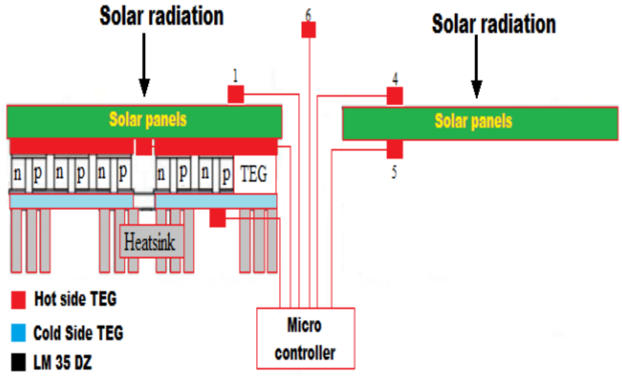

Fig 4. TEG and solar panel temperature measurements

A short circuit is used in Figure 3 to measure current to get maximum power. A microcontroller is used in Figure 4 to measure temperature using the LM 35DZ sensor. In Figure 4 sensors 1, 2, 3, 4, 5, and 6 are respectively used to measure the temperature at the top of the solar panel with TEG, the bottom of the solar panel with TEG (hot side of TEG), the cold side of TEG, the top of the solar panel without TEG, the bottom of the solar panel without TEG, and the ambient temperature [19]. Measurements of solar radiation were made using a Solar Power Meter TM-206 directed directly at the sun. The specification of all research tools is shown in Table 1.

3. Results and Discussion

3.1 Overall System Testing

Four days of testing were conducted with test times ranging from 09.00 to 15.00. This ensured that the results would be as accurate as possible, as the test time was able to cover the time of day when the majority of people would be using the product. Additionally, a four-day timeframe would provide a large enough sample size to draw meaningful conclusions from the results [20]. A multimeter was used to measure voltage and current on solar panels with TEG, solar panels without TEG, and TEG itself. Power outputs were calculated based on voltage and current measurements and compared with theoretical power outputs. The results showed that the TEG was indeed efficient and managed to increase the energy output of the solar panel system by a significant amount [21]. The experiment was deemed a success and demonstrated the potential of utilizing TEG technology in the future. According to the results, the system with TEG produced more power than the other two. This increase in power output was due to the TEG's ability to capture waste thermal energy from the environment and convert it into electrical energy. This energy is then used to supplement the power output of the solar panel system, resulting in a higher overall energy output than the other two systems. A circuit configuration of five TEGs connected in series and five TEGs connected in parallel was used to assemble the 10 TEGs, which were then connected in series with five more TEGs. This allowed the TEGs to operate at a higher temperature range and produce more output power. This configuration also helped reduce the drop in voltage when the TEGs were used at a higher temperature. In solar panels and TEGs, temperature measurements are taken at the top of the panel with and without the TEG, at the cold side of the TEG, and in the surrounding environment using an LM35DZ sensor connected to a microcontroller [22]. This will allow for the comparison of the temperatures taken with and without the TEG, as well as the comparison of the temperatures to the surrounding environment. The data logger will store this data and allow for further analysis to be done on the temperature measurements. The purpose of temperature measurement is to observe changes in temperature in solar panels, TEG, and the surrounding environment. This analysis will help to determine the effectiveness of the TEG in capturing the energy of the sun, as well as the amount of energy lost due to conduction and convection to the surrounding environment. The data logger will enable researchers to track these temperature changes over time and better understand the solar energy capture process. A 60 cm high and 15° tilted stand supports the solar panels with and without TEG. By placing the TEG and non-TEG solar panels at different heights and angles, researchers can compare the amount of energy captured by each panel and observe any temperature changes over time. This is especially important when studying the efficiency of solar energy capture and the potential of TEG to improve the process. A Solar Power Meter TM-206 was used to measure solar radiation. The different heights and angles of the TEG and non-TEG solar panels allow for the observation of the amount of energy captured by each panel, as well as any temperature changes that may occur due to the TEG's potential to improve the solar energy capture process. The Solar Power Meter TM-206 was used to measure the amount of solar radiation hitting the panels, which helps researchers to determine the efficiency of the solar energy capture [23]. Once the measurement has been done, the efficiency of the solar panel will be calculated using equation (1) and the efficiency of the TEG will be calculated using equation (9). Full circuit analysis is carried out in order to calculate TEG efficiency.

Table 1. The specification of all research tools

S.No	Instruments	Model	Qty
1.	Multimeter	Fluke 87	1
2.	Solar PowerMeters	TM - 206	1
3.	Temperature sensor	LM35 DZ	1
4.	Data logger	SD Card	1
5.	10 Wp Solar Panel	Polycrystal, DECADEPD - 10	2
6.	Thermoelectric	SP1848 27145 SA	10

3.2 Test Results

The tests showed that the power generated by the combination of solar panels and TEG was significantly higher than the power generated by either component alone. This suggests that the combination of solar panels and TEG can produce more energy than either component would generate on its own [24]. A value for TEG's average efficiency will then be obtained using equation (9). The average efficiency of solar panels with and without TEG is also calculated using equation (1). Figure 5-9 shows the testing of all the parameters.

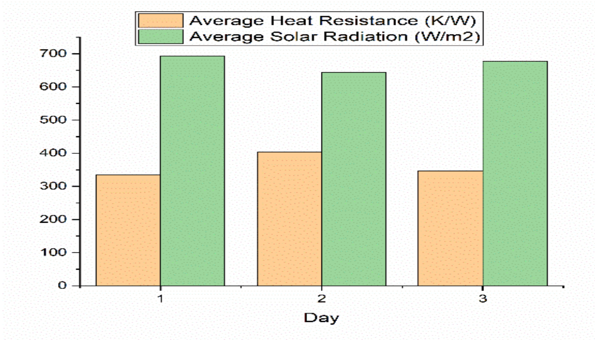

Fig 5. Average heat and solar radiation

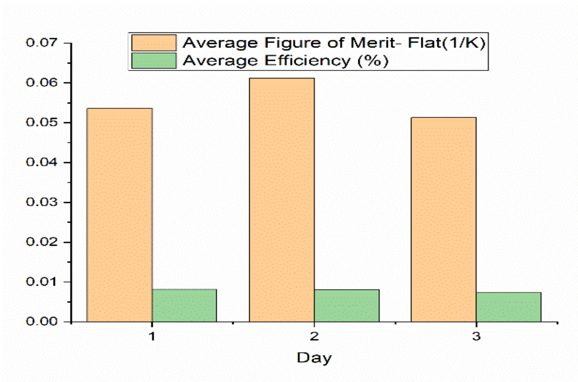

Fig 6. Average efficiency and merit flat

The thermoelectric generator utilizes the heat generated by solar radiation to produce 23.41 mW with an efficiency of 0.00877% by utilizing the heat on the solar panel. This is due to the thermoelectric effect, which is the conversion of temperature differences into electrical energy. The heat from the solar radiation causes a temperature differential between the two sides of the panel, which creates an electrical potential between them. This electrical potential is then used to generate power. There is a small temperature difference between the hot and cold sides of the TEG, namely an average of 4.35ºC. This happens because a heatsink on the cold side of the TEG acts as a heat dissipator, while airflow acts as a natural coolant. Therefore, the heatsink on the cold side of the TEG does not dissipate enough heat [18]. The heatsink does not have a large enough surface area to effectively dissipate the heat away from the TEG, and the airflow is not strong enough to cool the TEG quickly. As a result, the temperature difference between the hot and cold sides of the TEG remains small. Solar radiation causes the temperature on the hot side of the TEG to fluctuate, so the temperature on the hot side is solely dependent on solar radiation. Solar radiation is the main source of heat for the hot side of the TEG [15]. The amount of solar radiation that reaches the TEG changes depending on the weather, time of day, and location, so the temperature of the hot side of the TEG is constantly fluctuating. It is important to note that the efficiency of the thermoelectric generator depends on the temperature difference between the cold and hot sides of the TEG, as well as the temperature difference between the cold and hot sides of the TEG. Therefore, a larger temperature difference produces greater efficiency. The thermoelectric effect is based on a phenomenon called the Seebeck effect, which states that when a temperature difference is applied to two different metals, a voltage will be generated. This voltage can then be used to generate electricity [21]. The greater the temperature difference between the two sides, the higher the voltage generated, and thus the higher the efficiency of the thermoelectric generator.

The average power generated by solar panels with TEG and solar panels without TEG is not much different, 0.1 W, in the tests that have been conducted. However, the power generated by solar panels with TEG is much more stable, meaning that it remains constant even when the environment changes [22]. This makes it much more useful in applications where the environment is constantly changing, such as in mobile applications. Solar panels without TEG produced an average power of 9.318W with an average efficiency of 12.11%, while solar panels with TEG produced an average power of 9.218W with an average efficiency of 11.98%. This shows that, although there is a slight increase in power output from the solar panel without TEG, the increase is not significant enough to outweigh the additional cost of the TEG technology.

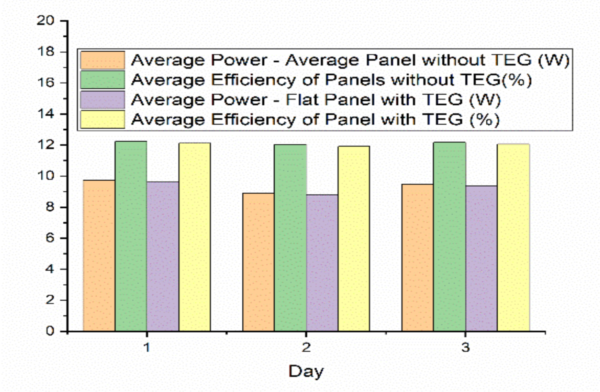

Fig 7. Average power and efficiency with TEG and without TEG

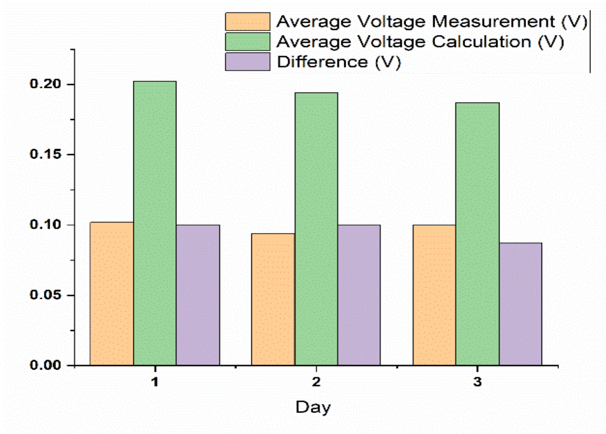

Fig 8. Average Voltage difference and calculation

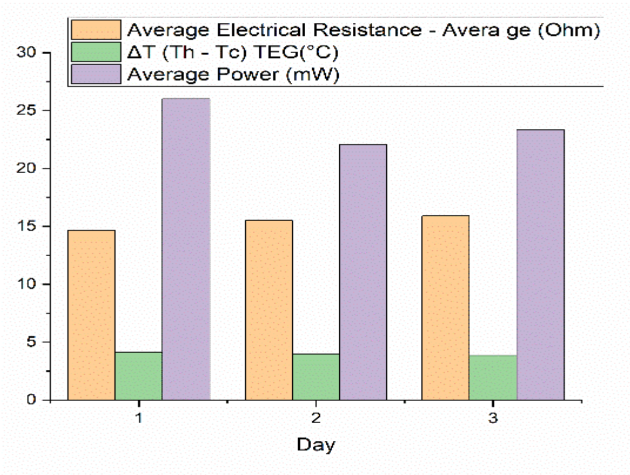

Fig 9. Average power and electrical resistance

The measured test results indicate that the power and efficiency differences between solar panels with and without TEG are not so great because the temperature difference between them is not great [8]. This is because the TEG can capture and convert some of the wasted energy from the sun's radiation into usable energy. This reduces the amount of lost thermal energy and increases the solar panel's efficiency. As a result, solar panels with TEG produce more power and are more efficient than solar panels without TEG.

However, the difference in power and efficiency produced is not very significant due to the small temperature difference between the two types of solar panels. The efficiency of a thermoelectric generator depends on the temperature on the hot and cold sides of the thermoelectric generator and the temperature difference between the hot and cold sides of the thermoelectric generator, that is, the greater the temperature difference, the higher the efficiency [13]. This is because the thermoelectric generator uses an electric current to move heat from a hot side to a cold side, and the greater the temperature difference between the two sides, the more heat energy can be transferred, which in turn increases the efficiency of the generator. The comparison shows that the calculated voltage is generally higher than the measured voltage, indicating that the equation used to calculate the voltage was accurate. A temperature difference of 20ºC and equation (5) generate a calculated voltage of 0.0486 with a Seebeck coefficient of 0.0486. This value can be used to calculate the voltage generated due to the thermal energy present in the circuit. The Seebeck coefficient is a measure of the thermopower or the voltage generated per unit temperature difference. The Seebeck coefficient value is used to calculate the voltage using equation (5), resulting in the equation: The measured voltage is much smaller because the heat of the TEG fluctuates, and the cold side of the TEG only uses a heatsink and airflow, so there is a small temperature difference between the hot and cold sides of the TEG, which is 4.34ºC on average. As the temperature difference decreases, the voltage generated also decreases.

4. Conclusion

A TEG-based system can convert the solar radiation heat generated by a solar panel into electrical energy, according to the results of the tests that have been conducted. Thermoelectric generators (TEG) function by using the Seebeck effect, which states that when a temperature difference is applied across two electrical conductors, a direct current (DC) will be generated. This DC can then be used to produce electricity. An average efficiency of 0.00876% and a power output of 23.40 mW are the averages for TEG. Solar panels without TEG have an average output power of 9.319 W with an average efficiency of 12.10%, while solar panels with TEG produce an average power of 0.00876% and 9.219 W with an average efficiency of 11.97%. The average power and efficiency of solar panels without TEG produced are greater than those of solar panels with TEG. Because TEG is present on solar panels, heat is retained in TEG, so solar panels with TEG have higher temperatures than solar panels without TEG. This results in a decrease in the power generated by solar panels with TEG and a decrease in their efficiency.

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