International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 12s,2025
https://theaspd.com/index.php

Experimental Investigation And Performance Analysis Of A Fixed Solar System Enhanced By Geothermal Cooling

D D Prasanna Rani[1], **Domala Suresh**[2], **Anil Kumar Bodukuri** [3]
[1,2]Department of Physics and Electronics, Chaitanya (Deemed to be University), Himayathnagar, Ranga Reddy (District), Hyderabad, Telangana, India 500075.
[3]Department of Mechanical Engineering, K U College of Engineering and Technology, Kakatiya University Warangal – 506009, Telangana, India.
***Corresponding Author Email ID:** suresh.domala@gmail.com

Abstract
Solar panels provide a renewable energy source, harnessing sunlight to generate electricity without depleting natural resources. This contrasts with fossil fuels, which are finite and contribute to environmental degradation. Solar panels allow countries and individuals to produce their own electricity, reducing reliance on imported fossil fuels, thus enhance energy security and can stabilize energy costs. Solar panels are essential in driving the global transition towards a more sustainable, resilient, and equitable energy system. Photovoltaic (PV) cells absorb about 80% of solar radiation but only convert 12 to 18% into electricity, with mono-crystalline cells achieving up to 24% efficiency. The remaining energy is lost, primarily as heat, increasing the temperature of PV cells significantly. Studies indicate that every 1°C rise above 25°C reduces module efficiency by approximately 0.45%. Consequently, effective cooling techniques are crucial to prevent overheating and improving PV module efficiency. Solar panels typically experience a decrease in efficiency as their temperature rises. The innovative aspect of this research lies in the application of geothermal energy as a cooling mechanism for the fixed panels. The objective is to analyze and achieve the maximum possible power output from this configuration. By leveraging geothermal cooling, the study aims to maintain the panels at an optimal temperature, thereby improving their efficiency and energy output. The current study investigates the effectiveness of integrating fixed solar panels with geothermal cooling to enhance system performance. Instead of employing a traditional tracking system, it utilizes fixed panels. Geothermal energy is used as a cooling mechanism to boost the efficiency of the solar panels. The study's findings could have significant implications for the design and deployment of solar energy systems, particularly in areas where traditional tracking systems are not feasible or where maximizing energy efficiency is critical.
Keywords: *Solar energy, renewable energy, geothermal energy, efficiency, power, active cooling and passive cooling.*

I. INTRODUCTION

The global demand for energy is rising daily due to factors like population growth, evolving lifestyles, and rapid industrialization. Solar energy, derived from sunlight's heat and light, exemplifies a renewable and abundant power source. Its wide availability and cost-free nature make it an essential alternative energy source. Solar energy's versatility is evident in its ability to be converted into both heat and electricity. Additionally, solar energy remains environmentally friendly, as no pollutants are emitted during the electricity generation process.

There are two ways that sunlight can reach earth, one is by direct beams, and the other is through dispersed sunlight. 90% of the energy is carried by the direct beam, with the remaining 10% being carried by the dispersed beam. The diffuse portion shows that the atmosphere is hazy. Due to cloud cover throughout the winter and wet season, it is extremely high. As the sun is shining directly on the solar panels as much as feasible, the direct beam will yield the highest collection. These days, the ratio can be 90:10, which has little bearing. However, the direct beam to diffuse light ratio on cloudy days will be 60:40, which will affect the generation of power on certain days, which will be significantly less than anticipated [1].

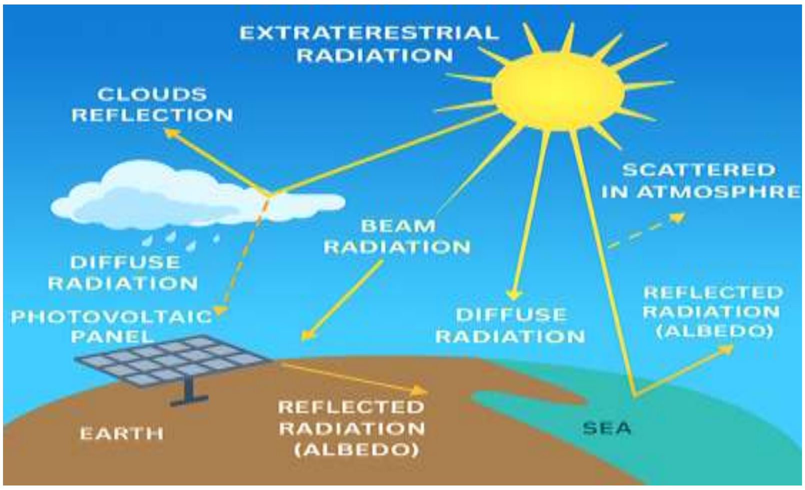

Figure 1: Representation of solar radiation components

The reliance on fossil fuels, known for their high pollution and associated dangers, is shifting towards renewable energy sources due to their cleaner and safer nature. Solar energy, following wind energy, has become a primary non-conventional energy source. Annually, Earth receives The Earth receives an estimated 1,500 quadrillion kilowatt-hours (kWh) of solar energy annually. This vast amount of solar energy dwarfs global energy consumption, which in 2024-25 is estimated at approximately 1,100 terawatt-hours (TWh), highlighting the immense potential of solar energy. Solar energy can be utilized for thermal applications and electricity generation through photovoltaic (PV) technology. The solar radiation components are shown in figure 1. The growing interest in PV technology is attributed to the declining costs of PV modules, with the global weighted average levelized cost of electricity (LCOE) for commercial-scale PV projects falling by 13% year-on-year to $0.048/kWh in 2021. Despite this, the efficiency of converting solar energy to electricity remains limited, necessitating advancements in PV technologies to enhance efficiency and mitigate energy loss. Photovoltaic cells absorb about 80% of solar radiation but only convert 12 to 18% into electricity, with monocrystalline cells achieving up to 24% efficiency. The remaining energy is lost, primarily as heat, increasing the temperature of PV cells significantly. Studies indicate that every 1°C rise above 25°C reduces module efficiency by approximately 0.45%. Consequently, effective cooling techniques are crucial to preventing overheating and improving PV module efficiency.

II. LITERATURE REVIEW

Active water cooling is more efficient than air cooling, often employing micro-channels for enhanced heat dissipation. Forced water circulation through channels or tubes in the back of PV panels effectively reduces panel temperatures. Rahimi et al., compared single-headed and multi-headed microchannels for water cooling. Multi-headed micro-channels demonstrated a greater reduction in temperature and increase in power output, with a 28% increase in power and a 6.8% decrease in temperature [2]. Barrau et al., combined fracture jet impacts with uneven micro-channels. The innovative design achieved a thermal resistance coefficient of 2.18 X 10^-5 (Km^2)/W, allowing higher output power than conventional microchannels [3]. Baloch et al., utilized a converging heat exchanger to reduce PV panel temperatures from 71.2°C to 48.3°C, resulting in a power output increase from 35.5% to 36.1% [4]. Irwan et al., sprayed water on the front surface of PV panels, reducing temperatures by 5 to 23°C and increasing power output by 9 to 22%. Nanofluids, due to their high thermal conductivity, efficiently remove heat from PV panels, significantly lowering surface temperatures. These fluids can also serve as spectral filters, selectively absorbing infrared radiation [5]. Sardarbadi et al., used a water/(SiO_2) nanofluid solution for PV panel cooling. A concentration of 3% reduced operating temperature by 19°C and increased electrical efficiency from 9.2% to 11% [6]. Rostami et al., employed CuO nanofluid and ultrasonic waves to cool PV module. The system increased cooling capacity by 2.75 - 57.25% and maximum power output by 3.4 - 51.2%, depending on vapour flow rate and ultrasonic power [7].

The efficiency of PV cooling systems is influenced by local climatic conditions, such as irradiance, ambient temperature, wind velocity, and air humidity. Diaz et al., compared the performance of a Phase Change Materials (PCM) passive cooling system in two Chilean cities with semi-arid and arid climates. They found

that passive cooling increased electricity generation by 5.8% in the semi-arid city and 4.5% in the arid city. Active cooling methods, though requiring additional energy and equipment, significantly enhance the efficiency and reliability of PV panels. Water-based and nanofluid cooling systems, in particular, offer substantial temperature reductions and efficiency improvements. Further research should explore optimizing these methods for various climatic conditions to maximize their benefits across different environments [8]. These systems can be categorized based on the working medium (air, water, hybrid systems) and the method of refrigerant distribution. Passive cooling relies on natural convection and heat conduction without mechanical components. This method increases the heat transfer surface of PV panels using materials with high thermal conductivity, such as pipes or fins. The primary types of passive cooling include natural circulation using air, water or phase change materials.
Air cooling is the simplest and most cost-effective passive cooling method. It typically involves fins or aluminium sheets attached to the bottom of the PV module to enhance radiative and convective heat transfer. Studies by Cuce et al., demonstrated a 20% increase in energy conversion efficiency using an aluminium heat sink under different ambient temperatures and solar radiation intensities [9]. Rajput and Yang's experiments with 197 aluminium radiation elements showed potential for significant passive heat removal from PV panels [10]. Mittelman et al., found that perforated aluminium fins reduced operating temperatures and increased electrical efficiency, with a 10% and 18.67% increase in voltage and maximum operating point, respectively [11]. Amber et al., compared rectangular and circular fins, finding rectangular fins dissipated 155% more heat, improving efficiency by 14.5% [12]. Najafi and Woodbury explored thermoelectric cooling using the Peltier effect, which controlled PV cell temperatures and optimized power generation. The effectiveness of photovoltaic (PV) cooling systems can vary significantly based on local climatic conditions. These conditions include factors such as irradiance, ambient and module surface temperature, wind velocity, air humidity, and the geographical location of the installation. The performance of cooling systems can be influenced by these factors, and thus, the efficiency of a given cooling method may not be consistent across different environments. The literature reveals various effective cooling techniques for PV panels, essential for mitigating efficiency losses due to overheating. Passive cooling methods, especially those using air and water, show significant potential in enhancing PV module performance [13].

III. Methodology

The present study focuses on leveraging geothermal energy to cool solar panels, a technique that significantly boosts their efficiency. Solar panels often experience a drop in performance when they overheat, as high temperatures can negatively impact their ability to convert sunlight into electricity. To counteract this, we tap into the Earth's naturally stable underground temperatures to effectively dissipate the excess heat that accumulates on the panels during operation. The proposed system is illustrated in figure 2.

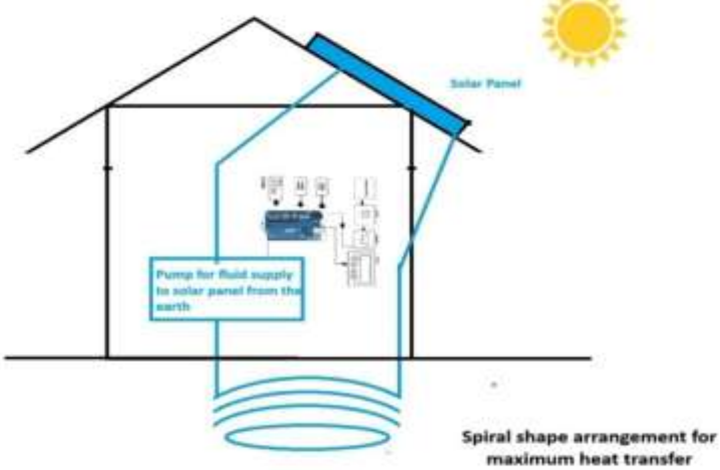

Figure 2: Proposed geothermal cooling system for solar panel

Continued research and development in cooling technologies are crucial for optimizing PV systems and maximizing their energy conversion efficiency. Thus the literature survey reveals that the using of geothermal cooling of solar panel with coconut oil is not yet attempted. So the innovative aspect of this research lies in the application of geothermal energy as a cooling mechanism for the fixed panels. The objective is to analyze and achieve the maximum possible power output from this configuration. By leveraging geothermal cooling, the study aims to maintain the panels at an optimal temperature, thereby improving their efficiency and energy output.

By circulating a cooling fluid through a geothermal loop, the excess heat is transferred away from the solar panels, maintaining them at an optimal temperature range. This cooling process not only ensures that the panels operate at peak efficiency but also reduces thermal stress, which can degrade materials and components over time. As a result, the lifespan of the solar panels is extended, and their overall power output is maximized.

IV. Experimental Setup

Photovoltaic effect of semiconductors is based on the principle that light energy can be converted into electrical energy using a solar cell. The photovoltaic effect typically indicates that the voltage of the output power can be created at the electrodes at both ends of the diode when a photon is incident on a diode element with a PN junction. The primary process in this case is photon emission. The electron-hole pair in a semiconductor is made up of electrons and holes that are kept apart by the PN junction, an internal electric field. A photocurrent forms on the loop when these electrons and the holes drift in opposite directions and produce an output to the load via the electrodes at both ends. When the solar panel receives sunlight, the surface temperature will also increase. Under the influence of temperature, the efficiency of the solar panel will decrease. Calebe et al., explains the effect of temperature on solar panel power and voltage [14].

A functional experimental setup is developed on the basis of proposed cooling system, to ascertain the impact of geothermal cooling on solar module. The cooling substance that circulates throughout the system was considered to be coconut oil. The combination of a ground pit acting as a geothermal heat sink and solar panels acting as a heat source determines how well the cooling cycle works. The proposed system is illustrated in figure 2. The system is made up of several parts, including an oil-jacketed solar panel, copper pipes, a hydraulic pump, and a ground pit. Voltmeters, ammeters, and thermocouples are used to measure power generation and load temperature. PV panel cooling systems are essential to counteract the efficiency loss due to increased operating temperatures. The table 1 depicts the everyday sun rise, sun set, elevation, azimuth, latitude and longitude display. Table 2 depicts hour to hour elevation and angular variation value. The table 3 presents the hourly availability of solar radiation at test place. The table 4 depicts the properties of coconut oil

Table 1: Every day sun rise, sun set, elevation, azimuth, latitude and longitude display

Sun Position	Elevation	Azimuth	Latitude	Longitude
29/08/2024	49.9°	226.05°	40.76°N	73.98°W
Twilight	**Sunrise**	**Sunset**	**Azimuth Sunrise**	**Azimuth Sunset**
Twilight -6.833	05:56:22 AM	06:27:23 PM	80° E of N	280° W of N
Day Light	**hh:mm:ss**	**Diff,dd+1**	**Diff,dd-1**	**Noon**
29/08/2024	01:13:39 PM	-00:02:35	00:02:33	12:56:33 PM

Table 2: Hour to hour elevation and angular variation value

Date	29/08/2024	
Time	**Elevation**	**Azimuth**
06:27:44 AM	0.833°	76.84°
08:00:00 AM	28°	85.2°
12:00:00 PM	83.2°	148.21°
4:00:00 PM	35.77°	272.13°
5:33:23 PM	7.83°	282.9°

Table 3: Available Solar Radiation at Test Place

Time	Irradiance

9:00 AM	724
9:30 AM	800
10:00 AM	876
10:30 AM	919
11:00 AM	962
11:30 AM	968
12:00 PM	974
12:30 PM	943
1:00 PM	911
1:30 PM	845
2:00 PM	776
2:30 PM	680
3:00 PM	587
3:30 PM	475
4:00 PM	358
4:30 PM	259
5:00 PM	160

Table 4: Thermo-physical properties of coconut oil

Properties (units)	Coconut oil (Solid)	Coconut oil (Liquid)
ρ (kg/m^3)	920	918
μ (Pa-s)	~	0.0268
cp (J/(kg-K))	3.750	1.670
k (W/(m-K))	0.166	0.166
β (1/K)	0.7×10^{-3}	0.7×10^{-3}
hf (J/kg)	103.000	103.000
Tm (K)	297	297

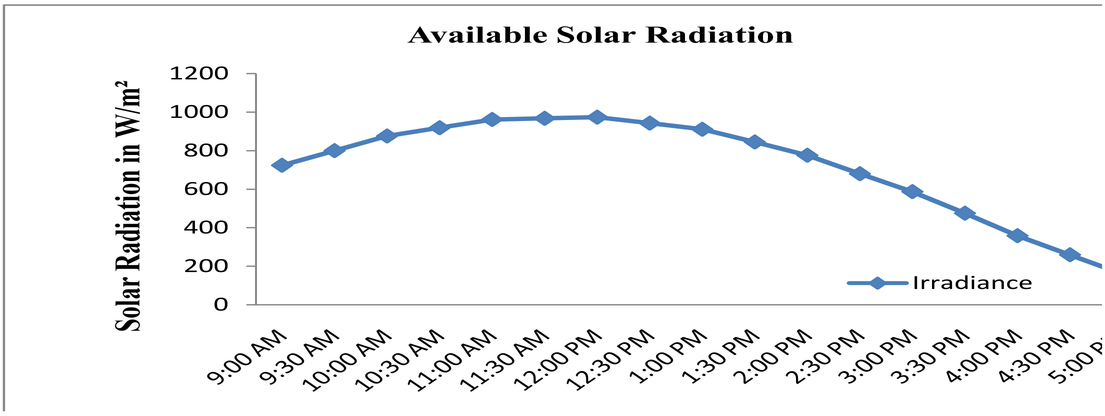

Figure 3: Available Solar Radiation at Test Place

Figure 3, illustrates the variation of available solar radiation throughout the day at a location with coordinates approximately 40.76°N and 73.98°W. The solar radiation is plotted against time in Indian Standard Time (IST), showing a typical diurnal pattern. At 9:00 AM, the solar radiation begins at around 720 W/m² and steadily rises, reaching a peak of nearly 990 W/m² between 11:30 AM and 12:00 PM. This peak represents the time when the sun is highest in the sky and solar energy is most intense. After noon, the solar radiation gradually declines as the sun begins to descend, dropping to about 800 W/m² by 1:00 PM and continuing to decrease steadily through the afternoon. By 5:00 PM, the radiation level falls below 200 W/m² indicating the end of significant solar input for the day. The overall shape of the graph is a smooth bell curve, typical of clear, sunny days, and suggests a full cycle of solar exposure from morning to evening. The data implies that the most efficient period for harnessing solar energy on this day was between late morning and early afternoon.

The experiments were conducted as per the proposed system exhibited in figure 2. The components involved in the system are shown in figure 4 and figure 5.

Figure 4: Solar panel setup

Figure 5: Pit, Oil circulating Pump and Output measuring devices

The solar energy harvesting system is designed with several integrated components to maximize power generation. At its core, the solar panel captures sunlight and converts it into electricity; however, its efficiency can decline due to excessive heat accumulation. To counteract this, the system incorporates a geothermal cooling mechanism. In this setup, an oil pump circulates a specially prepared nanofluid composed of coconut oil infused with ferrous powder at a 20% volume fraction to enhance thermal properties. This nanofluid flows through a network of copper pipes attached to the solar panel, absorbing the excess heat. The heated nanofluid is then routed in a closed loop to an underground pit that functions as a geothermal heat sink. Here, the absorbed heat is dissipated through the pipe walls into the surrounding soil. This cooling process helps to regulate the solar panel's temperature, maintaining it within optimal operating limits and thereby improving its efficiency. The coordinated operation of the solar panel, oil pump, nanofluid coolant, copper piping, and geothermal pit ensures stable and efficient energy harvesting over time.

V. Results and Discussions

The performance of the solar panel is connected a load with a resistance of 15 ohms in the circuit. To evaluate the panel's efficiency under different conditions, both the voltage and current generated by the panel are carefully measured in two scenarios: one where the panel is actively cooled and another where no cooling is applied. These measurements are crucial as they help determine how cooling impacts the panel's ability to generate power. To capture the electrical performance, the current is measured using an ammeter, which accurately records the flow of electric charge through the circuit. Simultaneously, the voltage is measured with a voltmeter, which indicates the potential difference across the panel's terminals. These measured values of current and voltage are then systematically recorded and organized into a table for easy comparison and analysis. The table 5 provides a clear picture of the solar panel's performance under both cooled and uncooled conditions, enabling a comprehensive evaluation of the effectiveness of cooling on solar energy generation.

Table 5: Comprehensive evaluation of both cooled & uncooled conditions of solar panel's

Time (IST)	Without Cooling					Cooling				
	Panel Temperature (°C)	Voltage (Volts)	Current (Amps)	Power (Watts)	Efficiency	Panel Temperature (°C)	Voltage (Volts)	Current (Amps)	Power (Watts)	Efficiency
9:00 AM	37.3	17.50	1.90	33.25	15.94	29.2	17.62	1.9	33.48	16.05
9:30 AM	40.1	18.10	1.89	34.21	14.84	30.1	19.37	1.9	36.81	15.97
10:00 AM	42.1	18.30	1.90	34.77	13.78	34.9	20.95	1.9	39.80	15.77
10:30 AM	43.3	18.90	1.90	35.91	13.56	32.8	22.06	1.85	40.81	15.42
11:00 AM	44.1	18.60	1.96	36.49	13.17	31,5	22.22	1.88	41.77	15.07
11:30 AM	45.6	19.10	1.90	36.29	13.01	30.8	21.90	1.9	41.61	14.92
12:00 PM	47.6	19.21	1.89	36.31	12.94	29.3	20.80	2	41.59	14.82
12:30 PM	51.2	19.33	1.82	35.18	12.95	28.7	19.05	2.1	40.01	14.73
1:00 PM	50.3	18.75	1.82	34.13	13.00	28.5	18.38	2.1	38.60	14.71
1:30 PM	48.7	18.22	1.78	32.49	13.35	28.1	18.77	1.9	35.66	14.65
2:00 PM	45.3	17.78	1.68	29.89	13.37	25.8	17.37	1.88	32.66	14.61
2:30 PM	44.3	17.21	1.58	27.19	13.88	25.3	15.50	1.85	28.68	14.64
3:00 PM	42.5	17.90	1.30	23.31	13.79	24.3	13.82	1.8	24.88	14.71
3:30 PM	41.3	16.10	1.21	19.45	14.22	23.4	11.92	1.7	20.26	14.81
4:00 PM	39.8	12.00	1.20	14.40	13.96	23.2	9.40	1.65	15.50	15.03
4:30 PM	36.2	8.00	1.30	10.40	13.94	22.8	7.14	1.6	11.42	15.31
5:00 PM	33.5	5.60	1.30	7.21	15.79	28	4.80	1.5	7.58	15.62

The figure 6 illustrates the relationship between time and voltage generated by a solar panel over a period from 10:00 AM to 4:00 PM. From 10:00 AM to 12:00 PM, there is a gradual increase in voltage, starting around 19 volts and rising steadily as the day progresses, likely due to increasing sunlight intensity. Between 12:30 PM and 1:00 PM, the voltage reaches its peak at approximately 20.5 volts, which suggests that this time frame represents the period of maximum solar irradiance. After 1:00 PM, the voltage drops sharply, returning to around 19 volts by 2:00 PM and continuing to decrease gradually until the end of the observation period at 4:00 PM, where it dips to about 18.5 volts. This decline likely corresponds to a reduction in sunlight intensity as the afternoon progresses. Overall, the chart shows that the solar panel's voltage output increases with rising sunlight intensity, peaks around midday, and then decreases as sunlight wanes in the afternoon.

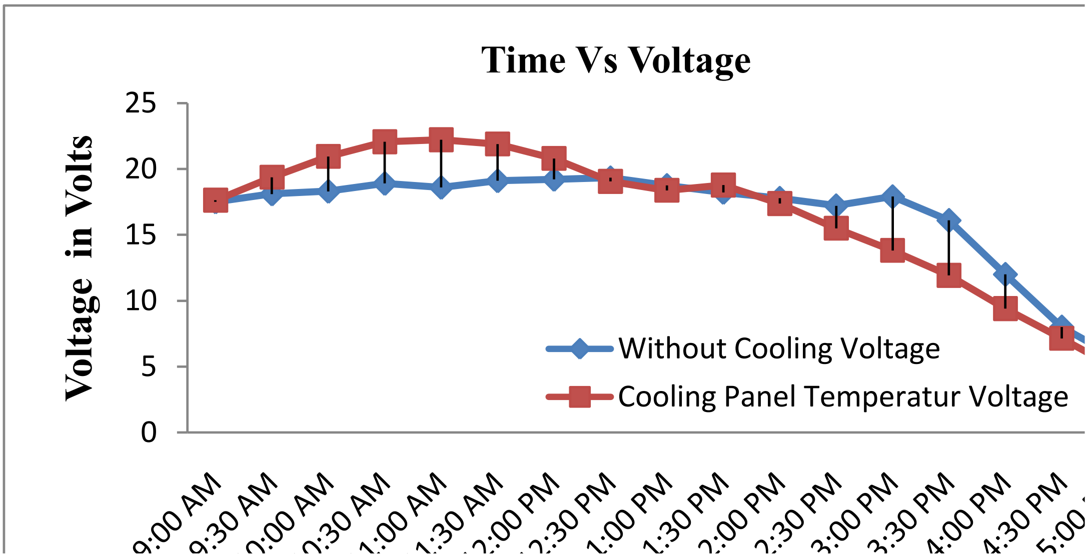

Figure 6: Time Vs Voltage

The figure 6, entitled "Time vs Voltage" shows how the voltage output of a system, likely from a photovoltaic (solar) panel, varies over the course of a day in IST (Indian Standard Time). Starting from 9:00 AM, the voltage is around 17.5 volts and gradually increases, peaks between 11:30 AM and 12:30 PM at just below 19.5 volts. This indicates that the solar panel receives maximum sunlight during this period, resulting in the highest energy conversion. After this peak, the voltage slowly starts to decline, maintaining relatively high values until about 3:00 PM. A noticeable drop begins after this point, with voltage falling sharply to around 5 volts by 5:00 PM. This trend reflects the natural solar cycle, where sunlight intensity increases during the morning, reaches its peak at mid-day, and then diminishes toward evening, thereby affecting the panel's output voltage accordingly. The steady performance between late morning and early afternoon demonstrates the panel's efficiency during peak sunlight hours.

The figure 7, entitled "Panel Temperature vs Time" compares the temperatures of a cooled photovoltaic panel and an uncooled panel throughout the day from 9:00 AM to 05:00 PM. The uncooled panel shows a steady increase in temperature starting at around 38°C at 9:00 AM, peaking at approximately 52°C by 12:30 PM, and then gradually declining to about 35°C by 5:00 PM. In contrast, the cooled panel, likely using a geothermal or nanofluid-based system, starts at a lower temperature of around 30°C and reaches a maximum of only 36°C at 10:00 AM, remaining consistently lower than the uncooled panel throughout the day. The cooled panel's temperature shows a slight dip after 10:00 AM, hovering around 29 to 30°C during peak solar hours, and drops further to about 23°C by 4:30 PM before slightly rising again by 5:00 PM. The largest temperature difference between the two panels occurs around 12:30 PM, demonstrating the cooling system's effectiveness in preventing overheating. Maintaining a lower temperature helps improve the solar panel's efficiency, as excessive heat typically reduces energy conversion. The graph clearly highlights that the cooled panel operates within a much more stable and optimal thermal range compared to the uncooled panel. This thermal regulation is crucial for long-term performance and reliability in photovoltaic systems. The gradual decline in both panel temperatures toward the evening reflects the natural reduction in solar radiation after midday. The use of cooling not only enhances output but also reduces thermal stress on the panel. The consistent gap between the two curves signifies the consistent performance of the cooling technique used.

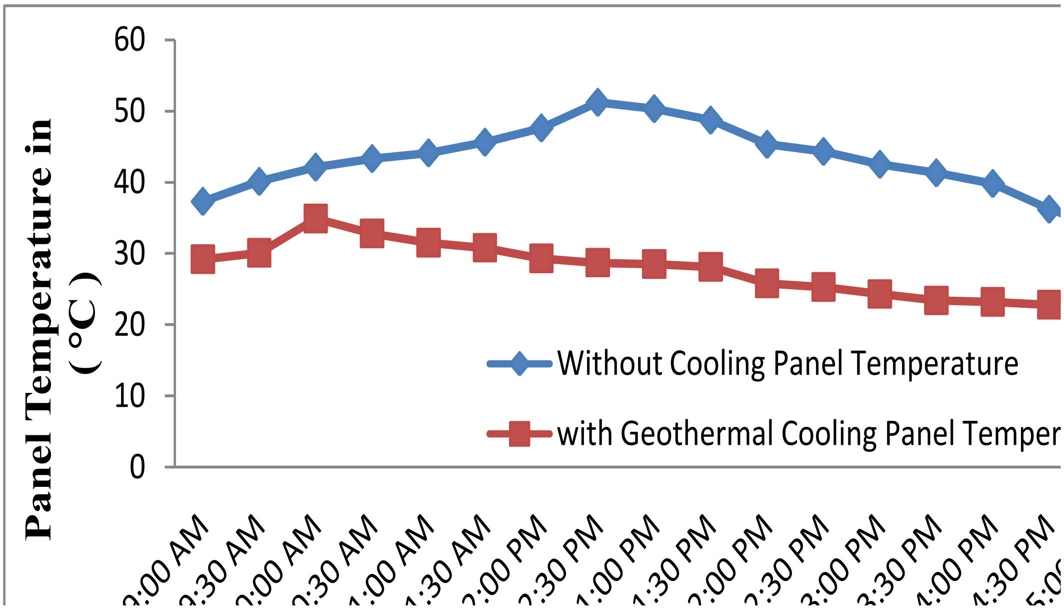

Figure 7: Time Vs Panel Temperature

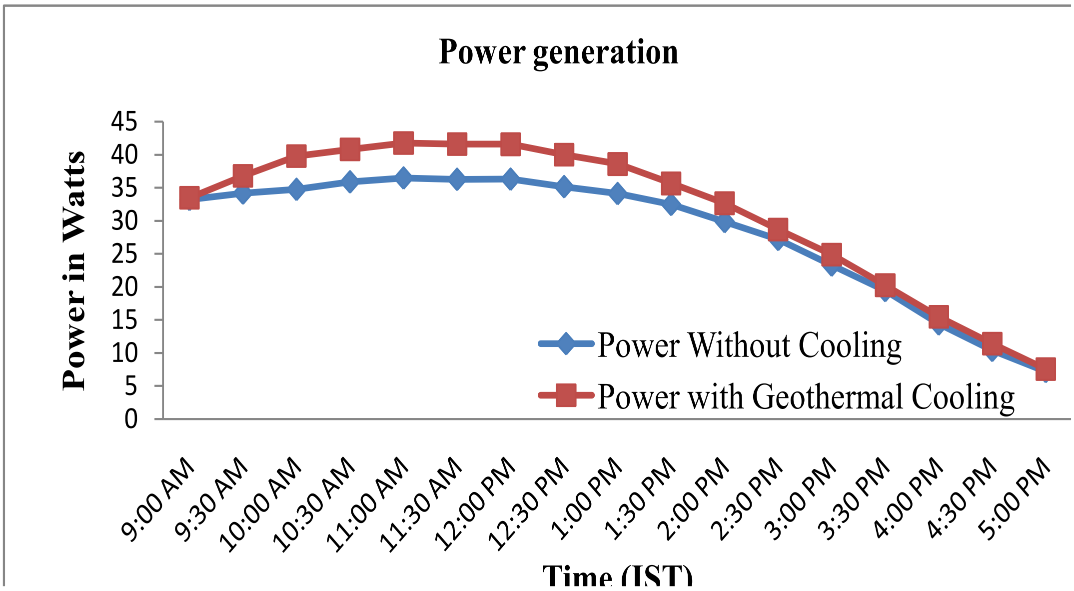

Figure 8: Power generation with cooling Vs without Cooling

The figure 8 entitled, "Power Generation with Cooling Vs without Cooling" illustrates the variation in electrical power output from a photovoltaic (PV) system over time under two operating conditions: one with geothermal cooling and the other without any cooling. The X-axis represents the time of day in IST, ranging from 9:00 AM to 5:00 PM, while the y-axis shows the power output in watts, ranging from 5W to 45 W. At the start of the day 9:00 AM, both systems generate nearly equal power, around 33 W. However, as sunlight intensity increases, the geothermal-cooled system starts producing more power than the uncooled system. By 10:00 AM, the cooled system experiences a noticeable jump to 40 W, compared to about 36 W from the uncooled one.

The power output for the cooled system peaks between 11:00 AM and 1:00 PM, maintaining values slightly above 41 W, while the uncooled system levels off at around 37 W. This consistent difference highlights the effectiveness of the cooling mechanism in maintaining panel efficiency during the hottest part of the day. After 1:00 PM, both systems begin to show a gradual decline in power, following the natural reduction in solar radiation. However, the geothermal-cooled system consistently remains ahead, producing higher power even during the afternoon hours. Between 2:00 PM and 4:30 PM, both curves descend more steeply, but the cooled system continues to outperform the uncooled one by about 2 to 4 W. By 5:00 PM, the output from both systems drops significantly to about 7 to 8 W, as sunlight becomes minimal. This graph clearly demonstrates that geothermal cooling helps to reduce panel temperature, leading to more efficient power conversion, especially during peak radiation hours. Over the course of the day, the cooled system consistently produces more energy, emphasizing the benefit of integrating thermal regulation with solar panels to enhance total daily output and system efficiency.

This improvement is due to the fact that high temperatures negatively impact photovoltaic efficiency, as increased heat raises the internal resistance of the panel and reduces voltage. By using geothermal cooling, excess heat is efficiently dissipated, maintaining optimal thermal conditions. As seen in the graph, the system with cooling sustains higher power levels for a longer period during the day, thereby increasing the total daily energy yield. This translates to improved performance and better reliability, particularly in regions with high ambient temperatures or extended sunlight exposure.

VI. Conclusion

The consistent superiority of the cooled system highlights its value in large-scale or off-grid solar installations, where maximizing power output is essential. Even though the advantage is most noticeable during midday, the accumulated energy gains over the entire day can be significant. The graph emphasizes that integrating thermal regulation techniques into PV systems is not just beneficial but essential for maximizing their potential, especially under real-world operating conditions. The steady difference in power output clearly justifies the use of cooling methods such as geothermal systems in modern solar power applications. The cooling effectively reduces the panel temperature over time. Without cooling, the panel's temperature tends to rise, peaking during the hottest part of the day, which can negatively impact performance. The solar panels with cooling produce consistently higher power output compared to panels without cooling. The power generation is not only higher but also more stable throughout the day, especially during peak sunlight hours. The power output of the cooled panel reaches a higher peak and maintains this peak longer than the uncooled panel. This indicates that cooling allows the panel to operate more efficiently under optimal conditions.

Incorporating geothermal cooling into solar energy systems represents a cutting-edge strategy that enhances the performance of renewable energy technologies. By combining these two sustainable energy sources, we create a more resilient and efficient system, contributing to the broader goal of improving the reliability and effectiveness of renewable energy solutions.

REFERENCES

1. Automatic Solar Tracking System: Development and Simulation by Akshay Urja IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE).
2. Masoud Rahimi, Masomeh Asadi, Nooshin Karami, Ebrahim Karimi, A comparative study on using single and multi header microchannels in a hybrid PV cell cooling, Energy Conversion and Management, Volume 101, 2015, Pages 1-8, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2015.05.034.
3. Barrau, J.; Rosell, J.; Chemisana, D.; Tadrist, L.; Ibañez, M. Effect of a hybrid jet impingement/micro-channel cooling device on the performance of densely packed PV cells under high concentration. Sol. Energy 2011, 85, 2655–2665. DOI:10.1016/j.solener.2011.08.004
4. Baloch, A.A.B, Bahaidarah, H.M.S, Gandhidasan, P, AlSulaiman, F.A., 2015. Experimental and numerical performance analysis of a converging channel heat exchanger for PV cooling, Energy Conversion and Management, vol. 103, pp. 14-27.
5. Irwan, Y. M., Leow, W. Z., Irwanto, M., Fareq.M, Amelia, A. R., Gomesh, N., & Safwati, I. (2015). Indoor Test Performance of PV Panel through Water Cooling Method. Energy Procedia, 79, 604–611. doi:10.1016/j.egypro.2015.11.540.
6. Sardarabadi, M., Passandideh-Fard, M., & Zeinali Heris, S. (2014). Experimental investigation of the effects of silica/water nanofluid on PV/T (photovoltaic thermal units). Energy, 66, 264–272. doi:10.1016/j.energy.2014.01.102
7. Rostami, Z.; Rahimi, M.; Azimi, N. Using High-Frequency Ultrasound Waves and Nanofluid for Increasing the Efficiency and Cooling Performance of a PV Module. Energy Convers. Manag. 2018, 160, 141–149. DOI:10.1016/j.enconman.2018.01.028
8. Díaz, F. A.; Moraga, N. O.; Cabrales, R. C. Computational modeling of a PV-PCM passive cooling system during a day-night cycle at arid and semi-arid climate zones. Energy Convers. Manag. 2022, 270, 116202. DOI:10.1016/j.enconman.2022.116202
9. Cuce, E.; Bali, T.; Sekucoglu, S. A. Effects of passive cooling on performance of silicon photovoltaic cells. Int. J. Low-Carbon Technol. 2011, 6, 299–308. DOI:10.1093/ijlct/ctr018.

10. Rajpu, U.J.; Yang, J. Comparison of heat sink and water type PV/T collector for polycrystalline photovoltaic panel cooling. Renew. Energy 2018, 116, 479–491. DOI:10.1016/j.renene.2017.09.090.

11. Mittelman, G.; Alshare, A.; Davidson, J. H. A model and heat transfer correlation for rooftop integrated photovoltaics with a passive air cooling channel. Sol Energy 2009, 83, 8, 1150-1160. DOI:10.1016/j.solener.2009.01.015.

12. Amber, K. P.; Akram, W.; Bashir, M.A.; Khan, M.S.; Kousar A. Experimental performance analysis of two different passive cooling techniques for solar photovoltaic installations. J. Therm. Anal. Calorim. 2021, 143, 2355-2366. DOI:10.1007/s10973-020-09883-6.

13. Najafi, H.; Woodbury, K. A. Optimisation of a cooling system based on Peltier effect for photovoltaic cells. Sol. Energy 2013, 91, 152-160. DOI:10.1016/j.solener.2013.01.026

14. Calebe A.M., Licínio M.S., Aylton J. A., Wesley P.C. (2017). Increasing photovoltaic panel power through water cooling technique. [Online]. Available at: https://teee.eu/index.php/TEEE/article/download/90/59.