

# EVALUATION OF PV/T AND PV SYSTEMS USING VARIOUS MAXIMUM POWER POINT TRACKING MPPT METHODS

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## Abstract

Due to the growing demand for renewable energy solutions, the integration of photovoltaic-thermal (PV/T) systems and photovoltaic (PV) systems is attracting more and more attention. High temperatures have a substantial impact on the efficiency of photovoltaic (PV) power panels. As the temperature of a photovoltaic (PV) panel rises, the efficiency and power production generally decline. The main reason for this is that photovoltaic cells are highly responsive to variations in temperature, which directly impact the choice of semiconductor materials employed in their fabrication. An experimental set up has employed for a cooled and non-cooled panel and the cooled panel has been cooled with a back surface cooling technology with Cu tubes. An important obstacle in improving the efficiency of these systems during high temperature conditions is the efficient use of PV panel cooling system along with Maximum Power Point Tracking (MPPT) techniques. These approaches assure that the systems function at their highest power output even when faced with changing environmental constraints. This work provides a thorough assessment of PV/T and PV systems using distinct MPPT approaches, such as Perturb and Observe (P&O), Incremental Conductance (IC) Particle Swarm Optimization (PSO) and Cuckoo Search (CS) algorithm. Simulation and experimental analysis are used to examine the combined effect of panel cooling & MPPT. The combine effect has been observed in the output power of the system by increasing electricity production efficiency by over 16%.

**Keywords:** Solar Photovoltaic system(SPV); PV cooling; MPPT; PV/T Mass Flow Rates; Multi-concept method

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## Introduction

Photovoltaic (PV) systems have gained an exponential growth as compared to its renewable counterparts due to its modular characteristic (Ibrahim *et al.*, 2023). It does not deliver any hazardous components like conventional fuels during the energy conversion process. Photovoltaic (PV) power generation will be varying continuously according to climatic conditions. The variation in climatic factors like irradiation, wind speed, temperature varies the power generated by the panel (RTIMI *et al.*, 2020). The amount of solar radiation received by photovoltaic system is not fully used for the generation of electrical energy; only part of the energy of the incident insolation is transformed into heat developed inside these panels. This heat is the cause of two types of losses. The first type of loss is the increase in the operating temperature which causes the heating of PV panels and the deterioration of their efficiency and life span. The second type of losses describes that some amount of the energy is converted into heat inside the panels and does not produce electrical energy. The operating temperature of the photovoltaic panel plays a vital role while converting them into electric power. To overcome these issues, various cooling techniques are used in limiting the temperature of the panel.

It is also critical to utilize all of the energy generated by the photovoltaic panels to optimize the system's performance, which necessitates the usage of maximum power point tracker (MPPT). In order for photovoltaic to function properly, it is imperative that the surface temperature of solar panels be uniform. The cooling system makes photovoltaic panels last longer, which is good from an economic point of view (Ibrahim *et al.*, 2024). A cooling and MPPT multi-concept system can be deployed to improve the efficiency of a PV system. The goal of the proposed system is to keep a low operating temperature while enhancing system power under variable solar insolation. By combining Maximum Power Point Tracking (MPPT) methodology with PV cooling technology, the energy efficiency of solar panels can be greatly improved. This is achieved by ensuring the maintenance of optimal power output even in changing temperature circumstances, as compared to employing MPPT techniques alone without cooling.

Again, the orientation of solar panels is important for optimum energy generation. Proper orientation ensures that the panels receive the maximum possible sunlight throughout the day, thereby increasing energy output. Solar panel

orientation is possible by both the means either manually or by motor. Though manual orientation is cost effective, simple and easy to control at the same time the process is less flexible, labor intensive and less efficient. However, motorized tracking system automatically changes the orientation of solar panel according to the position of the sun. This approach has maximum efficiency, more flexible but comes with higher cost as well as maintenance is required. Any one of the above-mentioned systems is chosen based on location, budget, and installation size.

Asl-Soleimani *et al.* discusses the integration of Solar-PV inverters with intelligent Maximum Power Point Tracking (MPPT) control, focusing on power system stability and regulation of DC-link capacitor voltage. It highlights the importance of MPPT in maximizing energy harvested from PV panels and the need for integrated control algorithms to manage these elements. The paper suggests a growing focus on developing sophisticated AI-based control algorithms to adapt to complex grid conditions and enhance the robustness of power systems with high PV penetration (Asl-Soleimani *et al.*, 2021).

Rajeev *et al.* examines the application of metaheuristic optimization techniques to improve the stability of power systems integrated with PV-STATCOM systems. The research highlights the importance of maintaining voltage stability, frequency stability, and overall system reliability, especially in systems with high renewable energy penetration. The paper also discusses the hybridization of metaheuristic techniques, focusing on improving convergence speed, accuracy, and handling complex optimization problems. The study contributes to the development of advanced solutions for power system stability enhancement (Rajeev *et al.*, 2022).

Wei *et al.* explores the use of a hybrid Wind-PV farm as a STATCOM for controlling chaotic oscillations in a two-area power system. The system is simulated using Kundur's modified system and a unique controller, with a swarm-based hybrid metaheuristic optimizer. The simulation results show the farm's potential in alleviating chaotic oscillations under various conditions, including without control, Wind-STATCOM, PV-STATCOM, and hybrid Wind-PV-STATCOM (Wei *et al.*, 2011).

Studies by Ibrahim *et al.* (Ibrahim *et al.*, 2023) who examined the passive cooling systems to enhance the photovoltaic panels' output power and efficiency, indicated that the efficiency of transforming sunlight into electrical energy reduced

by 0.06% for every 1-degree Celsius rise in panel temperature. A literature review conducted by RTIMI *et al.* (RTIMI *et al.*, 2020) established a comparative study between concentrator panel CPV and conventional panel PV and concluded that the output power of a solar module changes linearly with respect to its operating temperature. Research conducted by Panda *et al.* (Panda *et al.* 2023a) determined the technologies and Future Trends of Cooling techniques used for Solar PV systems. Wei *et al.* (Wei *et al.*, 2011) explored various cooling techniques for hybrid systems and concluded that water back cooling provided the most significant improvement. The use of an air-cooled heat sink on the back of a solar panel has been investigated by Panda *et al.* (Panda *et al.*, 2023a) and the findings indicated an increase in output power of 6.97 to 7.55%. Akhbari *et al.* (Akhbari *et al.* 2019) discovered that spraying water over the back and front of a photovoltaic panel reduced the panel's temperature from 52°C to an average of 24°C, resulting in a 5.9% increase in output power. However, very little research has been conducted on the integration of MPPT with cooling system. This work focuses on the combined effort to enhance the performance of the solar PV system.

The majority of research is dedicated to enhancing either Maximum Power Point Tracking (MPPT) algorithms or cooling methods for PV panels individually. But there is a shortage of studies studying the combined impact of MPPT optimization and PV panel cooling on performance of a PV system. Many studies rely heavily on theoretical models or numerical simulations of panel cooling without adequate experimental validation to assess real-world performance under varied environmental conditions. Panel efficiency can be greatly influenced by cooling, thereby affecting the efficacy of the MPPT algorithm. The inclusion of cooling effects in MPPT simulation studies has the potential to provide novel insights into the performance of systems in dynamic environments.

## Experimental Set Up

An experimental set up has been installed on a shade free roof at Gwalior, Madhya Pradesh, India location. It is located at 26.2183°N, 78.1828°E. The schematic layout of the experimental setup is presented in Figure 1. The PV panel is equipped with copper tubes at the back surface which works as heat exchanger. Water is used as coolant for the set up. At Gwalior, the tilt angle of the photovoltaic module is 28° with respect to the north-eastern direction in India. The outdoor experimental set up is shown in Figure 2. Data was collected over a 10 hour period in the month of May,

covering a range of climatic conditions typical of the summer season in Gwalior. The PV panels used are of 250W with a dimension of 3.25 feet by 5.5 feet. The solar irradiation has been recorded by a pyranometer (Apogee-S110) placing it near the panel. The data have been logged in each 30minutes for 8 hours duration by using a data logger made by Everon Company. Cu tubes of outer diameter 6mm has been used with wall thickness of 0.8mm with a tube spacing of 10cm. Total length of the Cu tube is 10.7metres.

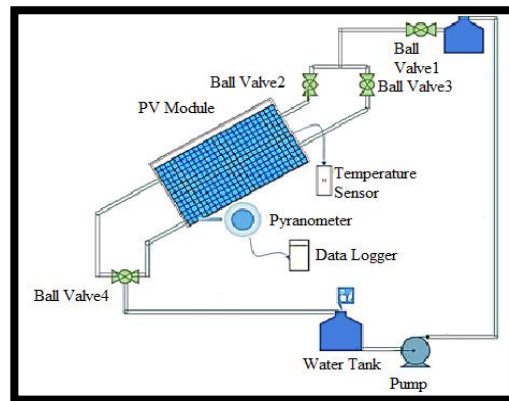


Figure 1. Schematic layout of the experimental set up

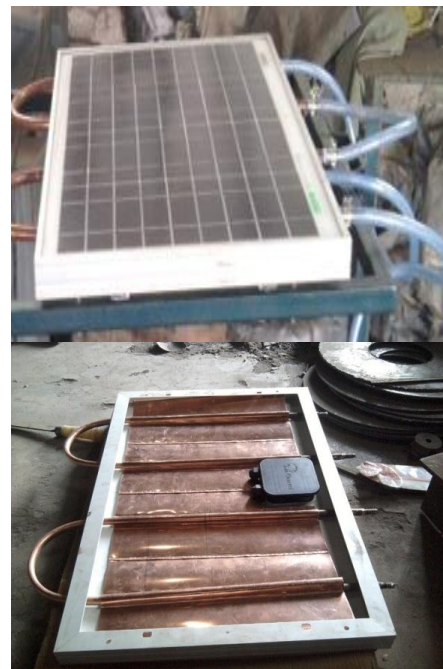


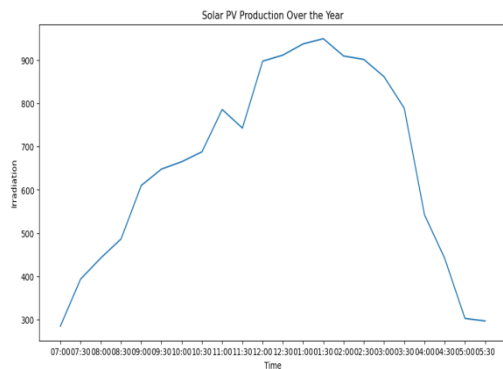
Figure 2. Outdoor Experimental set up

Water is made to flow in the tubes through gravitational flow. The outlet water can be used for cleaning and other domestic purposes. The water flow rate has been decided by allowing 4 types of flow rates in the tubes given in Table 1.

**Table 1. Overall Efficiency for Different PV/T Mass Flow Rates**

| S.No | Mass Flow Rate | Overall Efficiency Values in % |
|------|----------------|--------------------------------|
| 1    | 2LPM           | 56.63                          |
| 2    | 2.5LPM         | 72.20*                         |
| 3    | 3LPM           | 74.06**                        |
| 4    | 4LPM           | 59.43                          |

Though 3 LPM water flow rate produces optimum result, because of potential water saving, 2.5 LPM has been further considered for experimentation and evaluation. In terms of electrical efficiency, the difference between 2.5LPM and 3LPM is minimal.



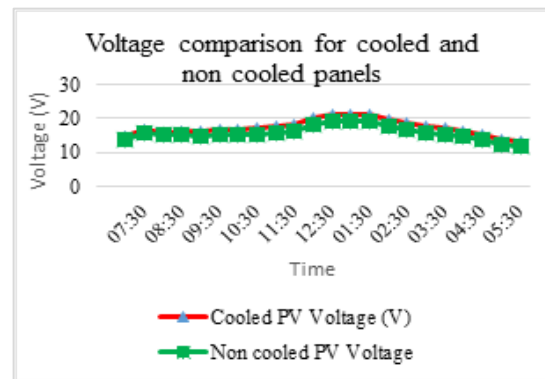
**Figure 3. Variation of Solar radiation over time**

Figure 3 displays the variation of solar irradiation values with respect to time. This table eases the process for better comparative analysis. The maximum daily sun irradiance has reached 950 W/m<sup>2</sup>. The minimum and maximum ambient temperatures recorded for the day are 30°C and 41°C, respectively. Although nearly the same surface temperature has been observed for the front surface cooling type panel and the back surface cooling with Cu tube type panel, the output voltage of the back surface cooling with Cu tube panel is greater (Wei *et al.*, 2011; panda *et al.*, 2023a).

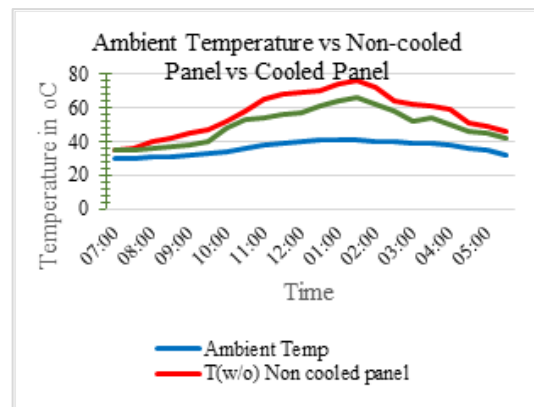
As the front surface cooling type panel achieves a lower panel temperature, solar radiation is obstructed by a layer of water on the front surface, which has a negative effect on the PV panel's output voltage. During the peak hours of that day, the highest voltage observed is 21.2V and the lowest is 19.1V. The maximum value of voltage has been recorded for the back surface cooling with Cu tube type panel and the least has been observed for the back surface cooling with grass type panel.

Figure 4 represents the PV panel's output voltage which demonstrates the voltage difference between the cooled and non-cooled panel.

Figure 5 depicts about temperature difference between cooled and non cooled panel.



**Figure 4. Output voltage for cooled and non-cooled panels**



**Figure 5. Temperature values of the cooling and non-cooling panel**

## Integration of MPPT with Photovoltaic Cooling Technology for Enhanced Performance:

The cooling effect of the PV panel will ensure the operating temperature of the PV panel and the MPPT will consistently track the maximum power for drawing optimum power from the PV panel. This combined effect will enhance the efficiency of the SPV.

Figure 6 illustrates the block diagram presentation of the proposed system where the PV panel with cooling technology combines with a MPPT to form a hybrid kind of SPV for better performance. A multi-concept system with cooling and MPPT have been implemented in order to increase the efficiency of a PV system (Akhbari *et al.*, 2019; Basavaraj *et al.*, 2021). The PV panel cooling mechanism has maintained a low operating temperature, while the MPPT has achieved maximum system power under fluctuating irradiance conditions.

With an overall efficiency of 68%, the rear side cooling with Cu tubes and water eliminates the use of any other cooling methods. In this system, copper tubes have been provided on the backside of the panel in the form of a heat exchanger. Water has been circulated through the back of panel by an AC Motor. The water from outlet can be collected and will have a temperature above 50°C and can be used for various domestic purposes and cleaning in hotels or industries. The real time data collected from this cooling mechanism has been used while simulating the SPV system with a MPPT to study the combine effect in efficiency of the SPV.

It is also critical to utilise all of the energy generated by the photovoltaic panels to optimise the system's performance, which necessitates the usage of maximum power point tracker (MPPT) (Abdul-Ghafoor *et al.*, 2024). In order for photovoltaic to function properly, it is imperative

that the surface temperature of solar panels be uniform. The cooling system makes photovoltaic panels last longer, which is good from an economic point of view. A cooling and MPPT multi-concept system can be deployed to improve the efficiency of a PV system. The goal of the proposed system is to maintain a low operating temperature while maximizing system power under varying solar radiation conditions. The refore, a cooling mechanism is essential for photovoltaic cells.

Many researches prioritise either Maximum Power Point Tracking (MPPT) optimisation methods or photovoltaic (PV) cooling systems alone. The extant literature frequently treats these two domains as separate subfields of inquiry. Earlier studies frequently concentrate on broad or theoretical models without taking into account the local meteorological variables. Many studies that take into account local variables sometimes fail to incorporate both Maximum Power Point Tracking (MPPT) and cooling. This work presents a novel integration of Maximum Power Point Tracking (MPPT) with cooling technologies, resulting in a synergistic impact that enhances the efficiency of photovoltaic (PV) panels past the capabilities of either approach individually. The adoption of this integrated strategy can lead to enhanced stability and increased energy production, especially in areas characterised by extreme temperature variations. This work offers practical insights into customising the integration of Maximum Power Point Tracking (MPPT) and cooling for distinct climatic zones, with an emphasis on Gwalior, which is characterised by high temperatures and sun irradiance. The findings provide a detailed plan for other areas with comparable conditions, therefore enhancing the practicality and feasibility of the research.

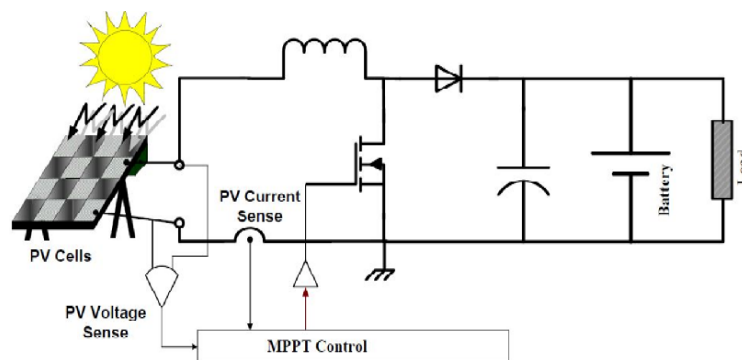


Figure 6. Block diagram of the proposed Solar PV system

## MATLAB simulation Models

Four MPPT techniques have been taken into account while simulating the SPV cooling model and are as follows:

- Perturbation and observation (P&O)
- incremental conductance (IC)
- Particle swarm optimization (PSO)
- Cuckoo Search (CS)

Real time data have been incorporated in the SPV designed in MATLAB/SIMULINK. Each of the mentioned MPPT has been simulated with the cooling type SPV system (Panda *et al.*, 2021; Gonzatti *et al.*, 2023; Panda *et al.*, 2023b). The results have been compared to find compliance of MPPT with the cooling SPV system. The real time data recorded and presented for cooling has been taken for incorporating cooling in Solar Photovoltaic System.

The selection of the MPPT technique has taken into account its capability to precisely track the actual maximum power point (MPP) under different conditions, as well as the rate at which the MPPT algorithm adapts to changes in environmental conditions (such as temperature fluctuations caused by cooling) and determines the new MPP. Achieving higher tracking precision is essential for optimising the energy production of the photovoltaic (PV) system, particularly in the presence of fluctuating external circumstances such as temperature changes resulting from cooling.

### Implementation of P&O MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System

The standard P&O algorithm has been implemented using a 300W PV module in both cooling and non-cooling conditions as illustrated in Figure 7.

Based on the setup's real-time data, the temperature is set at 46°C during cooling and 57°C without cooling. The results of this model have shown advantages of PV cooling. It ensures that a PV system functions with the combined effect of PV panel cooling and a maximum PowerPoint Tracker (MPPT) for better efficiency. Figure 7 depicts the model of the simulation.

### Implementation of Incremental Conductance (InC) MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System

In both cooling and non-cooling conditions, the typical InC algorithm has been implemented on a 150W PV module. Based on the setup's real-time data, the temperature during cooling is set at 46°C,

while the temperature without cooling is 57°C. The simulation time has set to 2 seconds. An m-file has been prepared for the PV module in the MATLAB coding platform through which temperature values recorded and evaluated from the experimentation of PV cooling systems have been given to the system. The results ensure the performance of PV under combine effect of cooling and MPPT. The simulation model is displayed in Figure 8.

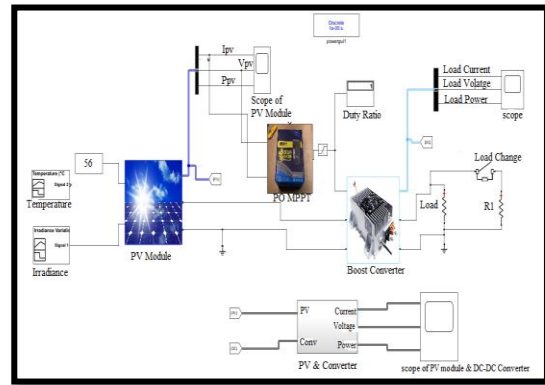


Figure 7. Implementation of P&O MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System

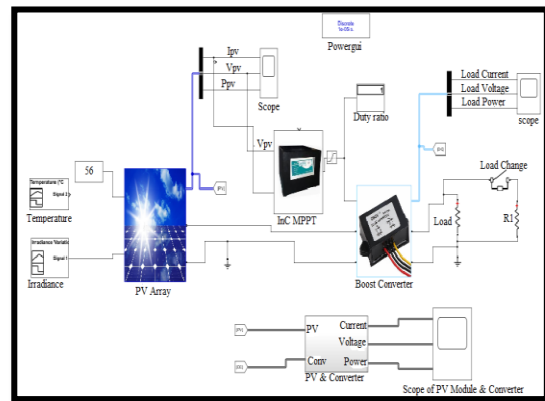
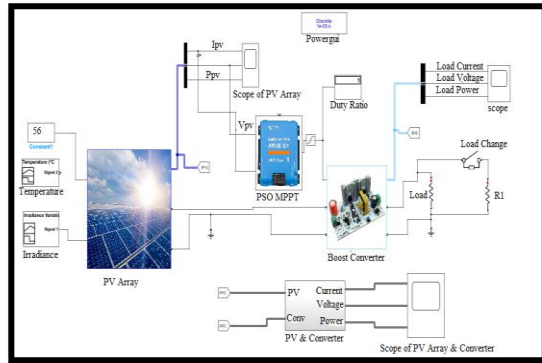


Figure 8. Implementation of InC MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System

It ensures that a PV system operates with the combined impact of PV panel cooling and a maximum Power Point Tracker (MPPT) for enhanced efficiency.

### Implementation of PSO Logic MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System

PSO is a stochastic optimization method based on the intelligence and movement of swarms. On a 150W PV module, the PSO algorithm has been applied under cooling situations through the simulation model as shown in Figure 9.



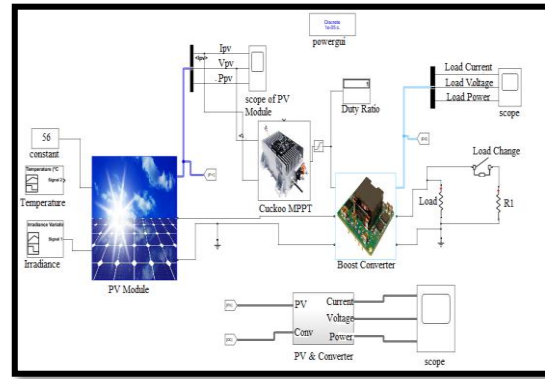
**Figure 9. Implementation of PSO MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System**

The temperature during cooling is set to 46°C based on the setup's real-time data, whereas the temperature without cooling is 57°C. It guarantees that a PV system operates with PV panel cooling and a maximum PowerPoint Tracker (MPPT) for increased efficiency.

### Implementation of Cuckoo Logic MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System

Simulation model for Cuckoo search algorithm based MPPT with cooling SPV system is presented in Figure 10. Researchers support better performance of Cuckoo search algorithm which has been tested through this Simulink model. Also, the output difference between cooling and non-cooling panel can be seen through this model. For cooling the temperature has been set to 46°C and for non-cooling panel it is 57°C.

Two conventional MPPTs and two Meta heuristic MPPTs have been simulated for cooling and non-cooling circumstances to improve their efficiencies. All six combinations have been investigated.



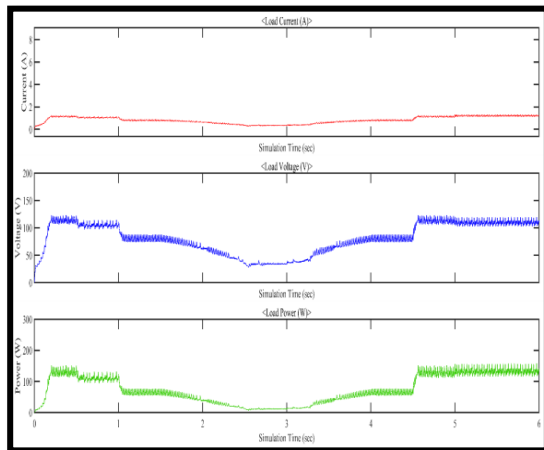
**Figure 10. Implementation of Cuckoo MPPT with PV Cooling for Electrical Characteristic and Performance Analysis of SPV System**

## Results and Discussions

The efficacy of two conventional MPPTs and two Meta heuristics MPPTs has improved by simulating cooling and non-cooling situations. Firstly, two conventional MPPTs are tested in both cooling and non-cooling situations. Then again the same PV system is integrated with two Meta heuristics MPPTs in both cooling and non-cooling situations. A wide range of 06-combinations are tested for cooling and non-cooling conditions. All the systems are compared with each other to find the Performance of SPV system in all conditions.

### Performance of SPV with P&O MPPT and without Cooling Technology

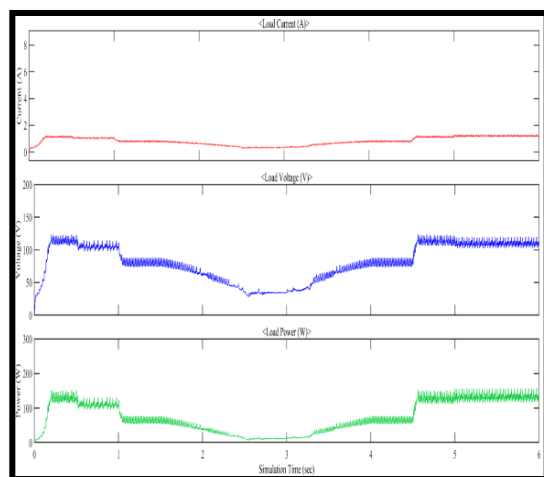
The SPV system includes PV module with copper tubes on the backside of the panel in the form of a heat exchanger, MPPT module, Boost converter and Load. In the PV module, solar insolation, temperature, and voltage are all included. PV voltage boosts the converter by acting as a controlled voltage source. The duty cycle of MOSFET which is used in the DC/DC Boost converter is supplied from MPPT. The MPPT block receives the PV current and voltage as inputs. The output power attains a peak of 140W at 56°C of operating temperature for the panel with the said set up. The load current remains at 1.5A as displayed in Figure 11.



**Figure 11. Load Voltage, Load Current and Output Power for P&O MPPT without PV Cooling**

#### Performance of SPV with P&O MPPT and With Cooling Technology

The SPV system performance is observed with cooling technology. From the result, it is clear that all parameter values are improved with the help of cooling system. As shown in Figure 12, the current draw stays at 1.9A while without cooling it was 1.5A. The output power reaches a maximum of 150W which was 140 W earlier without cooling as shown in Figure 12 at an operating temperature of 45°C for the panel with the aforementioned configuration.

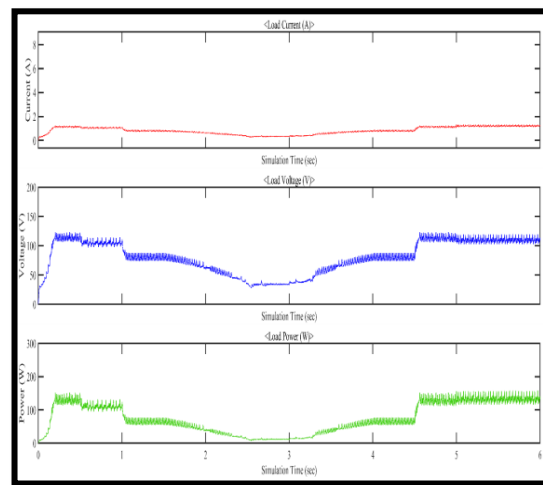


**Figure 12. Load Voltage, Load Current and Output Power for P&O MPPT with PV Cooling**

Compared to a system without PV cooling, the multi-concept solution has showed an increase of 11W. However, the performance of the PO-based system fails in partial shade situations.

#### Performance of SPV with InC MPPT and Without Cooling Technology

The output power attains a peak of 145W at 56°C of operating temperature for the panel with the said set up. The load current remains at 1.6A as depicted in Figure 13.



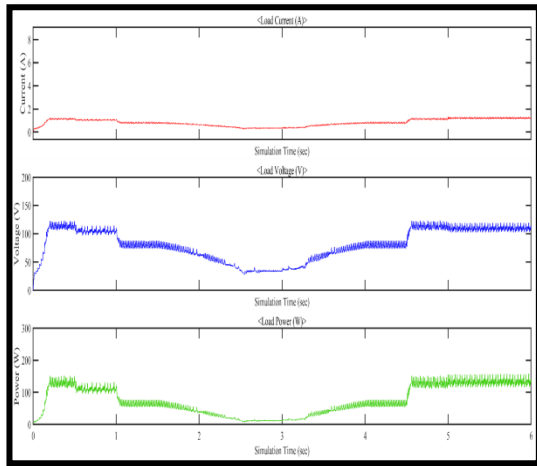
**Figure 13. Load Voltage, Load Current and Output Power for InC MPPT without PV Cooling**

#### Performance of SPV with InC MPPT and With Cooling Technology

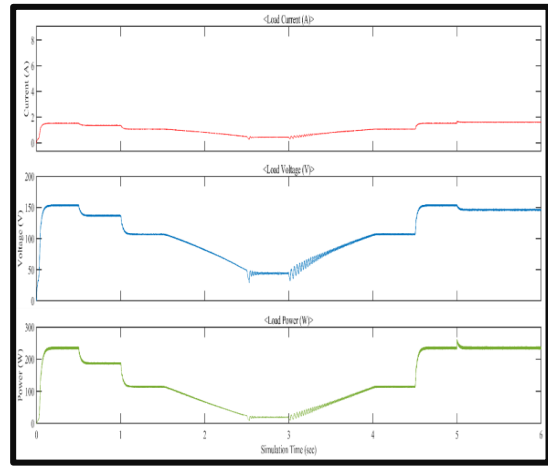
The present current remains unchanged at 1.9A as displayed in Figure 14. At an operating temperature of 40°C, the panel with the aforementioned setup obtains a maximum output power of 160W. The multi-concept approach has shown an increase of 12W compared to a system without PV cooling. However, the performance of the InC-based system fails in conditions involving partial shade.

#### Performance of SPV with PSO MPPT and without Cooling Technology

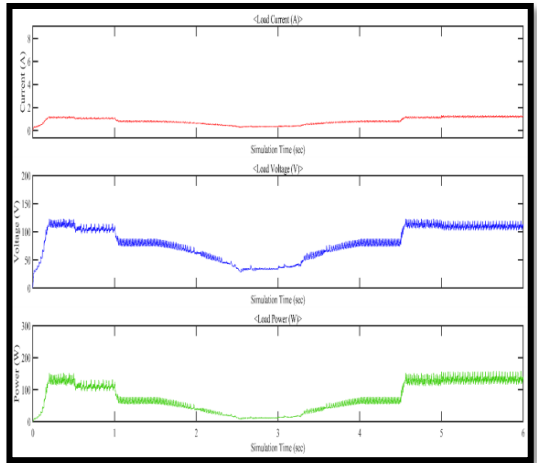
The output power attains a peak of 170W at 56°C of operating temperature for the panel as shown in Figure 15 with the said set up. The load current remains at 1.7A.



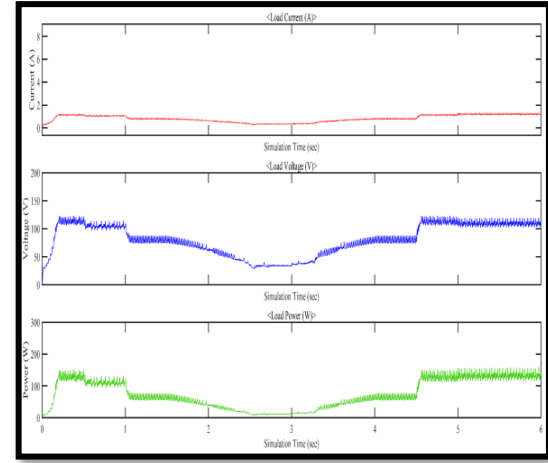
**Figure 14. Load Voltage, Load Current and Output Power for InC MPPT with PV Cooling**



**Figure 16. Load Voltage, Load Current and Output Power for PSO MPPT with PV Cooling**



**Figure 15. Load Voltage, Load Current and Output Power for PSO MPPT without PV Cooling**



**Figure 17. Load Voltage, Load Current and Output Power for Cuckoo MPPT without PV Cooling**

Output parameters for PSO MPPT are displayed in Figure 16. At a 40°C working temperature, the panel with the aforementioned arrangement generates 219W of maximum power output at 1.9A, the current is unchanged. Compared to a system without PV cooling, the multi-concept approach has showed an increase of 12W. The PSO-based system, on the other hand, continues to function well under partial-shade settings.

#### **Performance of SPV with Cuckoo MPPT and Without Cooling Technology**

Figure 17 provides Output parameters for Cuckoo MPPT. The current drawn by the load is 1.7A.

Figure 17. Load Voltage, Load Current and Output Power for Cuckoo MPPT without PV Cooling

#### **Performance of SPV with Cuckoo MPPT and With Cooling Technology**

Figure 18 shows the results for Cuckoo MPPT. Maximum power output is 230W at a 40°C working temperature for the panel with the above setup. The current is the same at 1.9A as it was before. 12W more power was generated by the multi-concept method compared to a system with no PV cooling the PSO-based system, on the other hand, continues to perform well even under partial shade.

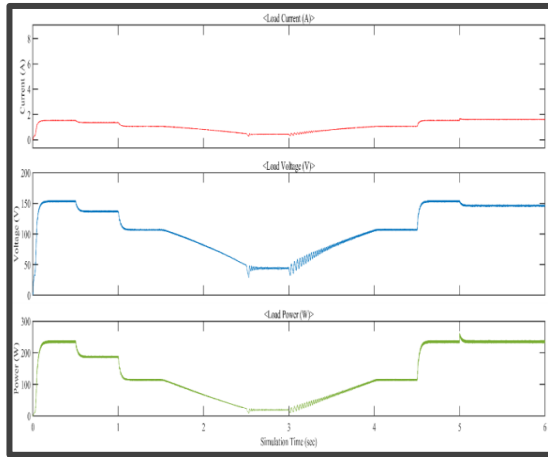


Figure 18. Load Voltage, Load Current and Output Power for PSO MPPT with PV Cooling

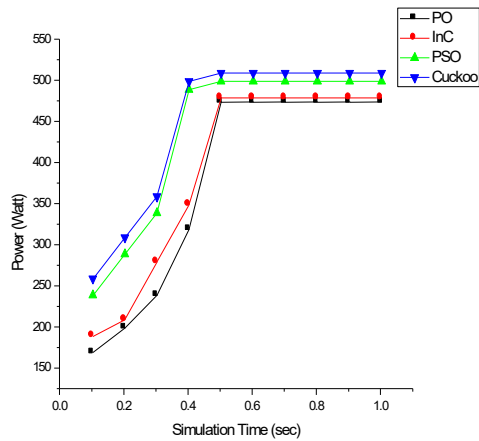


Figure 19. Comparison graph for PV system with MPPT (without cooling)

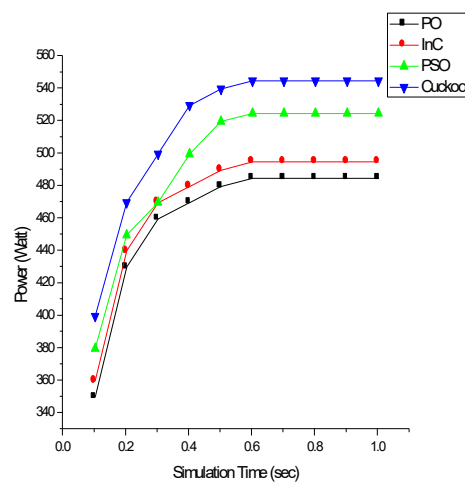


Figure 20. Comparison graph for PV System with Cooling and MPPT

### Comparison of PV systems with MPPT and Without Cooling

Four panels of 150W each are connected to this configuration for comparison. Figure 19 compares the output power of each MPPT in the absence of cooling. Cuckoo MPPT has attained the maximum power of 550W followed by PSO, InC and PO.

### Comparison of PV systems with MPPT and With Cooling

Comparatively, four 150W panels are linked in this setup. Figure 19 compares the power output of each MPPT without cooling. Figure 20 depicts the performance of the system with back surface cooling and MPPT in terms of output power.

Cuckoo MPPT has achieved 556W of highest power, followed by PSO, InC and PO. Utilized cooling method is back surface cooling with Cu tubes and water. The combine effect has been observed in the output power of the system. The system with cooling and Cuckoo search algorithm based MPPT provides maximum output power. The advantage of Meta heuristic algorithms is its sustainability in variable irradiation condition.

### A Comparison of PV/T and PV Power Output with MPPT:

Power output of each configuration is given in Table 2. Table 2 depicts that PVT system is providing more power as compared to normal PV system. Cuckoo MPPT along with cooling has achieved 556W of highest power, followed by PSO, InC and PO with 480W, 490W and 520W.

Table 2. Comparison graph for PV System with Cooling and MPPT

| Type of Configuration | P & O MPPT | InC MPPT | PSO      | Cuckoo   |
|-----------------------|------------|----------|----------|----------|
| Normal PV System      | 470 Watt   | 475 Watt | 490 Watt | 500 Watt |
| PVT System            | 480 Watt   | 490 Watt | 520 Watt | 556 Watt |

### Conclusion

Cuckoo MPPT along with cooling has achieved highest power, followed by PSO, InC and PO with 480W, 490W and 520W respectively. Utilized cooling method is back surface cooling with Cu tubes and water. The combine effect has been observed in the output power of the system by increasing electricity production efficiency by

over 16%. The system with cooling and Cuckoo search algorithm based MPPT provides maximum output power. The advantage of Meta heuristic algorithms is its sustainability in variable irradiation condition. Photovoltaic panels implemented in hot and arid environments frequently encounter elevated temperatures, resulting in diminished efficiency. Despite being less arid than Gwalior, humid and tropical locations can have high temperatures. Application of cooling methods can effectively reduce the impact of humidity and heat on the efficiency of PV panels, therefore promoting a more consistent energy production. Metropolitan regions frequently encounter elevated temperatures compared to rural areas as a result of the urban heat island phenomenon. Adapting the cooling techniques demonstrated in Gwalior to these regions would help to preserve the best possible performance of the panels.

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