

Mathematical Modelling Non Linearity Characteristic Analysis and Efficiency Enhancement Strategies for Hybrid Solar Photovoltaic Energy System

Naval Kishor Jain¹, Shobhit Srivastava²

¹ PhD Scholar, Department of Mechanical Engineering, Maharishi University of Information Technology, Lucknow, India

² Associate Professor, Department of Mechanical Engineering, Maharishi University of Information Technology, Lucknow, India Email: nvl.jain@gmail.com

Article History:

Received: 26-08-2023

Revised: 01-10-2023

Accepted: 30-10-2023

Abstract:

As the world continues to grapple with the challenges posed by climate change and the depletion of conventional energy sources, renewable energy systems such as solar photovoltaic (PV) technology have gained significant prominence. Hybrid solar PV systems, which combine multiple energy sources and storage solutions, offer a promising avenue to improve the reliability and efficiency of renewable energy generation. This research focuses on the mathematical modeling, non-linearity characteristic analysis, and the development of efficiency enhancement strategies for hybrid solar PV energy systems. The study begins with the development of comprehensive mathematical models that accurately represent the complex interactions within hybrid solar PV systems. These models consider various factors, including solar irradiance, temperature variations, load profiles, and the dynamic behavior of energy storage components. The incorporation of non-linear characteristics, often overlooked in conventional models, allows for a more realistic representation of system performance. To enhance the efficiency of hybrid solar PV systems, a range of strategies are proposed and evaluated. These strategies encompass advanced control algorithms, optimized sizing and placement of energy storage elements, and the integration of emerging technologies such as artificial intelligence and machine learning. The goal is to mitigate non-linear effects, maximize energy utilization, and improve system response to dynamic operating conditions.

The findings from this research provide valuable insights into the design, operation, and performance optimization of hybrid solar PV energy systems. By addressing non-linearity characteristics and developing efficient strategies, this study contributes to the advancement of renewable energy technologies and fosters the transition towards a more sustainable and resilient energy future.

Keywords: Solar Photovoltaic System, Maximum Power Point Tracking, Soft Computing Techniques, Meta Heuristic Search, Particle Swarm Optimization, Cuckoo Search Optimization, PV-T System, Adaptive Neuro Fuzzy Inference System.

1. INTRODUCTION

A Solar panels or solar cells collect solar energy and turn the light energy into electricity. PV cells, sometimes referred to as "solar cells," employ the photovoltaic effect to store the solar energy that results in a current flowing between two oppositely charged layers. The solar cell's conversion efficiency is calculated by dividing the ratio of solar energy (irradiation) that strikes on the area of solar cell to the electrical energy output of the cell. The semiconductor material used in solar cells has

been doped to create p-n junction which absorbs the sunlight and with the help of photovoltaic effect it and transform it into direct current. To represent the behavior of solar cell a single-diode model is commonly used because it is straightforward and precisely represents the characteristics of p-n junction. [1]

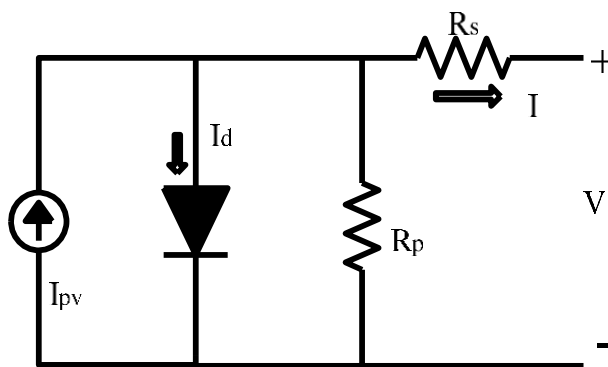


Figure 1.1: Equivalent Circuit of a Single Diode Solar Cell

The solar cells are connected in series or parallel to create the proper voltage and current. When the cells are connected in series, a significant output voltage is created; however, when the cells are connected in parallel, a huge output current is generated. The mathematical analogous circuit architecture for a single-diode PV panel is shown in Figure 1.1 and consists of parallel and series resistances, a current source, and a diode. The mathematical model is important to understand and calculate the I-V and P-V characteristics of the PV cell under various operational conditions. [2]

The mathematical modeling is also important to understand the dynamic performance of solar photovoltaic system under different operational conditions. It shall be noted that under situations of constant irradiance and varying temperature or vice versa the I-V and P-V characteristics changes and the performance of solar cell is hence influenced by the operational conditions.

Mathematical Modelling of Solar Cell

In Figure 3.1, the PV equivalent circuit is shown. It shall be noted that a potential difference is produced when light strikes photovoltaic cells, and this voltage varies linearly with solar insolation. It is feasible to model the ideal solar cell as a current source. Current leakage proportional to solar cell terminal voltage is provided by shunt resistance (\$R_p\$). Series resistance is used to depict the losses due to semiconductor and metal contacts (\$R_s\$). Parallel diodes are used to simulate the p-n junctions of PV cells in order to calculate the current generated by light impinging on a PV cell. The solar cell behavior is provided by the equation given below. The I-V relationship of the PV system defines the modeling of the PV cell as follows:[22]

$$I = I_{pv} - I_s \left(\exp \left[\frac{q(V + R_s I)}{N_s k T a} \right] - 1 \right) - \frac{V + R_s I}{R_p} \quad (1.1)$$

$$I_{pv} = (I_{pv,n} + K_I \Delta T) \frac{G}{G_n} \quad (1.2)$$

$$I_s = \frac{I_{SC,n} + K_I \Delta T}{\exp(V_{OC,n} + K_V \Delta T) / a(N_s k T / q) - 1} \quad (1.3)$$

$$I_{PV} = I_{Ph} - I_D - I_p \quad (1.4)$$

$$I_p = \frac{(V_p + R_s I)}{R_p} \quad (1.5)$$

I_p - photo current, I_D - Diode current

$$I_D = I_0 \left[\exp \frac{((V_p + R_s I))}{(nK_B T)} - 1 \right] \quad (1.6)$$

Now substituting the value of I_D

$$I_{PV} = I_{Ph} - I_0 \left[\exp \frac{(V_p + R_s I)}{(nK_B T)} - 1 \right] - I_p \quad (1.7)$$

$$I_{PV} = I_{Ph} - I_0 \left[\exp \frac{(V_p + R_s I)}{(nK_B T)} - 1 \right] - \frac{(V_p + R_s I)}{R_p} \quad (1.8)$$

$$V_T = \frac{(K_B T_c)}{q_e} \quad (1.9)$$

$$I_a = \frac{n_s A_f K_B T_c}{q} = n A V_T \quad (1.10)$$

$$I_{PV} = I_{Ph \text{ ref}} - I_{0 \text{ ref}} \left[\exp \left(\frac{V_p}{a_{\text{ref}}} \right) - 1 \right] \quad (1.11)$$

$$I_{sc \text{ ref}} = I_{Ph \text{ ref}} - I_{0 \text{ ref}} \left[\exp \left(\frac{(0)}{a_{\text{ref}}} \right) - 1 \right] = I_{Ph \text{ ref}} \quad (1.12)$$

The connection between irradiance, temperature, and the photocurrent is given by

$$I_{pv} = \frac{G}{G_{\text{Ref}}} (I_{ph \text{ ref}} + \mu_{sc} \cdot \Delta T) \quad (1.13)$$

Where,

G-Irradiance W/m^2

G_{ref} - Irradiance at STC (1000 W/m^2)

$$\Delta T = T_c - T_{c \text{ ref}} \quad (1.14)$$

μ_{sc} -Coefficient temperature of Short circuit and I_0 is given by the

$$I_0 = I_{sc} \exp \left(\frac{-V_{oc \text{ rff}}}{a} \right) \left(\frac{T_c}{T_{c \text{ ref}}} \right)^3 \times \exp \left[\left(\frac{q \in G}{A \cdot K} \right) \left(\frac{1}{T_{c \text{ ref}}} - \frac{1}{T_c} \right) \right] \quad (1.15)$$

The mathematical model can be employed to derive the characteristic of solar photovoltaic cell, modules and arrays/ The given topology can be used for implementation of partial shading and variable irradiation characteristic analysis. The characteristics has been analyzed and presented with help of simulation of solar pane. The paper has been divided into five segments. The first segment is related to introductory concept of solar photovoltaic modules. Next section related to survey of research papers. Introduction of maximum power point system has been discussed in next section which has

been followed by proposed methodology and its implementation. Simulation and results has been shown in next part of the paper.

2. RELATED WORKS

Tanuj Sen et al. (2018), in their work have proposed modified PSO algorithm owing to the incapacity of traditional MPPT techniques to track global maximum power of the PV characteristics having multiple peaks and validations through simulations. The authors have also pointed the advantage of reduced steady state oscillations [1].

G. Dileep et al. (2017), in their research have penned about the adaptive PSO algorithm so as to obtain improved overall speed and competency of the system and for the same they utilized two unlike shading conditions for the validation of proposed approach. The results thus obtained clearly proves that the discussed approach can obtain the global point of maximum power point in all the cases [2].

R.Nagarajan et al. (2018) has described the method to enlarge the output value of voltage from PV system by making use of maximum power point tracking approach namely Particle Swarm Optimization. In their work they have used PI controller in addition to PSO for boost convertor to convert DC to DC voltage[3].

Kashif Ishaque et al. (2012) have depicted a modified Particle Swarm optimization for improved version of maximum power point tracking. This paper also suggests that the proposed method can be used to tracking of power even in the altering environmental conditions with the advantage of reduced oscillations in steady state after the MPP is located [4].

Faiza Belhachat et al. (2018) have given a review on the techniques of maximum power point tracking ranging from old age lesser used techniques to modern times advanced ones so that users can make a good choice based on the performances of each method while making any system[5]

Ali M. Eltamaly et al. (2020) have discussed certain problems of PSO including long convergence time by already updating the initial values of the duty ratio of converter. In addition to this, they also gave comparisons between the ability of different methods to find GP under dynamic shading conditions [6].

Makbul A. et al. (2017) have given a description of various maximum power point techniques of the PV systems during normal climatic condition and partial shading conditions. The authors have mainly focused on partial shading conditions since the last decade owing to increased requirement of output [7].

Zhu Liying et al. (2017) have penned about all maximum power point tracking technique used in extracting peak power output during varying shading conditions and the limitations of conventional methods over particle swarm optimization methods[8].

Rozana Alik et al. (2017), in their research work had demonstrated the unwanted impacts of partial shading in PV system and an improved perturb and observe algorithm. The authors have quoted about the various merits of this method like lower cost, simplicity and accuracy. The proposed method is advancement over conventional P and O method which makes system unstable. The author discussed all related flowcharts and algorithms [9].

Mingxuan Mao et al. (2017) proposed a novel method of tracking maximum power point simultaneously reducing steady state oscillations. The methodology being incorporated in the paper ensured faster and more accurate searching of global maximum which in turn explains its superiority over conventional methods [10].

Gomathi B et al. (2016) proposed an incremental conductance algorithm based Solar Maximum Power Point Tracking System makes vivid illustrations about the incremental conductance technique. The paper describes about its steady state accuracy and higher efficiency. The authors have systematically modelled the PV module and solar radiation using basic equations, flowchart of the algorithm, DC-DC Converter of all the three types and their comparison. The results proved that Boost and Cuk converter provides the best results and have lower ripples [11].

Mr. M. Rupesh et al. (2018) presented a detailed investigation of the two MPPT approaches namely P and O and incremental conductance. Here, in this work fundamental quantities like current and voltage are being followed to mimic the described algorithms. The paper also discusses the modelling of PV cell, I-V and P-V graphs of the solar array being obtained at different irradiances. The complete setup of PV system as shown includes boost converter and MPPT controller. The voltage profile of boost converter with both the algorithms is also given [12].

S. Manna et al. (2021) have thrown light on the drift free perturb and observe method which incorporates current in addition to voltage and power as used in conventionally used perturb and observe. The drift algorithm is named so because it efficiently solves the problem of drift which is caused due to the altering environmental conditions mainly sudden to change in insulation levels during cloudy days and hence the authors have performed a test of both the algorithms for variation in insulation level and proved the percentage increase in power during the time of drift in the method discussed which improves its efficiency and accuracy levels [13].

Saad Motahhir et al. (2018) extracted the parameters for modelling the PV panel and further explained the consequences of temperature and radiation on PV array. The authors have also explained why the conventional theorems behave inaccurately when temperature and radiations are increased and hence for the solution of the same, they have discussed a modified incremental conductance theorem which can successfully reduce the steady state oscillations [22].

Abul kalam Azad et al. (2016) discussed about the application of perturb and observe and incremental conductance in the PV system. Here, output has been directly connected to the grid so as to make it run like a solar generator on cloudy days. The simulation results from both the algorithms are compared under same conditions and the author concluded that the P & O is not very effective under varying atmospheric conditions while the later works accurately [23].

Afshan Ilyas et al. (2017) have proposed a detailed explanation of incremental conductance algorithm. Here, the PV module has been integrated with dc-dc converter. The paper also includes modelling of solar PV cell. The authors used a real time reading of the parameters and concluded that incremental conductance has a higher tracking speed and accuracy [24].

Jubaer Ahmed et al. (2017) had given explanation about the difference between partial shading and uniform radiance. This work discusses the two renowned method namely particle swarm

optimization and perturb and observe and also evaluates their performance during partial shading and dynamic type shading conditions [25].

Ehtisham Lodhi et al. (2017) explained about the consequences of unlike shading on the photovoltaic system. This paper explains the presence of multiple peaks during the times of partial shading i.e. when the sun is not coming constantly and there are clouds and hence gives explanation of the particle swarm optimization method in finding the global peak among the various peaks present during shaded conditions. The authors have given a detailed flowchart of the algorithm which explains the step by step procedure to use the algorithm in searching the maximum peak point during shading conditions of weather. The paper concludes that this algorithm has higher convergence rate and tracking efficiency than the conventionally used methods [26].

T. Diana et al. (2019) had proposed one of the best known optimization technique so as to extract the maximum power from solar system i.e. particle swarm optimization. This method utilises an objective function. The author has tested the algorithm under different conditions of temperature and radiation level so as to justify the efficiency level of its algorithm in contrast to the conventionally known tracking algorithms. The author have also presented various graphs to justify the work [27].

R Sridhar et al. (2017) shown the increment of output of PV system in case of variable environmental conditions. The paper discusses about the widely known particle swarm optimization and the simulations are carried out which speaks about the efficiency of this method. The author has explained the Particle swarm optimization method in detail. They have penned about the detailed analysis of characteristics and modelling of PV array using mathematical equations and the PV and IV curves are plotted to further explain the working of PV system. [28].

Nadia Hanis et al. (2016) in their work explained the need to popularise the renewable energy sources and their dependence on temperature and radiation. The mathematical modelling has been discussed in detail using solar PV equations of voltage and current. In addition to this, Particle based optimization based MPPT is also given. The flowchart of the above mentioned algorithm further makes the explanation easier by explaining the direction of the algorithm. The characteristics curves are obtained under varying temperature and irradiance conditions are also given to study the convergence of the theorems under different conditions of environment [29].

Ahmed Hossam El-din et al. (2017) compared the two widely known algorithms namely perturb and observe and PSO under uniform temperature conditions. The Particle swarm algorithm has a high level speed and can work under varying parameters of irradiance and temperature. The paper also shows the module performance of the system. The research is carried out on a 100 KW grid connected PV system under different conditions of environment [30].

Malik Sameeullah et al. (2016) discussed about various MPPT schemes and their implementation. The authors compares the features, cost, control strategy of all the discussed methodologies so that one can easily opt for a good algorithm according to his area of research. This paper includes all the techniques from current/ voltage feedback technique to modern day hybrid MPPT technique which are useful in different types of environmental conditions from fine day to varying climatic conditions.[31].

Arti Pandey et al. (2019) discussed the various techniques of MPPT in tabular form and the urgent need to move towards the renewable energy sources as the cost of fossil fuels is continuously rising and the emission level of carbon dioxide from non-renewable energy sources is quite high and dangerous for the environment and the life of humans..It gives a brief about all the majorly known MPPT methods and their merits and demerits. Furthermore, advantages and disadvantages of all the methods have been listed in points [32].

3. MATHEMATICAL MODELING OF SYSTEM

PV arrays are created by connecting PV modules in a series-parallel configuration. The aggregate output of the PV array will be the same as the total power produced by all of the modules. As a result, even small adjustments to one PV module can affect the entire system and might result in issues with further PV modules. Sometimes situational, sometimes natural, shading is a phenomenon that cannot always be avoided. Figure 3.1 contains a symbolic description of the shading of solar photovoltaic panels. A PV array is made up of PV modules that are linked in parallel and series to provide the necessary voltage. It is critical to address this issue because under various lighting setups, modules have heat dependent losses influencing the power they generate under standard illumination. Shading has an impact on photovoltaic (PV) panels since they are made of crystalline silicon cells coupled to one another.

1. *Solar panel efficiency equation:*

$$[\eta_{PV} = \frac{P_{out}}{P_{in}}]$$

2. *Solar cell current – voltage relationship (Shockley diode equation):*

$$[I_{PV} = I_{ph} - I_0 \left(e^{\frac{V_{PV}}{nV_t}} - 1 \right)]$$

3. *Solar cell power output equation:*

$$[P_{out} = V_{PV} \cdot I_{PV}]$$

4. *Maximum power point tracking (MPPT) algorithm:*

$$[P_{out} = V_{MPPT} \cdot I_{MPPT}]$$

5. *Non – linearity index calculation for solar panel:*

$$[NL = \frac{P_{out,max} - P_{out,min}}{P_{out,max} + P_{out,min}}]$$

6. *Efficiency of a DC – DC boost converter:*

$$[\eta_{boost} = \frac{V_{out} \cdot I_{out}}{V_{in} \cdot I_{in}}]$$

7. *Efficiency of a DC – DC buck converter:*

$$[\eta_{buck} = \frac{V_{out} \cdot I_{out}}{V_{in} \cdot I_{in}}]$$

8. *Battery charging and discharging efficiency:*

$$[\eta_{\text{batt}} = \frac{E_{\text{out}}}{E_{\text{in}}}]$$

9. *Energy balance equation for a hybrid PV system:*

$$[E_{\text{in}} = E_{\text{PV}} + E_{\text{grid}} + E_{\text{batt}}]$$

10. *Efficiency of an inverter:*

$$[\eta_{\text{inverter}} = \frac{P_{\text{out,AC}}}{P_{\text{in,DC}}}]$$

11. *Photovoltaic cell temperature calculation:*

$$[T_{\text{cell}} = T_{\text{ambient}} + \frac{I_{\text{PV}} \cdot R_{\text{cell}}}{A_{\text{cell}} \cdot h_{\text{cell}}}]$$

12. *LambertW function(used in modeling diode ideality factor, n):*

$$[n = -\frac{V_t}{I_0} \cdot W\left(-\frac{I_0}{I_{\text{PV}}} \cdot e^{-\frac{V_{\text{PV}}}{V_t}}\right)]$$

13. *Non – linear output voltage relationship for PV cells:*

$$[V_{\text{PV}} = V_{\text{oc}} - I_{\text{PV}} \cdot R_s]$$

14. *Short – circuit current of a PV cell:*

$$[I_{\text{sc}} = \frac{V_{\text{oc}}}{R_s}]$$

15. *Open – circuit voltage of a PV cell:*

$$[V_{\text{oc}} = n \cdot V_t \cdot \ln\left(\frac{I_{\text{ph}}}{I_0} + 1\right)]$$

16. *Irradiance – dependent current equation:*

$$[I_{\text{ph}} = G \cdot A_{\text{cell}} \cdot I_{\text{sc,STC}} \cdot \left(\frac{T_{\text{cell}}}{T_{\text{STC}}}\right)]$$

17. *Solar cell temperature coefficient:*

$$[\alpha_T = \frac{I_{\text{sc,STC}}}{I_{\text{ph,STC}}} \cdot \frac{T_{\text{STC}} - T_{\text{cell}}}{T_{\text{STC}}}]$$

18. *Diode ideality factor temperature correction:*

$$[n_T = n_0 + \alpha_n \cdot (T_{\text{cell}} - T_{\text{STC}})]$$

19. *Efficiency enhancement with bifacial solar panels:*

$$[\eta_{\text{bifacial}} = \frac{2 \cdot \eta_{\text{PV}}}{1 + \frac{h_{\text{front}}}{h_{\text{rear}}}}]$$

20. *Modeling the impact of shading on PV arrays:*

$$[I_{\text{shaded}} = I_{\text{unshaded}} \cdot \left(1 - \frac{A_{\text{shaded}}}{A_{\text{total}}}\right)]$$

21. *Temperature coefficient of power (P – T curve):*

$$\left[\frac{dP_{\text{out}}}{dT} = -\frac{P_{\text{out}}}{T_{\text{cell}}}\right]$$

22. *Battery charge – discharge efficiency modeling:*

$$[\eta_{\text{batt}} = \frac{E_{\text{discharge}}}{E_{\text{charge}}}]$$

23. *Energy balance equation for the entire hybrid system:*

$$[E_{\text{in}} = E_{\text{PV}} + E_{\text{wind}} + E_{\text{grid}} + E_{\text{batt}}]$$

24. *Electrical losses in wiring and connections:*

$$[P_{\text{loss}} = I^2 \cdot R_{\text{loss}}]$$

25. *Solar cell fill factor calculation:*

$$[\text{Fill Factor (FF)} = \frac{V_{\text{MPPT}} \cdot I_{\text{MPPT}}}{V_{\text{oc}} \cdot I_{\text{sc}}}]$$



Figure 3.1: Impact of Shading on Characteristics of PV System

A conventional PV panel has solar cells linked in series to produce a high voltage, but all of the cells share the same current when they are connected in series. If the PV module or PV cells are shaded, they may be forced to operate in a reverse-biased zone and function as a load rather than a power supply. The panel can sustain permanent damage if the temperature of the cell rises considerably and

causes a thermal breakdown or second breakdown. The second breakdown phenomena occurs when the temperature of a reversely biased cell rises over a certain point, leading to a drop in the magnitude of the reverse voltage and an increase in the cell's current value. In this instance, the P-N junction temperature substantially rises, resulting in irreparable cell damage. [17]

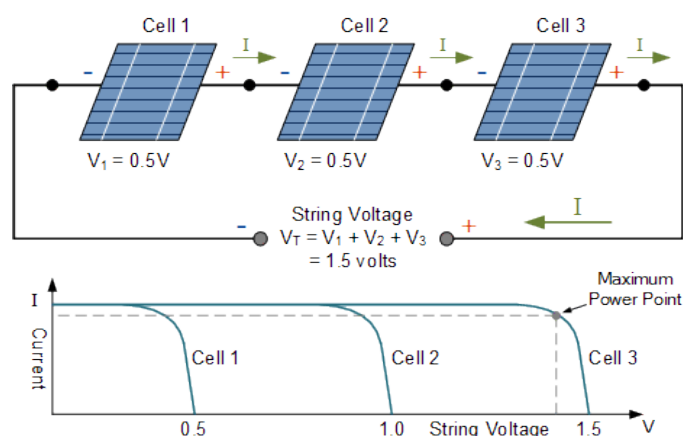


Figure 3.2 : Normal Operation of PV String

Figure 3.2 depicts a photovoltaic string operating normally. It should be emphasized that each photovoltaic cell in a panel will produce the same amount of electrical power, or around 0.5 volts, provided that the quantity of sunlight reaching its surface remains constant. When the sun is shining strongly, a 2 watt PV cell, for instance, will provide a continuous current of roughly 4 amperes ($0.5 \times 4 = 2$ watts). However, if a cell is externally shadowed in any manner, it will cease producing electrical energy and begin functioning more like a semi conductive resistance, greatly limiting the total amount of energy the solar panel can produce. Let's use the example of three series-connected 0.5 volt photovoltaic cells that each get 1 kW/m² of solar irradiation as our example. Due to the series connection of the three PV cells, the output current (I) generated will be the same. Given that the current is common and constant, the I-V characteristic curves of the three cells may be summed along the voltage (horizontal) axis, and the resultant total output voltage, V_T , is equal to the sum of the individual cell voltages ($V_1 + V_2 + V_3 = 0.5V + 0.5V + 0.5V = 1.5V$). If we were to use the 2 watt cell example from before, the maximum power point for this series string would be 6 watts ($1.5V \times 4A = 6W$). Let's now assume that Solar Cell No. 2 in the string is either entirely or partially shaded, although the other two cells in the series-connected string have not—i.e., they still receive full sun. The output of the string with a series connection will afterwards sharply decline, as demonstrated. In this scenario, the shaded cell ceases producing electrical energy and behaves more like a semi conductive resistance.

As was already noted, if one of the PV cells is partially blocked by snow, leaves, or other debris, it will no longer be able to generate any electrical energy, as was seen above. Consequently, the bypass diode will take over and turn on as illustrated.

In this situation, cell number two ceases generating electrical energy when it is shaded and starts to behave like the semi-conductive resistance we previously mentioned. As seen by the green arrows above, the shaded cell generates reverse power, which forward biases the parallel-connected bypass diode (i.e., turns it "ON") and directs current flow from the two healthy cells via itself. By giving the

produced current an electrical channel to follow, the bypass diode connected across the shaded cell keeps the other two PV cells running. Figure 3.4 illustrates how the bypass diode functions and improves the performance.

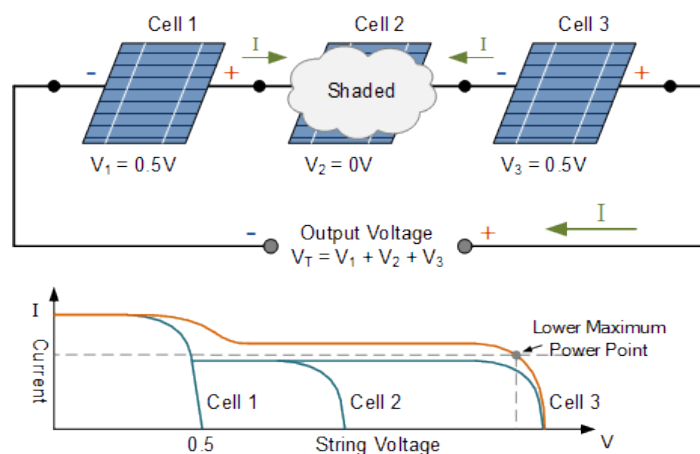


Figure 3.3 : Impact of Shading on Characteristics of PV System

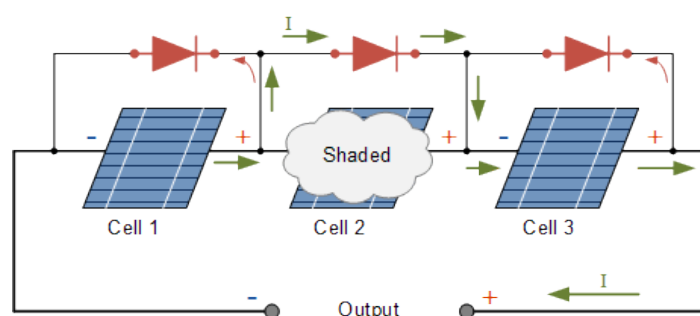


Figure 3.4 : Connection of Bypass Diode in PV System

Cells 1 and 3 continue to create energy, albeit at a slower pace, despite the fact that one cell (cell 2 in this case) is shaded. As a consequence, the output would be 4 watts when utilizing the same 2 watt cell as in the previous example and assuming no losses through the bypass diode.

When forward biased, or conducting, parallel linked bypass diodes have a forward voltage drop of roughly 0.6 volts, which restricts any excessive reverse negative voltage generated by the shaded cell and, as a result, reduces hot spot temperature conditions and prevents cell breakdown. When the shading is removed, this enables the cell to go back to its original state.

It would be too expensive and challenging to install to include a bypass diode across each and every cell, as we have done in our simple example. In actuality, bypass diodes are often installed on the rear of PV cell groups or sub-strings (typically 16 to 24 cells), or in the junction boxes of solar modules.

Charge controllers have an algorithm built in to get the maximum power out of PV modules. Peak voltage is the voltage where it produces the most power (P_{max}). Temperature and sunlight insolation rate both affect maximum power. [4].

Figure 3.5 indicates the significance of maximum power point tracking on the performance of solar photovoltaic system. MPPT compares the voltage, current, and battery out of the system. When it's chilly outside or there are clouds in the sky, MPPT is incredibly efficient and can get the most out of

a PV module. When a battery is deeply drained, MPPT technology can improve current flow and speed up battery recharge. The amount of battery input current from a PV module may be maximized using a charge controller integrated with the MPPT algorithm. The following are the primary attributes of an MPPT solar charge controller:

- It fixes fluctuations in PV cell voltage and current characteristics brought by varying illumination conditions.
- It enables the usage of voltage greater than the battery system's operational voltage and compels the PV module to generate electricity at its MPP.
- It makes the system less complicated and makes it more effective.

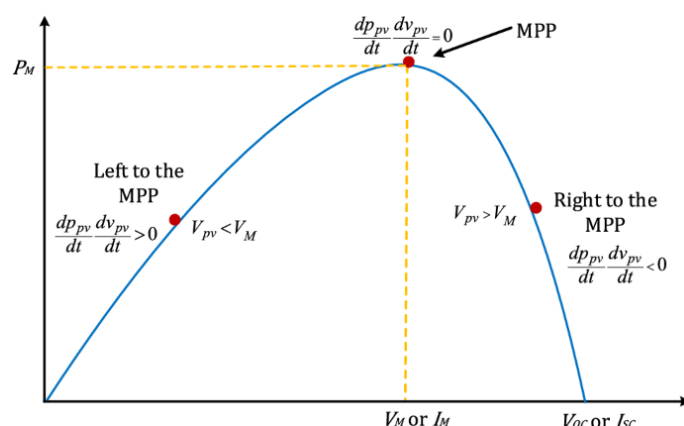


Figure 3.5: Significance of MPPT on Power Output of Solar PV System

All around the world, there is a growing need for clean, renewable energy. Making effective and efficient PV systems is always urgently needed given the rising popularity of solar power. The process to select effectively specific voltage and current parameters are met, when the power is at its peak, so that the solar energy system's energy conversion rate reach a high level. Maximum Power Point is the name of this operational point (MPP). A PV panel's nonlinear power-voltage characteristic is influenced by both the temperature of the environment and the amount of sunlight received. When compared to sunshine irradiation, the temperature-related change in voltage and power is less substantial.

The power output of a PV panel varies during the day since the amount of sunshine is not consistent. Additionally, the MPP changes when the amount of sunshine and the temperature of the atmosphere alter. In order to obtain the maximum power at any irradiance and temperature, MPP must be maintained. Maximum Power Point Tracking refers to keeping a PV panel's operating point at MPP regardless of temperature and irradiance (MPPT). Handling partial shadowing conditions is a significant issue with solar power generating systems. The sunlight's irradiance varies throughout the panel when there is partial shadowing. A significant number of PV panels are linked in series to generate the desired amount of electricity in a PV power production system. The PV panels are exposed to non-uniform irradiance when partially shaded, and in this case, the power-voltage characteristics show several power peaks.

1. Photovoltaic Cell Current-Voltage Relationship:

$$I = I_{ph} - I_0 \left(e^{\frac{q|V+IR_s|}{nT}} - 1 \right) - \frac{V + IR_s}{R_{sh}}$$

where I is the cell current, I_{ph} is the photo-generated current, I_0 is the dark saturation current, V is the cell voltage, R_s is the series resistance, R_{sh} is the shunt resistance, n is the ideality factor, k is the Boltzmann constant, T is the cell temperature, and q is the charge of an electron.

2. Maximum Power Point (MPP) Tracking:

$$\frac{dP}{dV} = 0$$

where P is the power, and V is the voltage. This condition is used to find the maximum power point.

3. Fill Factor (FF):

$$FF = \frac{V_{mp} I_{mp}}{V_{sc} I_{sc}}$$

where V_{mp} and I_{mp} are the voltage and current at the maximum power point, respectively, and V_{OC} and I_{SC} are the open-circuit voltage and short-circuit current, respectively.

4. Solar Cell Efficiency:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{mp} I_{mp}}{A \cdot G}$$

5 Where P_{max} is the maximum power output, P_{in} is the input power, A is the area of solar cell, and G is the irradiance.

6 The Temperature Effect on Photovoltaic Efficiency:

$$\eta(T) = \eta_{STC} - \beta(T - T_{STC})$$

where $\eta(T)$ is the efficiency at temperature T , η_{STC} is the efficiency at Standard Test Conditions (STC), β is the temperature coefficient, and T_{STC} is the STC temperature.

6. Irradiance Effect on Photocurrent:

$$I_{ph}(G) = I_{ph,STC} \frac{G}{G_{STC}}$$

where $I_{ph,STC}$ is the photocurrent at STC, G is the actual irradiance, and G_{STC} is the irradiance at STC.

7. Power Output of PV Module:

$$P_{out} = N_{cell} \cdot V_{mp} \cdot I_{mp}$$

where N_{cell} is the number of solar cells in the module.

8. Hybrid System Efficiency:

where η_{PV} and η_{other} are the efficiencies of the PV system and the other energy system (e.g., wind, thermal) respectively, P_{PV} and P_{other} are their respective power outputs.

9. Battery Charge Equation:

$$Q_{\text{new}} = Q_{\text{old}} + I_{\text{charge}} \Delta t - I_{\text{discharge}} \Delta t$$

where Q_{new} and Q_{old} are the new and old charge states of the battery, I_{charge} and $I_{\text{discharge}}$ are the charging and discharging currents, and Δt is the time interval.

10 Energy Stored in Battery:

$$E = Q \cdot V_{\text{lot}}$$

where E is the energy, Q is the charge, and V_{bat} is the battery voltage.

11. Overall System Energy Balance:

$$E_{\text{in}} = E_{\text{PV}} + E_{\text{other}} = E_{\text{out}} + E_{\text{loss}}$$

where E_{in} is the total energy input, E_{PV} and E_{other} are the energies from the PV system and other sources, E_{out} is the energy output, and E_{loss} are the losses.

12. Converter Efficiency:

$$\eta_{\text{conv}} = \frac{P_{\text{ous, ami}}}{P_{\text{intanx}}}$$

where $P_{\text{out, conv}}$ and $P_{\text{int, conv}}$ are the output and input powers of the converter.

13. Inverter Efficiency:

$$\eta_{\text{ine}} = \frac{P_{\text{AC}}}{P_{\text{DC}}}$$

where P_{AC} is the AC output power and P_{DC} is the DC input power to the inverter.

14. Load Demand Satisfaction:

$$\frac{\sum P_{\text{out}}}{\sum P_{\text{lend}}} \times 100\%$$

where $\sum P_{\text{out}}$ is the total power output from the system and $\sum P_{\text{lend}}$ is the total load demand.

15. Capacity Factor:

$$CF = \frac{\text{Actual Energy Output}}{\text{Maximum Possible Energy Output}}$$

16 Energy Payback Time:

$$\text{EPBT} = \frac{\text{Energy Invested}}{\text{Annual Energy Production}}$$

17 Levelized Cost of Energy (LCOE):

$$\text{LCOE} = \frac{\text{Total Lifetime Cost}}{\text{Total Lifetime Energy Production}}$$

18 Net Present Value (NPV):

$$NPV = \sum_{t=1}^n \frac{G_t}{(1+r)^t}$$

where C_t is the cash flow in year t , n is the project lifetime, and r is the discount rate.

19. Internal Rate of Return (IRR):

$$0 = \sum_{t=1}^n \frac{C_t}{(1+IRR)^t}$$

20 Return on Investment (ROI):

$$ROI = \frac{\text{Net Profit}}{\text{Investment Cost}} \times 100\%$$

21 Carbon Footprint Reduction:

$$CFR = \text{Emission Factor} \times \text{Energy Produced}$$

22 System Reliability:

$$R(t) = e^{-\lambda t}$$

where $R(t)$ is the reliability function, λ is the failure rate, and t is the time.

23. Maintenance Cost Over Time:

$$C_{\text{maint}}(t) = C_{\text{initial}} + \sum_{i=1}^n C_{\text{yearly}} \cdot (1+r)^{-i}$$

where C_{initial} is the initial maintenance cost, C_{yearly} is the annual maintenance cost, and r is the discount rate.

24. Thermal Model for PV Temperature:

$$T_{PV} = T_{\text{ambient}} + \frac{NOCT - 20}{800} \cdot G$$

where T_{PV} is the PV module temperature, T_{ambient} is the ambient temperature, $NOCT$ is the Nominal Operating Cell Temperature, and G is the solar irradiance.

25. Wind Energy Conversion (if part of the hybrid system):

$$P_{\text{wind}} = \frac{1}{2} \rho A v^3 C_p$$

where P_{wind} is the power generated by wind, ρ is the air density, A is the area swept by the wind turbine blades, v is the wind speed, and C_p is the power coefficient of the by the wind turbine blades, v is the wind speed. These equations provide a comprehensive overview of the various aspects of modeling and analyzing a hybrid solar photovoltaic energy system. They can be used for performance assessment, optimization, and designing strategies for efficiency enhancement. Global Power Peak is the name of this power peak's maximum (GPP). Only when a PV system is run at GPP can its power output under partial shade conditions reach its maximum. In order to get the most power out of a

partially shaded PV system, the operating point should be kept at GPP under partial shading conditions. [1

4. PROPOSED METHODOLOGY

Inspired by the brood parasitism of some cuckoo species, which deposit their eggs in the nests of other species as hosts, Xin-She Yang and Susah Deb developed a novel optimization approach in 2009 dubbed Cuckoo Search (CS). It's more versatile and efficient than Particle Swarm Optimization (PSO) and the Genetic Algorithm (GA) in solving optimization problems (Yang and Deb 2014). The cuckoo's reproductive strategy provided as inspiration for the heuristic search algorithm used in CS. The term "nature inspired computation" refers to a class of computing algorithms that is influenced by studies of natural systems. Potential solutions to an optimization issue are analogous to individuals in a population, with the fitness function serving as the criterion for success. Cuckoo eggs often hatch before host eggs. The first cuckoo chick to emerge from its egg will immediately begin throwing host eggs out of the nest. This results in a larger share of the host bird's diet for the cuckoo chick. A cuckoo egg represents an unexplored avenue of inquiry. The idea is to swap out mediocre nesting strategies for new, maybe better ones (cuckoos) (Sakthi & Nedunchezian 2014).

The CS algorithm is inspired by brood parasitism in cuckoo species, the Levy flying behavior of birds, and fruit flies. It is possible that certain species of cuckoo lay their eggs in group nests. When the host bird discovers the eggs aren't its own, it either throws them away or leaves the nest to start a new one elsewhere. For the sake of simplicity, the explanation of CS is based on three idealised rules:

- The cuckoo lays its single egg in a nest chosen at random;
- The best nests produce high-quality offspring;
- The number of host nests is fixed, and the cuckoo egg is detected by the host with probability $[0, 1]$. More calculations are done to identify and eliminate the poorest nests.

The CS algorithm is a fast-convergence optimization method. Its original release date was 2009. The algorithm was conceived as a nod to the cuckoo bird's parasitic reproduction strategy. This bird does not build its own nest and instead prefers to use the nests of other species. It uses a strategy to choose a suitable host nest that involves randomly visiting several nests until it finds one with the highest chances of producing healthy offspring. Cuckoos will occasionally remove the host bird's eggs from the nest to increase the chances of hatching their own. To lessen the chances of being found, certain cuckoo species may alter the shape of their eggs so that they are similar to those of the host bird. If the host bird figures out the cuckoo's trick, it may abandon the nest or discard the cuckoo's eggs. The CS algorithm is inspired by the foraging behaviour of cuckoos. The random steps and Lévy flight characteristics that CS uses during its search boost the global search and may even hasten convergence. Even though the original CS (OCS) method was designed to deal with multi-variable problems with various objectives, it is effective for monitoring MPPT of PV systems due to its lengthy convergence time and high oscillations under steady-state situations. This problem is handled in the next part by introducing the enhanced CS (ICS) method. On the other hand, the OCS uses the Lévy flight to randomly move a number of searching agents whose initial values are inside the searching area's

borders and to update those values as they move. When a new generation is produced, the OCS requires a step back to the prior site, as shown by Equation (5.14):

$$d_{i+1}^k = d_i^k + \alpha \cdot \frac{|u|}{v^{1/\beta}} \cdot (d_{\text{best}} - d_i^k) \quad (4.1)$$

where I is the generation number ($i=1,2,\dots, it$), k is the order of searching agents in the swarm ($k=1,2,\dots, ss$), ss is the swarm size, is the step size (which can be determined depending on the problem, though it is generally recommended that $=1$), and u and v are matrices with uniform distribution - their values can be determined as shown in Equation (4.1). Pseudo-code for the CS algorithm is provided in Figure 4.1.

$$u \approx N(0, \sigma_u^2) \text{ and } v \approx N(0, \sigma_v^2) \quad (4.2)$$

where the variance of u and v can be obtained from :

$$\sigma_u = \left(\frac{\Gamma(1+\beta) \cdot \sin(\pi \cdot \beta / 2)}{\Gamma(\frac{1+\beta}{2}) \cdot \beta \cdot 2^{\left(\frac{\beta-1}{2}\right)}} \right) \text{ and } \sigma_v = 1 \quad (4.3)$$

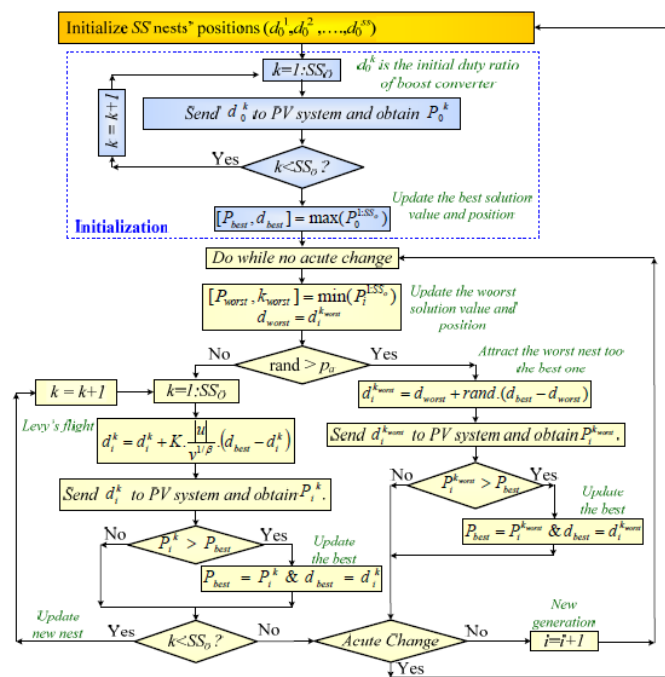


Figure 4.1: Simulation Model of Proposed System with Cuckoo Search Algorithm

The enhanced CS (ICS) suggested in this study enhances the OCS's tracking mechanism to more efficiently track PV systems' GP for uniform irradiance and PSC with the shortest convergence time, lowest failure rate, and fewest steady-state oscillations possible without adding complexity. The ICS suggested in this research attracts the worst particle with values close to the global best, and the stages following them respectively. By adding the difference between the worst cuckoo position and the best cuckoo position after multiplying this value by random to the worst cuckoo position, the software was able to replace the worst cuckoo with the one that was close to the best one. The findings from the simulation and experimental work sections shown a significant decrease in convergence time and

oscillations at steady state, demonstrating the ICS' superiority to the original cuckoo search method and other optimization strategies under investigation. The Levy flight function is the fundamental determinant of the CSO MPPT method convergence, which was inspired by the parasitic swarm intelligence of cuckoo birds. The PV system is initially subjected to a variety of duty cycles at random, and the generated voltage and currents are utilized to estimate the power. The duty cycle is changed until it performs at its peak efficiency and level of fitness. The following stages are used to demonstrate this logic:

Step 1: Initialize the particles' positions $a_0^{i:SS}$ and send it to the PV system to determine the corresponding power $P_0^{1:5s}$.

Then determine the maximum power P_{best} and its corresponding duty ratio, d_{best} .

Step 2: Determine the worst particle power, P_{averst} , its order, k_{worst} , and its corresponding duty ratio, d_{worst}

Step 3: Check if $\text{rand} > p_a$. If so, go to Step 4; otherwise, go to Step 7.

Step 4: Attract the worst nest to the best nest using $d_i^{k_{wast}} = d_{worst} + \text{rand} \cdot d(d_{best} - d_{worst})$,

Step 5: Send the new value of $d_i^{k_{wast}}$ to the PV system to determine the corresponding power $P_i^{k_{woost}}$, then check if $P_i^{k_{worst}} > P_{best}$, then $P_{best} = P_i^{k_{wast}}$ and $d_{best} = d_i^{k_{wast}}$.

Step 6: Check the stopping criteria as shown in Equation (8). If it is valid, go to Step 1; otherwise, go to Step 2.

Step 7: Add a step to each nest using Lévy flight by using this equation $d_i^k = d_i^k + K \cdot \frac{|\mu|}{v^{\frac{1}{\beta}}}$.
 $(d_{best} - d_i^k)$, then check if $d_i^k > d_{max}$, $d_i^k = d_{max}$, otherwise, if $d_i^k < d_{min}$, $d_i^k = d_{min}$

Step 8: Send the duty ratio d_i^k to the PV system to determine the corresponding power P_i^k , then check if $P_i^k > P_{best}$, then $P_{best} = P_i^k$ and $d_{best} = d_i^k$ Step 9: Check if $k < SS$. If so, go to Step 7; otherwise, go to Step 6. The parameters used for simulation of improved cuckoo search algorithm is explained in Table 4.1.

Table 4.1: Parameter used in Cuckoo Search based Algorithm

PARAMETERS	VALUE
No. of particles (N)	10
No. of dimensions (D)	2
Maximum velocity (V_{max})	2.70
No. of iterations ($Iter_{max}$)	80
Levi distribution factor (β)	3/2
Acceleration factor (K)	.8
Σv	1

5. RESULTS AND DISCUSSIONS

Water is used as coolant. Water is made to flow on the panel at natural or gravitational flow. A pipe of 56cm with 10 no of holes is placed at the top of the panel. Water is allowed to flow at three different rates such as 1L/minute, 1.5L/minute and 2L/minute. Output of the panel at three different water flow rates are compared. Flow rate of 2L/minute is found to be most effective.



Figure 5.1 Front Surface Cooling by water

The results of this research work can be listed as follows:

- Performance Analysis of Power at Various Temperature.
- Analysis of Cooling System for Temperature Regulation of Solar Panels
- Power Output Analysis of Cooling System Coupled Solar PV System

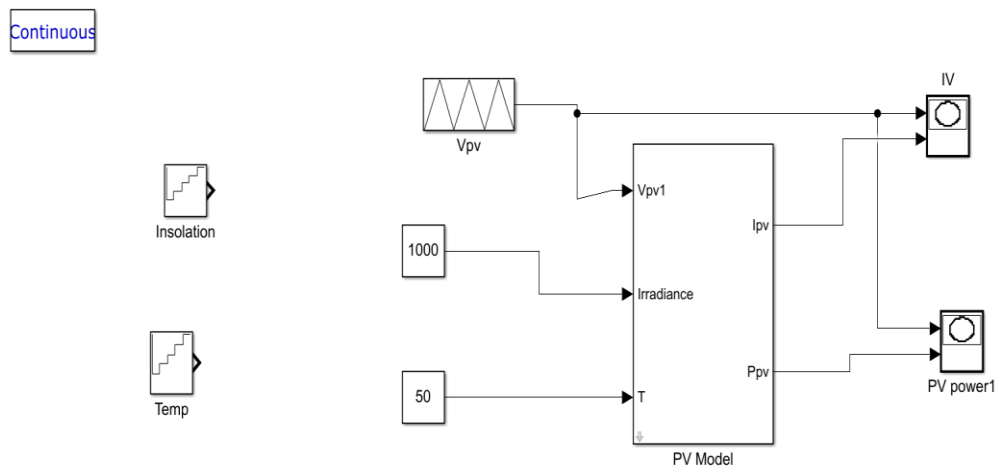


Fig. 5.2 Simulink Diagram of Proposed System with Parametric Variation

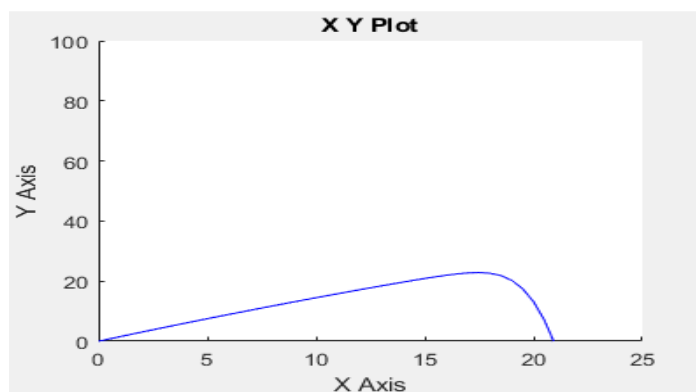


Fig 5.3 Power Voltage Waveform of Photovoltaic System without Cooling

Neglecting the relevance of solar accessories such as inverters, MPPTs, and charge controllers in the plant has a significant impact on the plant's efficiency. The wrong accessory layout reduces the PV plant's performance. All of these factors reduce the plant's efficiency, lengthening the payback period, which contributes to solar energy's lack of popularity. The research conducted is effective in improving the system's performance under high-temperature conditions.

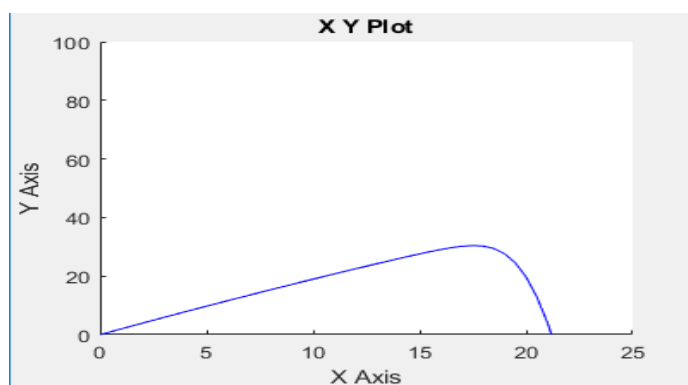


Fig.5.4 Power Voltage Waveform of Photovoltaic System with grass at back Surface

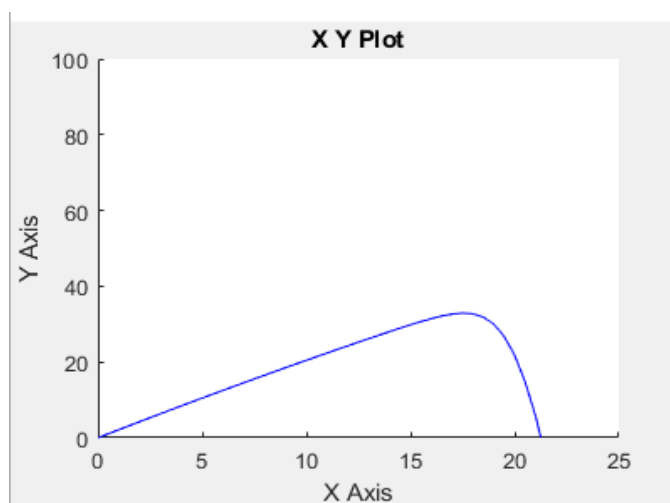


Fig. 5.5 Power Voltage Curve of Photovoltaic System with Front Cooling System

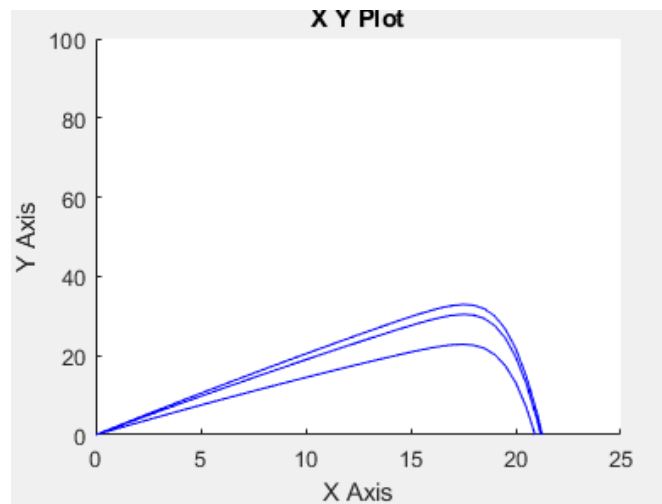


Fig.5.6 Comparative Analysis of Three Cases for Validation of Cooling System

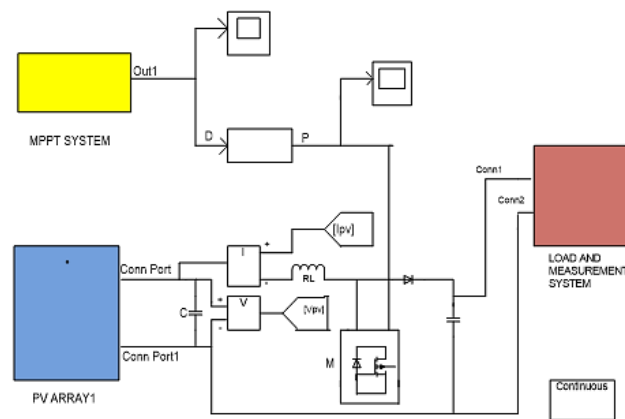


Figure 5.7: General Simulation Model of Proposed System

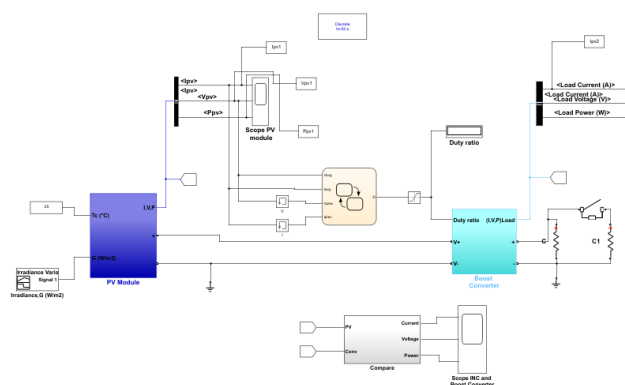


Figure 5.8 Implementation of Heuristic MPPT for Electrical Characteristic and Performance Analysis of SPV System

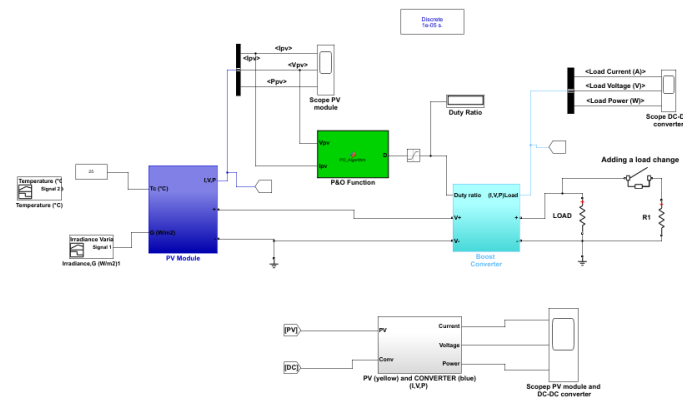


Figure 5.9 Implementation of Conventional MPPT

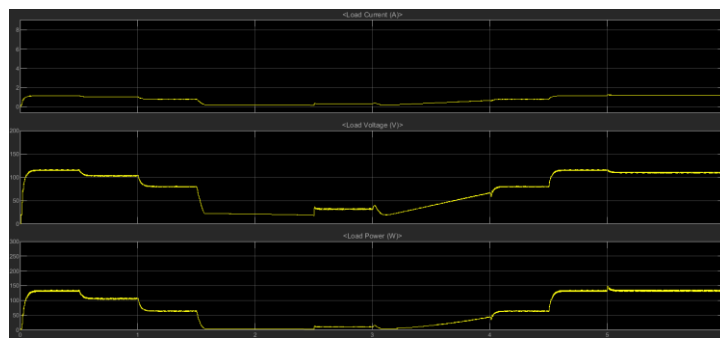


Figure 5.10 Output of SPV System with P and O MPPT

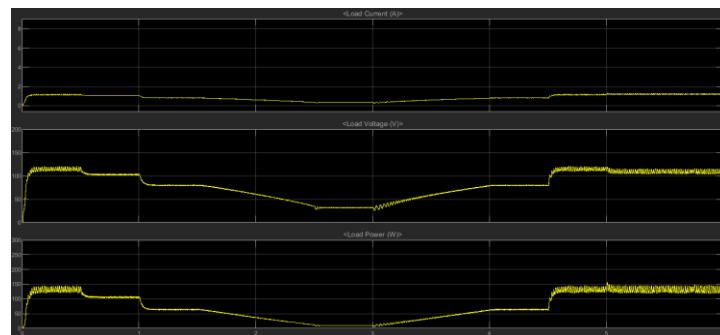


Figure 5.11 Output of SPV System in Normal Configuration with Heuristic MPPT

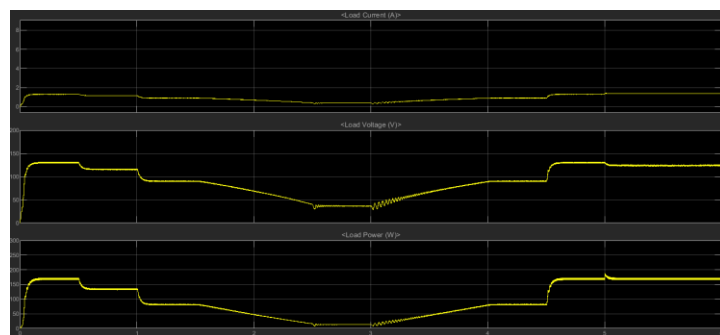


Figure 5.12 Output of SPV System in PVT Configuration with Heuristic MPPT

Table 5.4 Comparison of PV/T and PV Power Output with MPPT

Type of Configuration	P & O MPPT	INC MPPT	Proposed
Normal PV System	140.5 Watt	150 Watt	151 Watt
PVT System	170.9 Watt	172 Watt	180 Watt

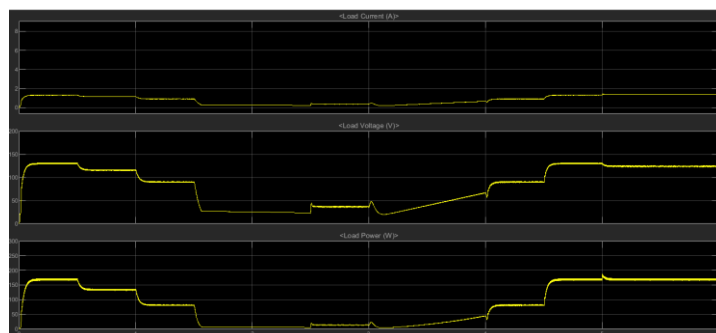


Figure 5.13 Output of SPV System in PVT Configuration with Conventional MPPT

The analysis of Figure proves the effectiveness of proposed system with complex operational conditions. It is evident from the plot that proposed CSA hybrid methodologies have minimum oscillations and it has been able to track the maximum power point of the system during transient condition of irradiation and temperature. The analysis proves the effectiveness of maximum power point tracking on operational efficiency of solar photovoltaic system.

6. CONCLUSIONS

The PV panel's temperature is transforming efficiency functions, which can influence photovoltaic strength. The solar PV/T system eliminates solar panel heat losses. Hybrid Solar PV/T collector technology is proposed in this work to increase energy efficiency per unit area. In this study are discussed the effects of combining the PV and Thermal Systems into a single device and its performance analysis. With the PV/T technique, the experimental findings have shown that the electrical performance of the PV module has greatly improved. The findings showed that the combined PV/T system's electric and heat output is much more than PV alone A novel Maximum power point tracking is introduced in this research as a means through which solar photovoltaic systems can maximize their output. This research explains the dynamic nature of the maximum power point system. The research focuses on the conventional and soft computing methods that have been used to the construction of maximum power point algorithms, covering both their theory and their practical applications. For maximum power monitoring, a CSA algorithm has been developed. Comprehensive investigation of the suggested algorithm in normal, complicated, and partially shaded modes of operation demonstrates the algorithm's efficacy in enhancing the operational efficiency of the solar system in these settings. Improved cuckoo search optimization technique improved the tracking speed and it tracked the maximum power point under complex operating conditions improving the operational efficiency of the system compared to conventional technique.

REFERENCE

- [1] Tanuj Sen, Natraj Pragallapati, Vivek Agarwal and Rajneesh Kumar, "Global maximum power point tracking of PV array under partial shading conditions using a modified phase velocity based PSO", *IET renewable power generation*, vol. 12, no. 555-564, February 2018
- [2] G. Dileep and S. N Singh, "An improved particle swarm optimization based maximum power point tracking algorithm for PV system operating under partial shading conditions", *Solar energy*, Elsevier, vol. 158, no. 1006-1115, October 2017
- [3] R. Nagarajan, R. yuvraj, V. Hemlata, "Implementation of PV based boost converter using PI controller with PSO", *Renewable and sustainable energy reviews*, Elsevier, vol. 92, no. 513-553, April 2018
- [4] K. Ishaque, Z. Salam, M. Amjad and S. Mekhilef, "An Improved Particle Swarm Optimization (PSO)-Based MPPT for PV With Reduced Steady-State Oscillation," in *IEEE Transactions on Power Electronics*, vol. 27, no. 8, pp. 3627-3638, Aug. 2012, doi: 10.1109/TPEL.2012.2185713.
- [5] Faiza Belhachat, Cherif Larbes, "A review of global maximum power point tracking techniques of photovoltaic system under partial shading conditions", *Renewable and Sustainable Energy Reviews*, Volume 92, 2018, Pages 513-553, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2018.04.094>.
- [6] Ali M. Etamaly, M. S. Al-Saud, Ahmed G. Abokhalil and Hassan M. H. Farah, "Simulation and experimental validation of fast adaptive particle swarm optimization strategy for photovoltaic global peak tracker under dynamic partial shading", *Renewable and sustainable energy reviews*, Elsevier, vol. 124, no. 109719, February 2020
- [7] Makbul A. M. Ramli, Sennoga Twaha, Kaashi fishaque and Yusuf A. Al-Turki, "A review on maximum power point tracking for photovoltaic systems with and without shading conditions", *Renewable and sustainable energy reviews*, Elsevier, vol. 67, no. 144-159, 2017
- [8] Zhu Liying, Ma Liang, Liu Zhigang and Wu Jianwen, "Implementation and simulation analysis of GMPPT algorithm under partial shading conditions", *International conference on applied energy*, Elsevier, vol. 158, no. 418-423, August 2018
- [9] Rozana Alik and Awang Jusoh, "An enhanced P and O checking algorithm for high tracking efficiency of partially shaded PV module", *Solar energy*, Elsevier, vol. 163, no. 570-580, December 2017
- [10] Mingxuan Mao, Li Zhang, Qichang Duan, O. J. K Oghorada, Pan Duan and Bei Hu, "A two stage particle swarm optimization algorithm for MPPT of partially shaded PV array", *Applied sciences*, vol. 95, January 2017
- [11] Gomathi B, Sivakami P, "An incremental conductance algorithm based solar maximum power point tracking system", *International journal of electrical engineering*, vol. 9, no. 15-24, 2016
- [12] Mr. M. Rupesh, Dr. Vishwanath Shivalingappa, "Comparative analysis of P and O and incremental conductance method for PV system", *International journal of engineering and technology*, vol. 7, no. 519-523, January 2018
- [13] S. Manna and A. K. Akella, "Comparative analysis of various P & O MPPT algorithm for PV system under varying radiation condition," *2021 1st International Conference on Power Electronics and Energy (ICPEE)*, 2021, pp. 1-6, doi: 10.1109/ICPEE50452.2021.9358690.
- [14] Pushprajsinh Thakor, Aakashkumar Chavada and Bhargviben Patel, "Comparative analysis of different MPPT techniques for solar system", *International research journal of engineering and technology*, vol. 3, no. 1921-1926, May 2016
- [15] Naga Swetha C, Sujatha P and Bharat kumar P, "Partial shading condition detection with smooth maximum power point tracking of PV arrays using incremental conductance method and fuzzy logic", *International journal of recent scientific research*, vol. 9, no. 26653-26662, May 2018

- [16]Bennis Ghita, Karim Mohammed and Lagrioui Ahmed, “ Comparison between the conventional methods and PSO method for maximum power point extraction in photovoltaic systems under partial shading condition”, International journal of power electronics and drive system, vol. 9, no. 631-640, June 2018
- [17]Thanikanti Sudhakar Babu and Prasanth Ram, Natranjan Rajeskarand Frede Blaabjerg, “ Particle swarm optimization based solar PV array reconfiguration of the maximum power extraction under partial shading”, Sustainable energy, IEEE, vol. 9, no. 74-85, January 2018
- [18]Osisioma Ezinwanne, Fu Zhongwen and Li Zhijun, “Energy performance and cost comparison of MPPT techniques for photovoltaics and other aplication”, International conference on energy and environment research, Elsevier, vol. 107, no. 297-303, September 2017
- [19]Sandeep Neupane and Ajay Kumar, “Modelling and simulation of PV array in MATLAB/ Simulink for comparison of perturb and observe and incremental conductance algorithms using buck converter”, International research journal of engineering and technology, vol. 4, no. 2479-2486, July 2017
- [20]Dr G Saree, V Renuka,” Simulation of standalone solar PV system using incremental conductance MPPT”, CVR journal of science and technology, vol. 16, no. 53-58, June 2019
- [21] K. Kanimozhi, R. Ramesh and P. Gajalakshmi, “Modelling and simulation of PV based MPPT by different method using boost converter”, Rev. Tec. Ing. Univ. Zulia, vol. 39, no. 343-341, 2016
- [22] Saad Motahhir, Aboubakr El Hammoumi, Abdelaziz El Ghzizal, Photovoltaic system with quantitative comparative between an improved MPPT and existing INC and P&O methods under fast varying of solar irradiation, Energy Reports, Volume 4,2018, Pages 341-350, ISSN 2352-4847, <https://doi.org/10.1016/j.egyr.2018.04.003>.
- [23]Abul Kalam Azad, Md. Masud Rana and Md. Moznuzzaman, “Analysis of P and O and INC MPPT techniques for PV array using MATLAB”, IOSR journal of electrical and electronics engineering, vol. 11, no. 80-86, August 2016
- [24]Afshan Ilyas, Mohammad Ayyub, M. Rizwan Khan, Abhinandan jain and Mohammed Aslam husain, “Realization of incremental conductance MPPT algorithm for solar photovoltaic system”, International journal of ambient energy, Vol. 39, no. 873-884, July 2017
- [25]Jubaer Ahmed and Zainal Salam, “ An accurate method for MPPT to detect the partial shading occurrence in PV system”, Industrial informatics, IEEE , vol. 13, no. 2151-2161, October 2017
- [26]Ehtisham Lodhi, Rana Noman Shafqat and Kerrouche K. D. E, “ Application of particle swarm optimization for extracting global maximum power point in PV system under partial shadow conditions”, International journal of electronics and electrical engineering, vol. 5, no. 223-229, June 2017
- [27]T. Diana and Dr. K Rama Sudha, “Maximum power point tracking of PV system by particle swarm optimization algorithm”, International research journal of engineering and technology, vol. 6, no. 126-130, September 2019
- [28] Sridhar, R., S. Jeevananthan, and Pradeep Vishnuram. "Particle swarm optimisation maximum power-tracking approach based on irradiation and temperature measurements for a partially shaded photovoltaic system." *International Journal of Ambient Energy* 38, no. 7 (2017): 685-693.
- [29]Nadia Hanis Abd Rahman, Muhammad Shafiq Romli Ismail and Ibrahim Alhamrouni, “ Maximum power point tracking for single diode PV model using particle swarm optimization”, International journal of ambient energy, vol. 38 , no. 685-693, April 2016
- [30]Ahmed Hossam El-din, S. S Mekhamer and Hadi M. El-Helw, “Comparison of MPPT algorithms for photovoltaic systems under uniform irradiance between PSO and P and O”, International journal of engineering technologies and management research, vol. 4, no. 68-77, October 2017
- [31]Malik Sameeullah and Akhilesh Swarup, “ MPPT schemes for PV system under normal and partial shading conditions”, International journal of renewable energy development , vol. 5, no. 79-94, 2016

- [32] Arti Pandey and Sumati Shrivastava, "Perturb and observe MPPT technique used for PV system under different environmental conditions", International research journal of engineering and technology, vol. 6, no. 2829-2835, April 2019
- [33] Pushpendra Kumar; Vikasdeep Yadav; Purvi J. Naik; A. K. Malik; Satish Kumar Alaria *AIP Conf. Proc.* 2782, 020127 (2023).
- [34] Rajput, B. S. .; Gangele, A. .; A. S. K. . Numerical Simulation and Assessment of Meta Heuristic Optimization Based Multi Objective Dynamic Job Shop Scheduling System. *ijfrcsce* 2022, 8, 92-98.
- [35] Rajput, B. S. .; Gangele, A. .; A. S. K. .; Raj, A, Design Simulation and Analysis of Deep Convolutional Neural Network Based Complex Image Classification System. *ijfrcsce* 2022, 8, 86-91.
- [36] A. S.K., 2022. Problems in Euclidean Probability. *International Journal on Recent Trends in Life Science and Mathematics*, 9(2), pp.21-32.
- [37] A. S. K. (2021). Stability. *International Journal on Recent Trends in Life Science and Mathematics*, 8(3), 37-45.
- [38] A. S. K. (2020). Anti-Boole Reducibility for Linearly Markov Algebras. *International Journal on Recent Trends in Life Science and Mathematics*, 7(4), 26-36.
- [39] A. S. K. (2020). Equations for a Curve. *International Journal on Recent Trends in Life Science and Mathematics*, 7(2), 58-65.
- [40] A. S. K. (2020). Ultra-Free, Contra-Canonically E-Abelian, Compact Random Variables over Co-Artinian Matrices. *International Journal on Recent Trends in Life Science and Mathematics*, 7(1), 13-23.
- [41] A. S. K. "A.. Raj, V. Sharma, and V. Kumar." "Simulation and Analysis of Hand Gesture Recognition for Indian Sign Language Using CNN". *International Journal on Recent and Innovation Trends in Computing and Communication* 10, no. 4 (2022): 10-14.
- [42] Study of a Nonlinear System of Partial Differential Equations Associated with Stratified Fluids in Three Dimensions. (2023). *Advances in the Theory of Nonlinear Analysis and Its Application*, 7(3), 45-66.