

A Novel Meta Heuristic Optimization Based Intelligent Maximum Power Point Tracking System for Operational Efficiency Enhancement of Hybrid Solar Photovoltaic Energy System

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Abstract— Solar energy is most promising renewable energy resource with huge potential which is yet to be explored and transformed into production of power. The conversion of solar energy into electricity is characterized with dynamic performance and losses. These losses are related to the conversion process, transformation process as well as utilization process. The performance of solar photovoltaic system largely depends on operational condition i.e. temperature, irradiation and shading. The operational efficiency depends on the conversion efficiency of power generated from the panel to the load. Charge controllers are designed to transform the generated power from solar photovoltaic to the external circuit. The research is aimed to investigate effective algorithms for enhancement of operational efficiency of solar photovoltaic energy system. The research is focused on the development of maximum power point tracking system (MPPT) under diverse operating conditions such as partial shading and variable irradiance to improve operational efficiency of solar photovoltaic system. The simulation of an equivalent mathematical model has been undertaken to investigate the performance of the system under diverse operational condition. A novel approach based on hybridization of PV-T System and cuckoo search optimization has been proposed for duty cycle control of charge controllers and cooling of photovoltaic system. The proposed system has been simulated under normal, variable and complex shading pattern and operational condition. Simulations have demonstrated superior performance of the developed algorithm in terms of tracked power as well as tracking time and stability. The proposed research improves the operational performance of solar photovoltaic system significantly as compared to conventional and soft computing based heuristic approaches.

Index Terms— 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.

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]

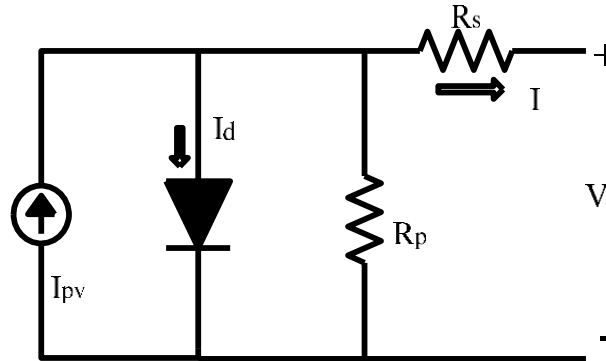


Figure 1.1: Equivalent Circuit of a Single Diode Solar Cell

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]

$$I = I_{pv} - I_s \left(\exp \left[\frac{q(V + R_s I)}{N_s k T a} \right] - 1 \right) - \frac{V + R_s I}{R_p} \quad (1.1) \quad (3.1)$$

$$I_{pv} = (I_{pv,n} + K_I \Delta T) \frac{G}{G_n} \quad (1.2) \quad (3.2)$$

$$I_s = \frac{I_{SC,n} + K_I \Delta T}{\exp \left((V_{OC,n} + K_V \Delta T) / a (N_s k T / q) - 1 \right)} \quad (1.3) \quad (3.3)$$

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

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

I_p - photo current, I_D - Diode current

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

Now substituting the value of I_D

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

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

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

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

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

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

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

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

Where,

G-Irradiance W/m^2

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

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

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

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

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.

I.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].

Maximum Power Point Tracking

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.



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]

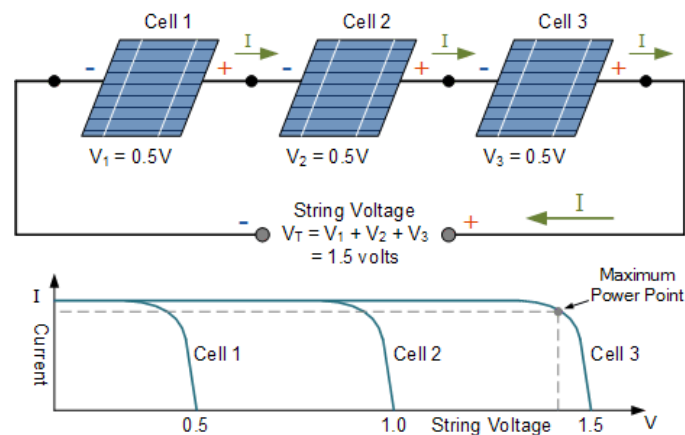


Figure 3.2 : Normal Operation of PV String

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.

By generating less current than the other two cells, the darkened cell drastically lowers the series string's energy output. Since the "dark" cell is now utilizing energy that was previously produced by the "sunny" cells, the bad cell may eventually perish from overheating as a result (hot spots). The outcome is a reduction in the generated current of the shaded cell. The good, non-shaded cells react to this drop in current by increasing the open-circuit voltage along their I-V characteristic curves, which leads the shaded cell to become reverse biased—that is, a negative voltage now appears across its terminals in the opposite direction. [29]

As a result of the reverse voltage, the current in the shaded cell is now flowing in the opposite direction and consuming energy at a rate determined by its operational current (I) and reverse voltage (RSC). In light of this, a fully shaded cell will undergo a reverse voltage drop and will dissipate or consume power rather than creating it. Bypass diodes have been connected in parallel over each of the three PV cells. Reverse bias mode is used to connect these internal or externally connected bypass diodes across the matching cell. The cathode (K) terminal of the diode is linked to the positive side of the solar cell, and the anode (A) terminal is connected to that side electrically. The diode thus exhibits reverse bias. Figure 1.4 contains an explanation of the effects of shading. When the three solar cells are fully illuminated, they generate voltage as normal, and any reverse current (red arrows) that tries to flow through one of the three bypass diodes positioned across the solar cells is blocked. The diodes operate as if they are not present since they are reverse biased, allowing the series string to produce its maximum output power (in the previous example, 6 watts) while the three solar cells function as predicted.

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.

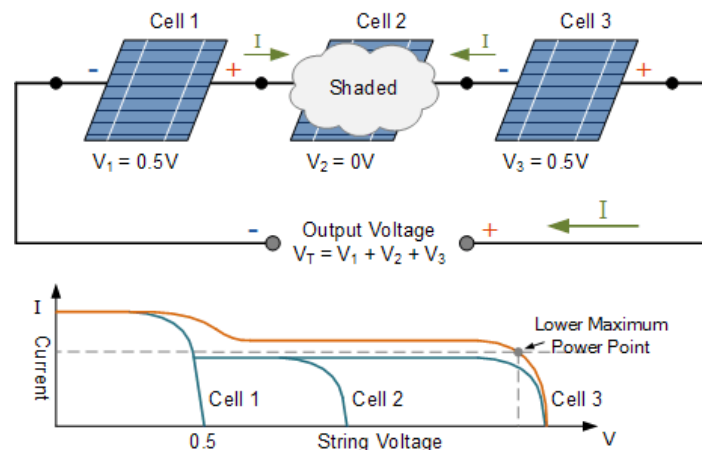


Figure 3.3 : Impact of Shading on Characteristics of PV System

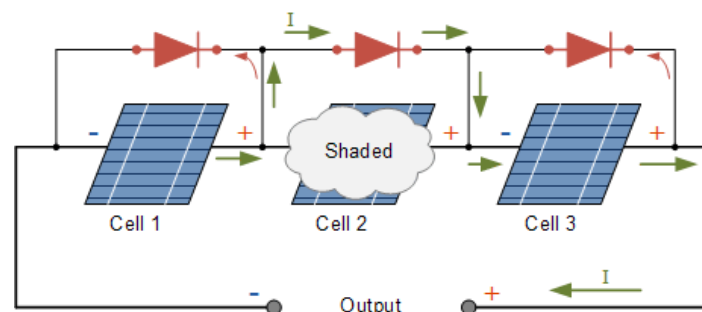


Figure 3.4 : Connection of Bypass Diode in PV System

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.

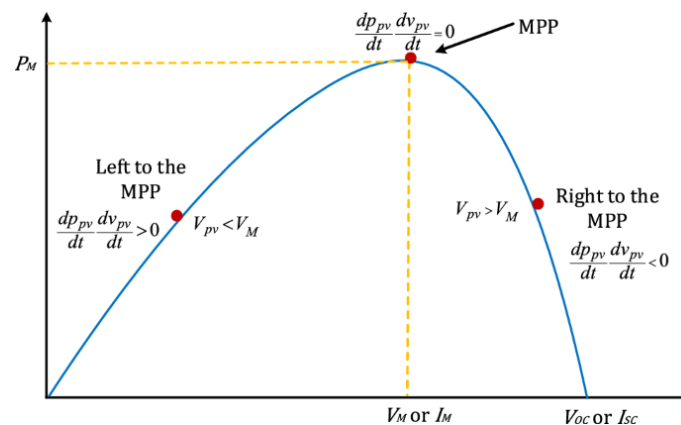


Figure 3.5: Significance of MPPT on Power Output of Solar PV System

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.

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. [12]

II. Proposed Methodology

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 4.1 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

This is done to study the effect of temperature and irradiation individually and then combine effect. First temperature is kept constant at 25°C but irradiation varies and then vice versa. After that both irradiation and temperature varies to study the IV and PV characteristics. Keeping Temperature constant and varying irradiation. To study the effect of Irradiation, temperature is kept constant at 25°C in the above shown PV simulation model and simulation is done. The Simulation has been done with three different time of day. Effect of cooling has been observed during morning, noon and evening respectively. The performance plot of characteristic has been moduled with respect to scaled down model of solar photovoltaic system. The analysis has been explained with help of simulink model explained in figure. Figure 6.22 indicates the simulink diagram of proposed system. The simulation has been performed for three different condition. The first case is panel having no cooling facility incorporated. The second case is panel having cooling with water and third case is cooling with water and grass respectively. PV panel output begins to decrease when the temperature exceeds the maximum permissible temperature. The PV Plant's efficiency suffers as a result of the fall in production. This functions as a stumbling block to solar energy's rapid expansion.

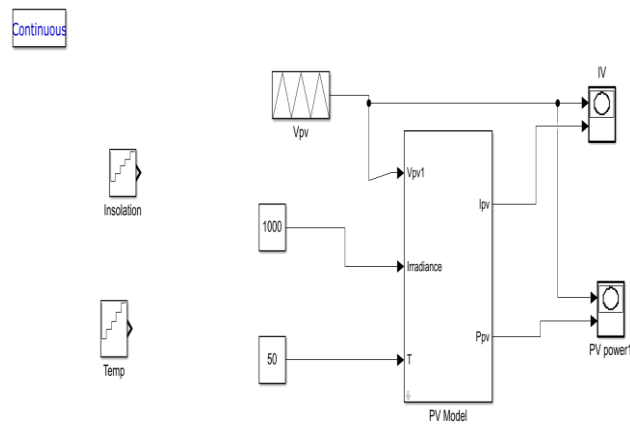


Fig. 4.2 Simulink Diagram of Proposed System with Parametric Variation

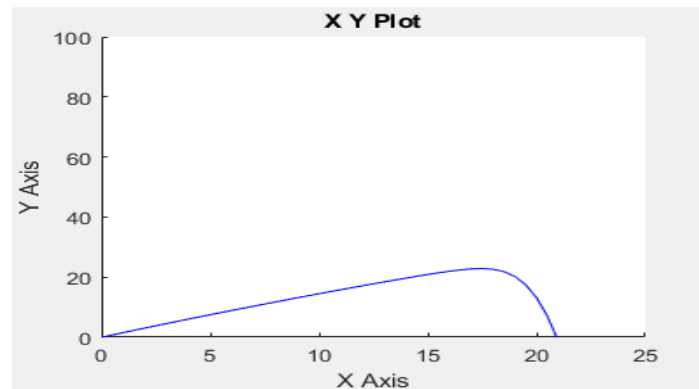


Fig. 4.3 Power Voltage Waveform of Photovoltaic System without Cooling

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.

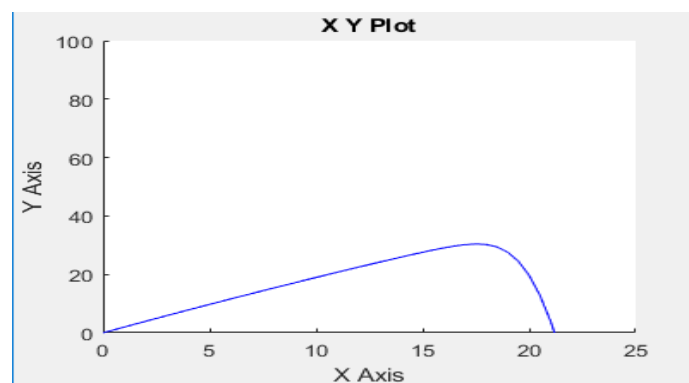


Fig.4.3 Power Voltage Waveform of Photovoltaic System with grass at back Surface

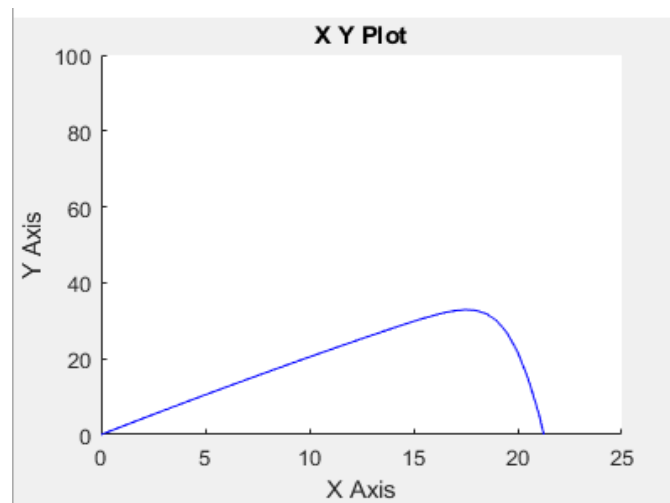


Fig. 4.4 Power Voltage Curve of Photovoltaic System with Front Cooling System

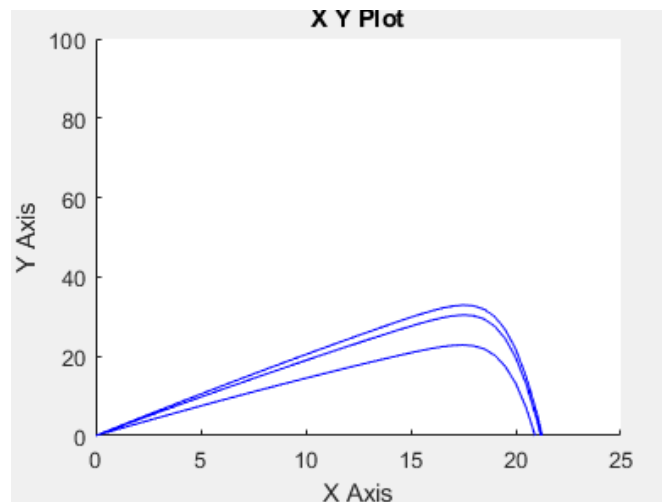


Fig.4.5 Comparative Analysis of Three Cases for Validation of Cooling System

The proposed research has been implemented for three cases of the cooling system with water, grass with different orientation of front cooling system incorporated with back surface grass cooling system. The contemporary analysis of three cases prove that there is significant increase in the performance of the photovoltaic system after the installation of cooling system. The system with front cooling perform best in the comprehensive analysis of the proposed system

Cuckoo Search Algorithm

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, α is the step size (which can be determined depending on the problem, though it is generally recommended that $\alpha=1$), 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 :

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

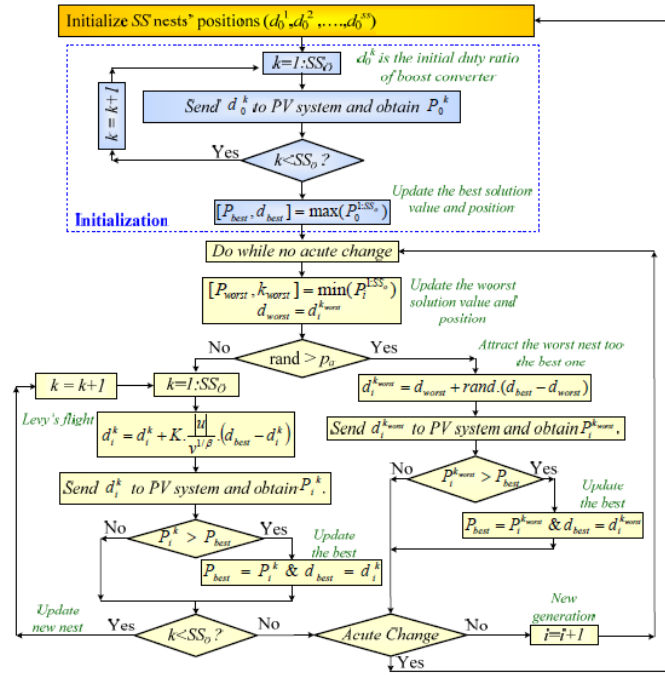


Figure 4.6: Simulation Model of Proposed System with Cuckoo Search Algorithm

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 $d_0^{i:SS}$ and send it to the PV system to determine the corresponding power $P_0^{1:55}$.

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

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

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

Step 4: Attract the worst nest to the best nest using $d_i^{k_{worst}} = d_{worst} + rand * (dbest - d_{worst})$,

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

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 $d_i^k = d_i^k + K \cdot \frac{|\mu|}{v^\beta} \cdot (d_{\text{best}} - d_i^k)$, then check if $d_i^k > d_{\text{max}}$, $d_i^k = d_{\text{max}}$, otherwise, if $d_i^k < d_{\text{min}}$, $d_i^k = d_{\text{min}}$

Step 8: Send the duty ratio d_i^k to the PV system to determine the corresponding power P_i^k , then check if $P_i^k > P_{\text{best}}$, then $P_{\text{best}} = P_i^k$ and $d_{\text{best}} = d_i^k$ Step 9: Check if $k < \text{SS}$. 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

V. Results And Discussions

Different studies suggest that MPPT methods cannot analyse the exact follow-up of the global MPP point. The complexity of the algorithm, costs and failure while working in shaded situations is thus the difficulty in the implementation of MPPT technology. In particular, in the last five years, the analysis of worldwide power peak identification under shading conditions has been carried out extensively. Each study explains a monitoring approach that varies in complexity, cost, operational speed and efficiency. Due to complexity in characteristics of power voltage characteristics and multiple peak points due to nonlinear behaviour, it is not possible to detect the peak power point using conventional algorithms. Due to rapid installations of solar photovoltaic system in all potential systems shading and non-uniform operational situation is common. The ability of tracker to detect the maximum power point is essential for operational efficiency of solar photovoltaic system. The simulation process is divided into different subcases of operation. These cases reflect the operational conditions ranging from normal mode of operation to dynamic weather conditions as well as complex operational condition along with partial shading condition.

The solar PV system has been interfaced with a charge controller coupled with maximum power point tracker and resistive load. The modules are given input from a string of inputs of irradiation and temperature. The mode of operations and the performance of maximum power point tracking algorithm ms has been discussed in details. Figure 5.1 shows the schematic diagram of proposed system. It consists of the photovoltaic array, the MPPT system, booster, load-and-measurement block for simulation. Our major objective is to track power in partial shading conditions. Hence our first block created a partial shade situation by connecting four PV modules in series with different irradiance and temperature inputs.

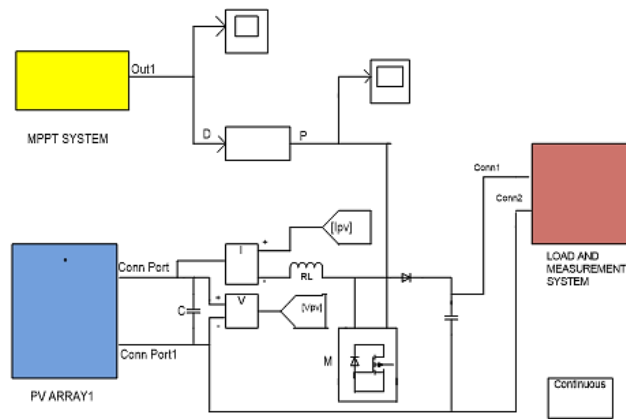


Figure 5.1: General Simulation Model of Proposed

System

Table 5.1: Parameters of Solar Photovoltaic System

Parameters	Specifications
Module Name	Tata Power- TP250MBZ
Maximum Power (W)	249 W
Cells Per Module (N Cell)	60
Open Circuit Voltage (V)	36.8 V
Short Circuit Current (A)	8.83 A
Voltage at maximum power point Vmp (V)	30 V
Current at maximum power point Imp	8.3 A
Temperature coefficient of Voc (%/deg.C)	-0.33
Temperature coefficient of Isc (%/deg.C)	0.063805
Number of Modules in String	04
Total Power Rating of Array	1000 W (1 kWp)

The array block output is sent directly to the optimization block for our output to maximize. The specification of solar modules, charge controller has been shown in Table 5.1 and 5.2 respectively. The overall operation has been analyzed on the basis of magnitude of tracked power as well as time taken to reach convergence based on iteration of the soft computing approached. The simulation has been done taking note of possible mode of complex operations of solar photovoltaic system. The parameters of charge controller is shown in Table 5.2. The boost type controller is integrated with maximum power point tracker for control of gate pulse and operating voltage. The system is integrated for the qualitative and quantitative analysis of the performance of the system.

The function of charge controller is to enable the maximum power transfer from the solar photovoltaic system to the load. The characteristic of solar module is explained in Figure 5.2. The interconnection of the solar photovoltaic systems has been done with individual input of irradiation and temperature.

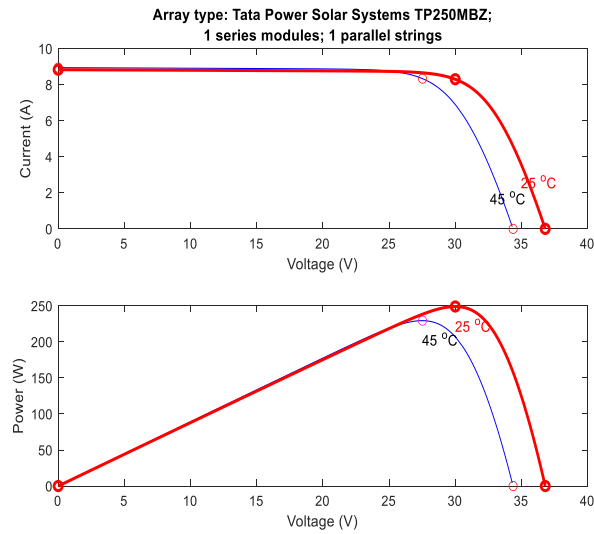


Figure 5.2: Characteristics of Photovoltaic Module Used in Simulation

Table 5.2: Parameters of Charge Controllers and Load

Parameters	Specifications
Capacitance	10e-6 F
Inductance	1.1478e-3 H
MOSFET Resistance	1e-3 ohms
Internal diode resistance Rd	1e-3 ohms
Shunt Capacitance	0.4676e-3 F
Load Resistance	53 ohms

Table 5.3 Comparison of Different PV/T and PV Efficiencies

S. No.	Solar PV/T Hybrid System						Solar PV
	Mass Flow Rate (kg/sec)	Average Electrical Efficiency (%)	Average Thermal Efficiency (%)	Overall Average Efficiency (%)	Average Energy Saving Efficiency (%)	Average Exergy Efficiency (%)	Average Electrical Efficiency (%)
1	0.002	7.54	52.30	59.84	52.49	11.26	7.59
2	0.0025	6.24	54.13	60.37	54.30	8.78	6.00
3	0.003	5.73	61.43	67.16	61.58	8.70	5.54

4	0.004	5.23	56.06	61.29	56.20	8.23	5.03
5	0.0025 with glass cover	6.39	50.11	56.49	50.27	9.48	7.50

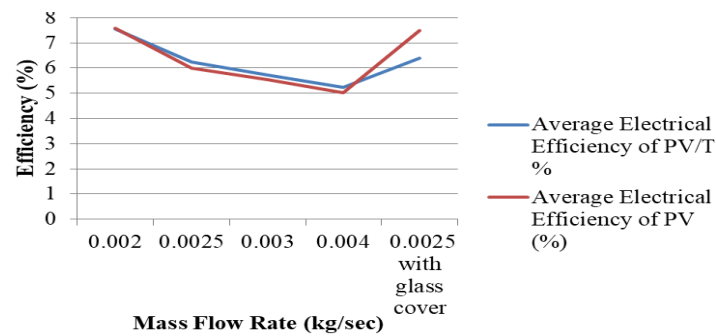


Figure 5.3 Shift in Average PV and PV/T Electric Performance for Different Mass Flow Rates

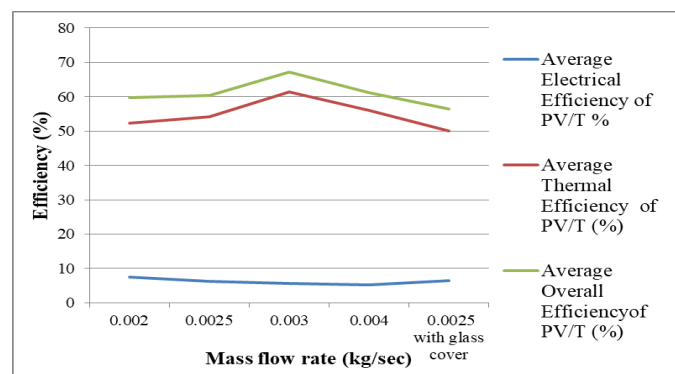


Figure 5.4 Shift in Average PV/T Electrical, Thermal and Total Efficiency for Different Mass Flow Rates

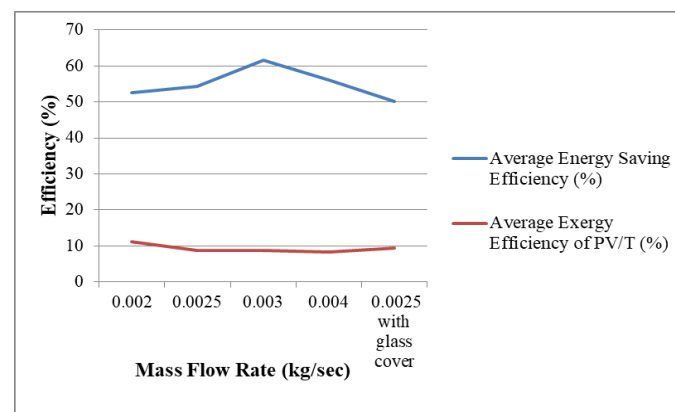


Figure 5.5 Shift of Average Exergy and PV/T Energy Saving Output for Different Mass Flow Rates

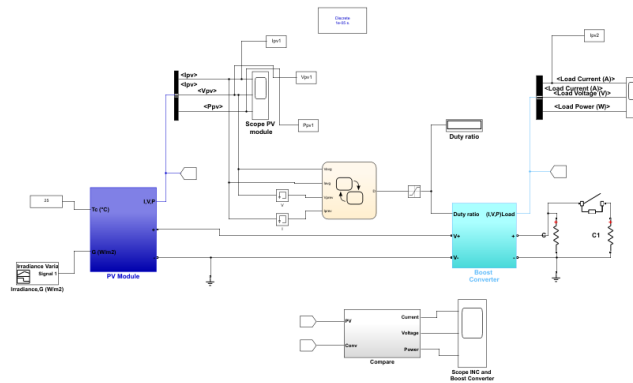


Figure 5.6 Implementation of Heuristic MPPT for Electrical Characteristic and Performance Analysis of SPV System

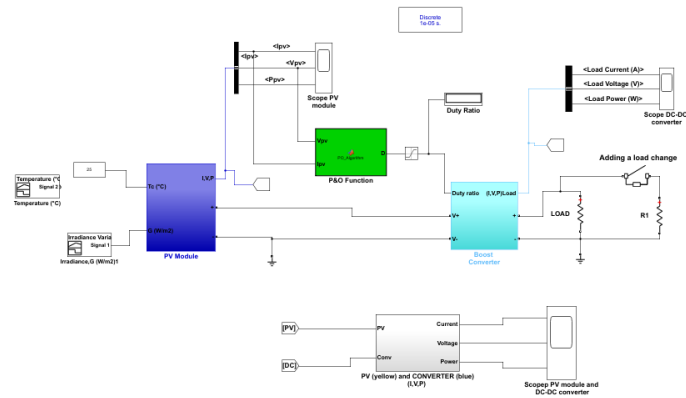


Figure 5.7 Implementation of Conventional MPPT

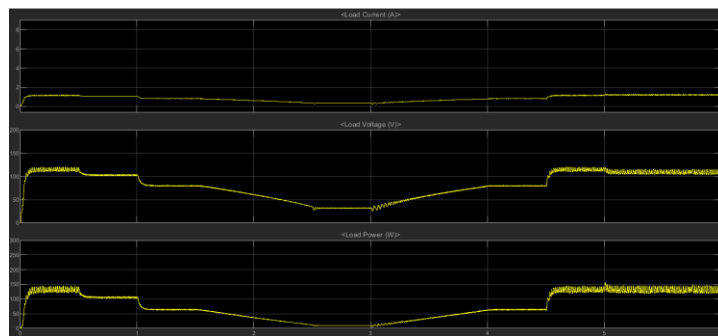


Figure 5.8 Output of SPV System in Normal Configuration with Heuristic MPPT

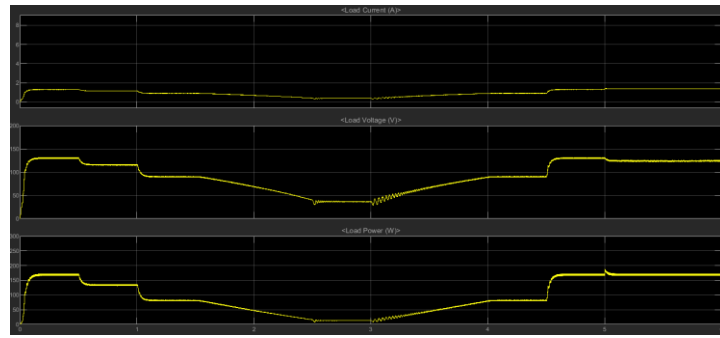


Figure 5.9 Output of SPV System in PVT Configuration with Heuristic MPPT

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 Watt	150 Watt	151 Watt
PVT System	170 Watt	172 Watt	180 Watt

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.

VI. 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 techniques.

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