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Design of Improved Soft Computing based Maximum Power Point Tracking System for Operational Efficiency Enhancement of Solar Photovoltaic Energy System

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Abstract— The most promising renewable energy source is solar energy, which has enormous potential but has not yet been fully investigated or converted into useful power. The process of converting solar radiation into electrical power is marked by fluctuations in output and waste. These losses are associated with the processes of conversion, transformation, and usage. Temperature, irradiance, and shade are the main operating conditions that affect how well a solar photovoltaic system performs. The efficiency with which power is converted from the panel to the load determines the operational efficiency. Charge controllers are made to convert solar photovoltaic power into electricity for an external circuit. The goal of the research is to look into efficient algorithms that can improve the solar photovoltaic energy system's operating efficiency. In order to increase the operational efficiency of solar photovoltaic systems, research is concentrated on developing maximum power point tracking systems (MPPT) under a variety of operating scenarios, including partial shade and fluctuating irradiance. The performance of the system under various operating conditions has been investigated through the simulation of an equivalent mathematical model. A unique method for charge controller duty cycle control and solar system cooling has been developed. It is based on hybridization of PV-T System and cuckoo search optimization. Simulations of the suggested system have been run under standard, complex, and changing shading pattern and operating conditions. Simulations have shown that the devised method performs better in terms of tracked power, tracking time, and tracking stability. Comparing the suggested research to heuristic approaches based on conventional and soft computing, the solar photovoltaic system's operational performance is much improved.

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.

I.INTRODUCTION

Solar energy is captured by solar panels or solar cells, which then convert it to electrical power. PV cells, also called "solar cells," use the photovoltaic effect to store solar energy that causes a current to flow between two layers that are oppositely charged. The conversion efficiency of a solar cell is determined by dividing its electrical energy output by the ratio of solar energy (irradiation) incident on its surface. The semiconductor material used in solar cells has been doped to produce a p-n junction, which collects solar radiation and converts it into direct current using photovoltaic effect. A single-diode model is frequently used to depict solar cell performance because it is simple to use and accurately captures the properties of the p-n junction. [1]

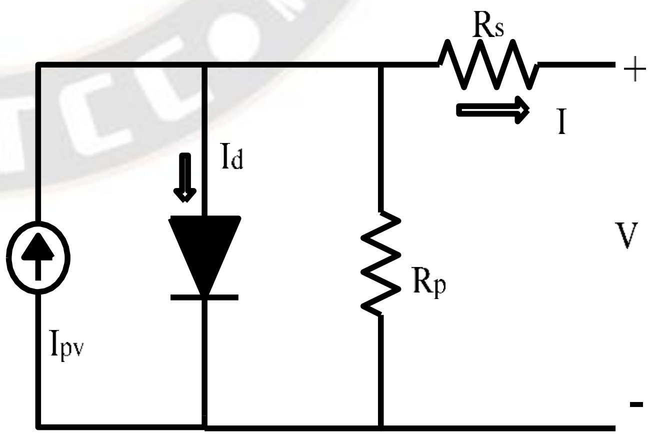

Figure 1.1: Equivalent Circuit of a Single Diode Solar Cell

In order to generate the correct voltage and current, the solar cells are linked either in series or parallel. An enormous output current is produced when the cells are connected in parallel, however a considerable output voltage is produced when the cells are connected in series. Figure 1.1 depicts the mathematically equivalent circuit layout for a single-diode photovoltaic panel, which consists of a diode, a current source, and parallel and series resistances. The significance of the mathematical model lies in its

Recognize and compute the PV cell's I-V and P-V properties under various operating scenarios. [2]
Understanding the dynamic performance of a solar photovoltaic system under various operating situations also requires mathematical modeling. It should be noted that the I-V and P-V characteristics alter in settings of constant irradiance and fluctuating temperature, or vice versa, and that these variations have an impact on the working conditions of the solar cell.
Solar Cell Mathematical Modeling
The PV equivalent circuit is depicted in Figure 3.1. It should be recalled that when light strikes photovoltaic cells, a potential difference is created, and that this voltage varies linearly with solar insolation. The perfect solar cell can be modeled as a current source. Shunt resistance (Rp) provides current leakage proportional to solar cell terminal voltage. The losses resulting from semiconductor and metal connections are represented by series resistance (Rs). To compute the current produced by light impinging on a PV cell, parallel diodes are employed to imitate the p-n junctions of PV cells. The following equation describes the behavior of a solar cell. The PV system's I-V relationship establishes the PV cell's modeling as follows: [22]

(&I=I_pv-I_S (exp[q(V+R_s I)/(N_s kTa)]-1)-(V+R_s I)/R_p (1.1)
(3.1)@&I_pv=(I_(pv,n)+K_I ΔT) G/G_n (1.2)
(3.2)@&I_S=(I_(SC,n)+K_I ΔT)/(exp(V_(OC,n)+K_V ΔT)/a(N_s kT/q)-1) (1.3)
(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

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

Now substituting the value of I_D

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

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

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

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

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

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

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

$$I_{pv} = \frac{G}{G_{\mathbb{R}\mathrm{ef}}}\left(I_{ph.ref} + \mu_{sc}\cdot\Delta T\right) \quad (1.13)$$

Where,
G-IrradianceW/m^2
G_{ref} - Irradiance at STC $(1000\ \mathrm{W/m^2})$

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

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

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

The characteristics of solar photovoltaic cells, modules, and arrays can be determined using the mathematical model. Partial shading and variable irradiation characteristic analysis can be implemented using the topology that has been provided. The features have been examined and demonstrated with the use of a solar panel simulation. There are five sections to the paper. The first section covers the fundamental idea of solar photovoltaic modules. The research paper survey is covered in the next section. The next section covers the introduction of the maximum power point system, which is followed by the suggested methodology and its application. The simulation and results are displayed in the paper's next section.

II. RELATED WORKS

Due to the limitations of conventional MPPT algorithms in tracking the global maximum power of PV characteristics with many peaks and validations through simulations, Tanuj Sen et al. (2018) presented a modified PSO algorithm in their study. The benefit of less steady state oscillations has also been highlighted by the writers [1].

G. In order to increase the system's overall speed and competency, Dileep et al. (2017) wrote about the adaptive PSO algorithm. To validate their suggested method, they used two dissimilar shading circumstances. The aforementioned results unequivocally demonstrate that the described approach is capable of obtaining the global point of maximum power point in any scenario [2].

The maximum power point tracking technique, or Particle Swarm Optimization, has been described by R. Nagarajan et al. (2018) as a way to increase the output value of voltage from PV systems. In their work, they used PI controller in addition to PSO for boost convertor to convert DC to DC voltage[3].

A modified Particle Swarm optimization for an enhanced form of maximum power point tracking has been presented by Kashif Ishaque et al. (2012). Additionally, after the MPP is found, this article proposes that the suggested method can be utilized to measure power even under changing environmental conditions, with the benefit of fewer oscillations in the steady state [4].

In order to help users make an informed decision when creating any system, Faiza Belhachat et al. (2018) have reviewed the techniques of maximum power point tracking, ranging from antiquated, less used techniques to contemporary, sophisticated ones[5].

In their 2020 study, Ali M. Eltamaly et al. addressed a number of PSO issues, such as the lengthy convergence time that results from revising the converter's duty ratio's starting values. Furthermore, they provided an analysis of how well various techniques could determine GP in the presence of changing shading conditions [6].

Makbul A. et al. (2017) have provided an overview of the several maximum power point strategies used by PV systems in both partially shaded and typical weather conditions. Since the previous ten years, the authors have mostly concentrated on partial shade circumstances due to an increase in output requirements [7].

Zhu Liying et al. (2017) have written about the limits of conventional approaches over particle swarm optimization methods and about all maximum power point tracking technique utilized in extracting peak power production during variable shading conditions[8].

In their study, Rozana Alik et al. (2017) illustrated the unfavorable effects of partial shadowing on photovoltaic systems and presented an enhanced perturb and observe technique. The writers have cited the method's many benefits, including its simplicity, accuracy, and reduced cost. The suggested approach is an improvement over the traditional P and O approach, which causes instability in the system. All relevant flowcharts and algorithms were covered by the author [9].

A unique technique for tracking maximum power point while concurrently lowering steady state oscillations was presented by Mingxuan Mao et al. (2017). The paper's methodology ensured a speedier and more accurate search for the global maximum, which accounts for its advantages over traditional methods [10].

The Solar Maximum Power Point Tracking System, which Gomathi B. et al. (2016) described as an incremental conductance algorithm based system, provides clear examples of the incremental conductance technique. Its improved efficiency and accuracy in steady state are described in the study. Using fundamental equations, an algorithm flowchart, and comparisons between all three types of DC-DC converters, the authors have methodically modeled PV modules and solar radiation. The outcomes demonstrated that the Cuk and Boost converters offer the best performance and have the fewest ripples [11].

In 2018, Mr. M. Rupesh and colleagues conducted a thorough analysis of the two MPPT methods, P and O, as well as incremental conductance. Here, basic quantities like voltage and current are monitored in order to replicate the methods that are discussed. The modeling of PV cells and the I-V and P-V graphs of the solar array obtained at various irradiations are also included in the study. The boost converter and MPPT controller are included in the whole setup of the PV system as it is illustrated. Additionally included [12] is the boost converter's voltage profile using both techniques.

S. The drift-free perturb and observe approach, which includes current in addition to voltage and power as utilized in the traditional perturb and observe method, has been clarified by Manna et al. (2021). The reason the drift algorithm got its name is that it effectively addresses the drift problem, which is brought on by abrupt changes in insulation levels on cloudy days. As a result, the authors tested both algorithms for variations in insulation levels and demonstrated the percentage increase in power during the drift period in the method they discussed, which raises the method's efficiency and accuracy levels [13].

In their 2018 study, Saad Motahhir et al. retrieved the parameters needed to simulate the photovoltaic panel and went on to discuss the effects of radiation and temperature on the array. The authors have also addressed a modified incremental conductance theorem that can successfully reduce the steady state oscillations and have explained why the traditional theorems act erroneously when temperature and radiations are increased [22].

The use of incremental conductance and perturb and observe in PV systems was covered by Abul Kalam Azad et al. (2016). In order to operate like a solar generator on cloudy days, the output in this instance has been directly connected to the grid. After comparing the simulation results from the two algorithms under identical circumstances, the author came to the conclusion that while the latter algorithm performs accurately under changing atmospheric conditions, the P & O is not as effective [23].

(2017) Afshan Ilyas et al. have put up a thorough justification of the incremental conductance algorithm. In this instance, a dc-dc converter is incorporated with the PV module. The paper also contains photovoltaic cell modeling. The authors came to the conclusion that incremental conductance has a higher tracking speed and accuracy by using a real-time readout of the parameters [24].

Jubaer Ahmed and colleagues (2017) provided an elucidation of the distinction between uniform brightness and partial darkening. This study examines two well-known approaches, perturb and observe and particle swarm optimization, and assesses how well they perform under partial shading and dynamic shading scenarios [25].

According to Ehtisham Lodhi et al. (2017), unlike shadowing has negative effects on solar systems. This paper explains why there are multiple peaks when there is partial shading, or when there are clouds and the sun isn't shining all the time. It also explains how to find the global peak among the multiple peaks that are present when there is partial shading. The authors have included a comprehensive flowchart of the technique that illustrates how to apply the algorithm step-by-step to find the maximum peak position when weather is shaded. The study comes to the conclusion that this algorithm outperforms the commonly used techniques in terms of tracking efficiency and convergence rate [26].

T. Particle swarm optimization, one of the most well-known optimization techniques to maximize solar power extraction, was proposed by Diana et al. (2019). The objective function is used in this procedure. In order to support the algorithm's efficiency level in comparison to other widely used tracking methods, the author has tested the algorithm under a variety of temperature and radiation circumstances. To support the work, the author has additionally included a number of graphs [27].

According to R Sridhar et al. (2017), a PV system's output can increase when the surrounding environment changes. The well-known particle swarm optimization technique is covered in the study, and simulations are run to demonstrate the effectiveness of this approach. The Particle Swarm Optimization approach has been well explained by the author. They have written about the in-depth examination of the properties and modeling of PV arrays using mathematical formulas, and they have drawn the PV and IV curves to further clarify how PV systems operate. [28].

In their study, Nadia Hanis et al. (2016) outlined the necessity of promoting renewable energy sources and their reliance on radiation and temperature. The voltage and current equations for solar photovoltaic systems have been used to explore the mathematical modeling in detail. Furthermore, MPPT based on particle-based optimization is also provided. The algorithm's direction is further clarified in the flowchart, which significantly simplifies the description. In order to examine the convergence of the theorems under various environmental conditions, the characteristic curves produced under variable temperature and irradiance conditions are also provided [29].

Under uniform temperature settings, Ahmed Hossam El-din et al. (2017) examined two well-known algorithms: PSO and perturb and observe. The particle swarm algorithm operates at a fast speed and is capable of operating at different temperatures and irradiance levels. The system's module performance is also displayed in the article. A 100 KW grid-connected photovoltaic system is used for the study, which is conducted in various environmental settings [30].

In 2016, Malik Sameeullah and colleagues talked about different MPPT schemes and how to use them. To make it simple for readers to select a suitable algorithm for their research topic, the authors assess the characteristics, costs, and control strategies of all the approaches that are described. This study covers all the strategies that are helpful in a variety of environmental settings, from pleasant days to changing climatic conditions, from the current/voltage feedback technique to the contemporary hybrid MPPT methodology [31].

The many MPPT techniques were covered in tabular form by Arti Pandey et al. (2019), along with the urgent need to switch to renewable energy sources due to the rising cost of fossil fuels and the high carbon dioxide emissions from non-renewable energy sources that endanger human life and the environment. The article provides a brief overview of all the most well-known MPPT methods and their benefits and drawbacks. Additionally, each method's benefits and drawbacks are enumerated in points [32].

III. 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.

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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]

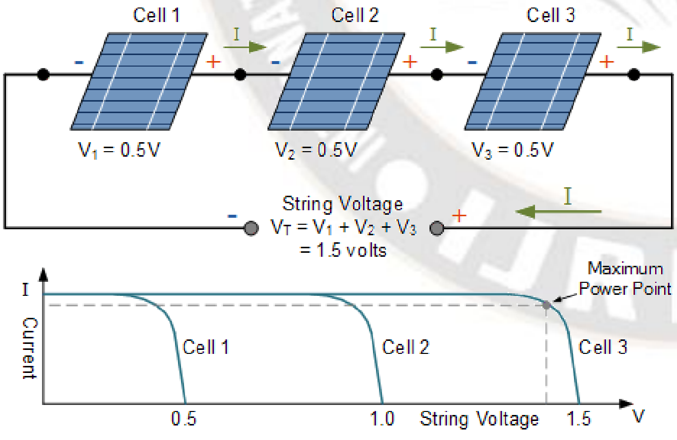

Figure 3.2 : Normal Operation of PV String

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 x 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, VT, is equal to the sum of the individual cell voltages (V1 + V2 + V3 = 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 x 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

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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.

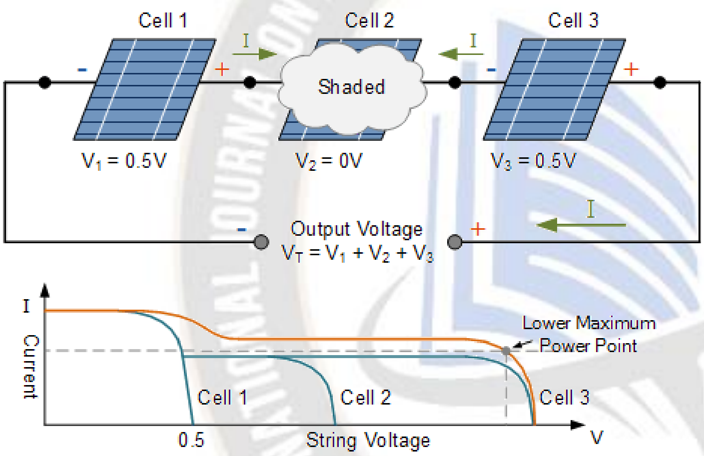

Figure 3.3 : Impact of Shading on Characteristics of PV System

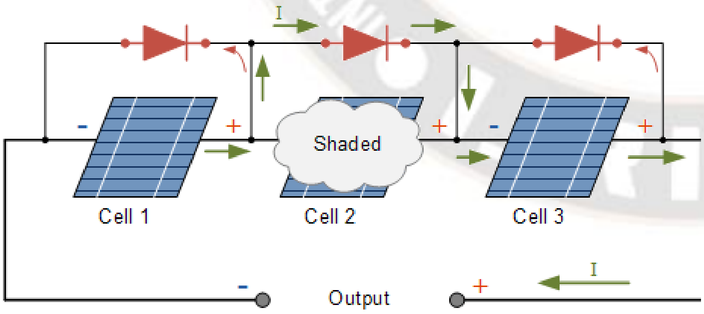

Figure 3.4 : Connection of Bypass Diode in PV System

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 (Pmax). 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.

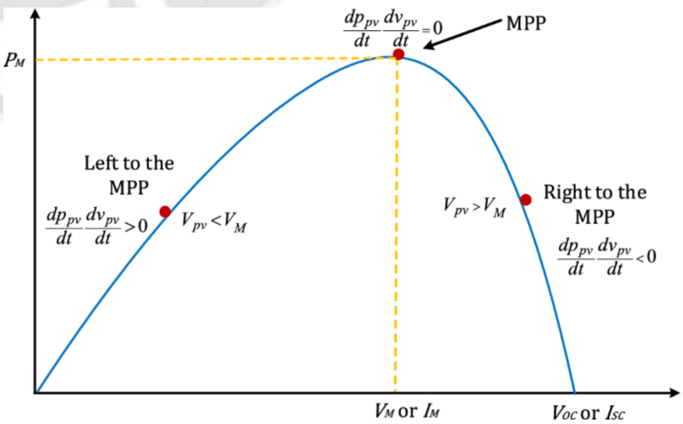

Figure 3.5: Significance of MPPT on Power Output of Solar PV System

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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]

IV.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 Tempearature 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 facilty 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.

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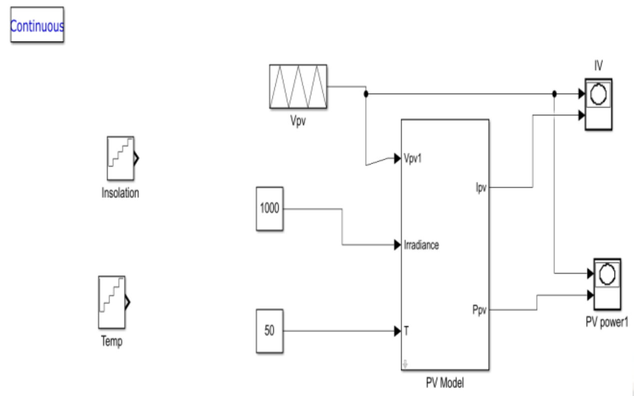

Fig. 4.2 Simulink Diagram of Proposed System with Parametric Variation

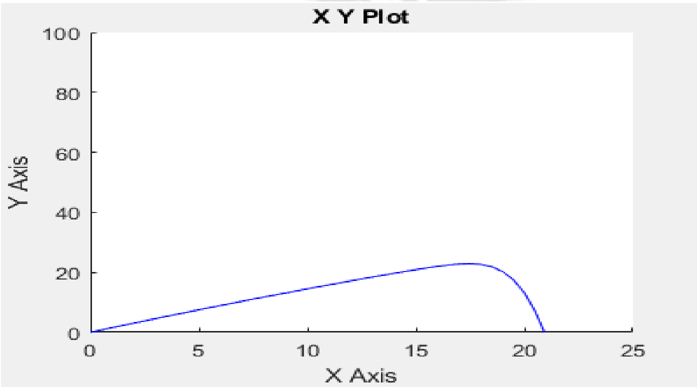

Fig 4.3 Power Voltage Waveform of Photovoltaic System without Cooling

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.

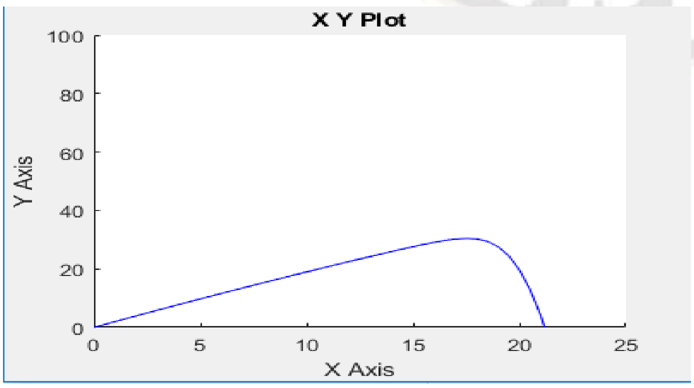

Fig.4.3 Power Voltage Waveform of Photovoltaic System with grass at back Surface

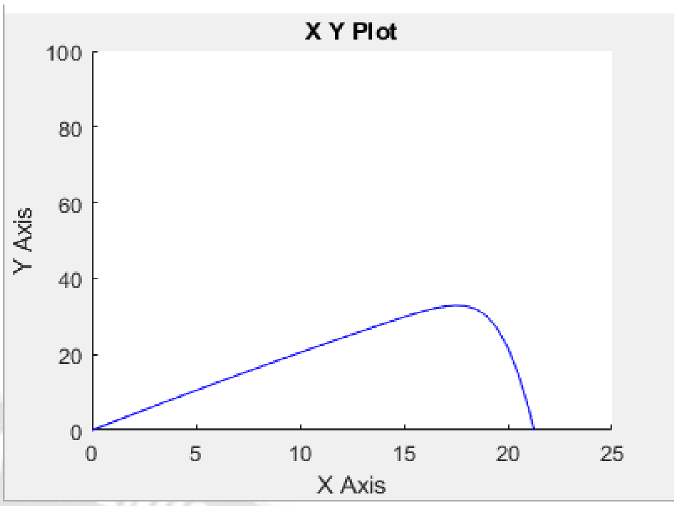

Fig. 4.4 Power Voltage Curve of Photovoltaic System with Front Cooling System

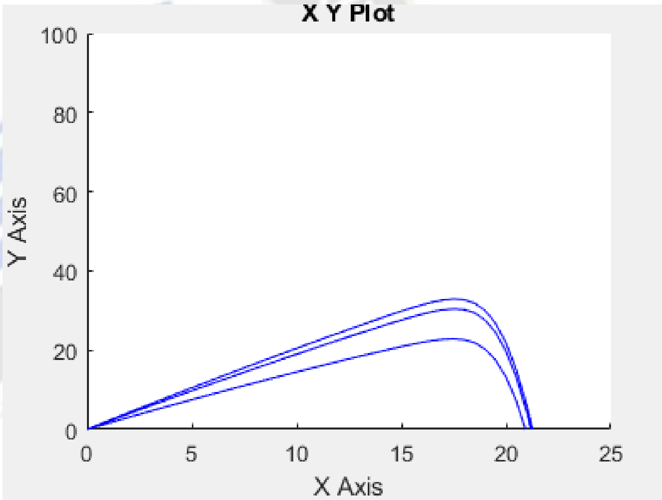

Fig.4.5 Comparative Analysis of Three Cases for Validation of Cooling System

The proposed research has been implemented for three cases of the cooling system with water, grass with different orientaton 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 propsoed sytem

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

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(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 & Nedunchezhian 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):

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

where I is the generation number (i=,1,2,......it), k is the order of searching agents in the swarm (k=1,2,....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.

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

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

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

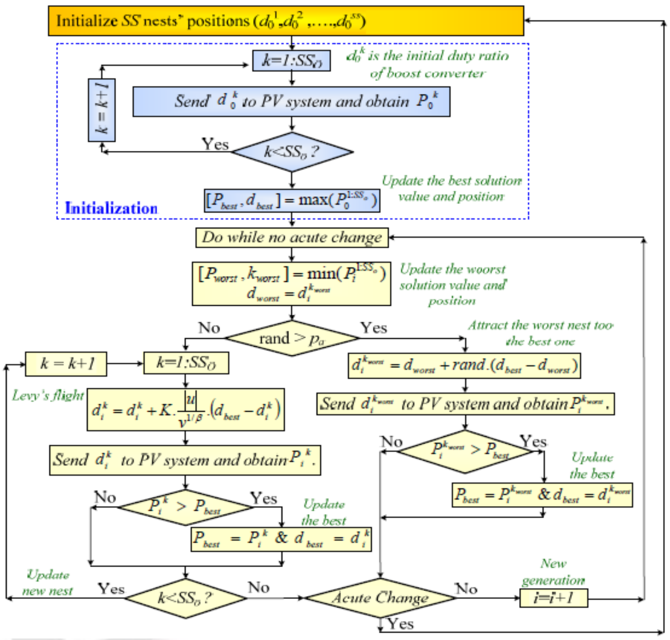

Figure 4.6: Simulation Model of Proposed System with Cuckoo Search Algorithm

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

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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 $a_0^{\mathrm{i:SS}}$ 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, dbest.

Step 2: Determine the worst particle power, $P_{\text{averst,}}$ its order, $k_{\text{worst,}}$ 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 $d_i^{k_{\text{wass}}} = d_{\text{worst}} + \text{rand}\ (d_{\text{best}} - d_{\text{worst}})$,

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

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 $d_i^k = d_i^k + K \cdot \frac{|\mu|}{v^{\frac{1}{\beta}}} \cdot \left(d_{\text{bent}} - d_i^k\right)$, 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 $P_i^k > P_{\text{best}}$, then $P_{\text{best}} = P_i^k$ and $d_{\text{best}} = d_i^k$ 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
∑V	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.

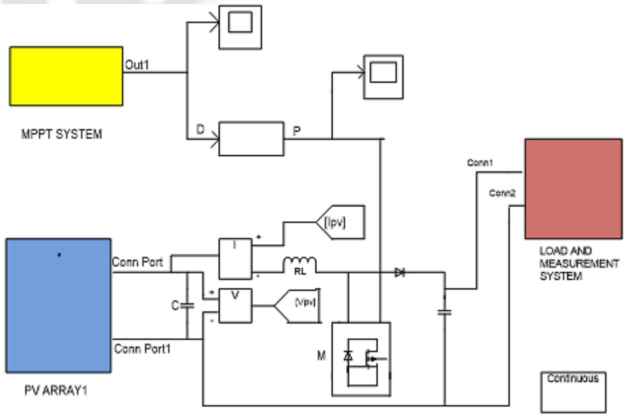

Figure 5.1: General Simulation Model of Proposed System

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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.

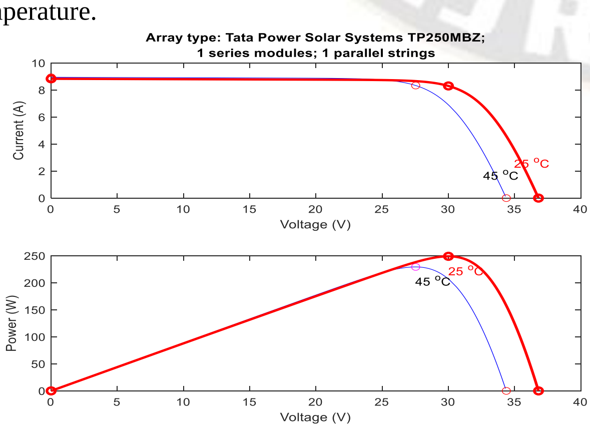

Figure 5.2: Characteristics of Photovoltaic Module Used in Simulation

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 (%)	Average Overall 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

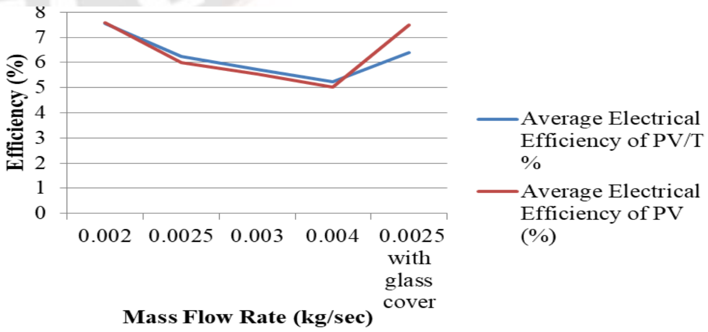

Figure 5.3 Shift in Average PV and PV/T Electric Performance for Different Mass Flow Rates

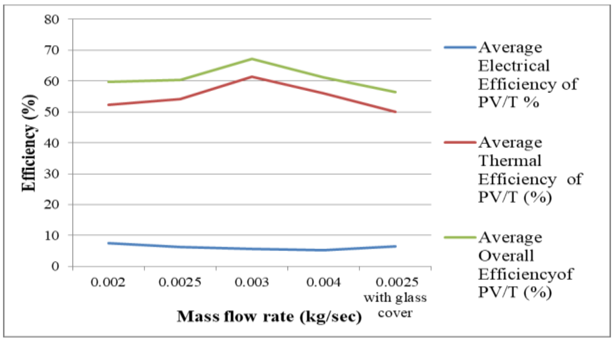

Figure 5.4 Shift in Average PV/T Electrical, Thermal and Total Efficiency for Different Mass Flow Rates

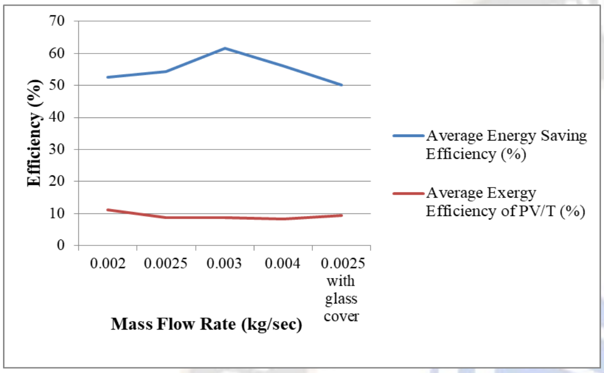

Figure 5.5 Shift of Average Exergy and PV/T Energy Saving Output for Different Mass Flow Rates

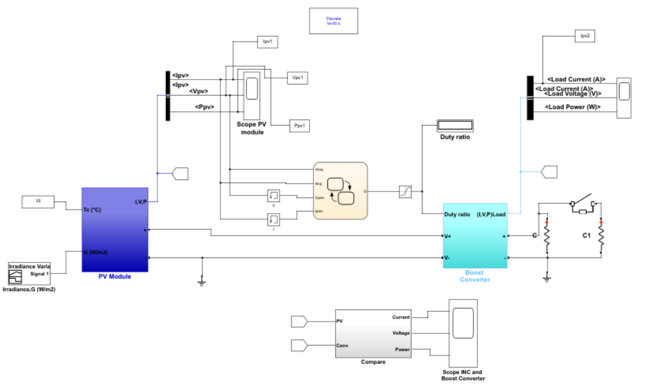

Figure 5.6 Implementation of Heuristic MPPT for Electrical Characteristic and Performance Analysis of SPV System

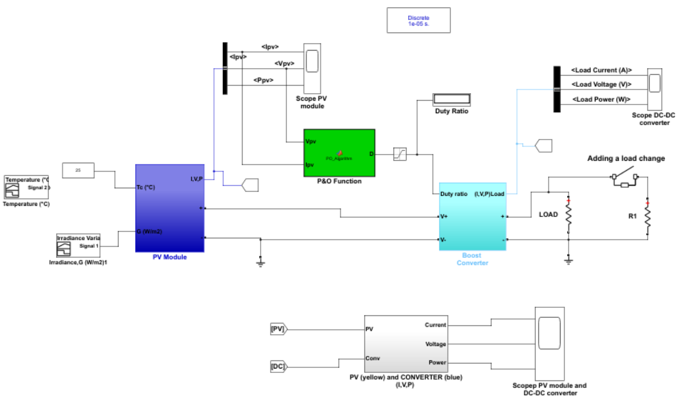

Figure 5.7 Implementation of Conventional MPPT

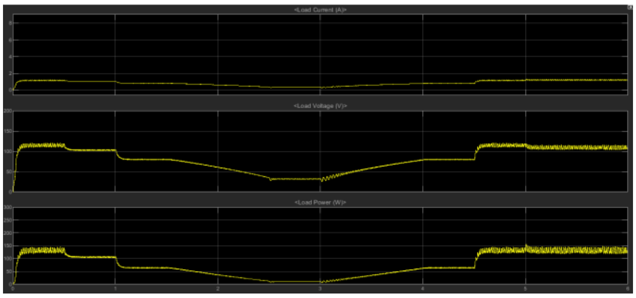

Figure 5.8 Output of SPV System in Normal Configuration with Heuristic MPPT

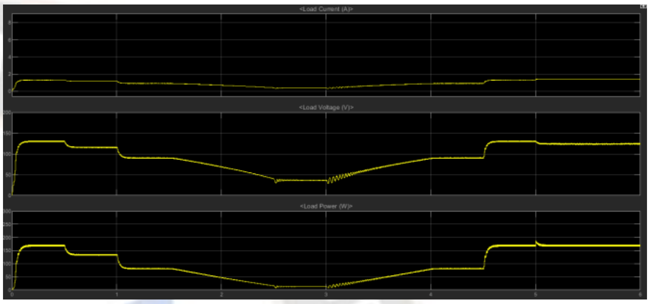

Figure 5.9 Output of SPV System in PVT Configuration with Heuristic MPPT

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 temperature of the PV panel is changing efficiency functions, which may have an impact on photovoltaic strength. Heat losses from solar panels are eliminated by the solar PV/T system. This work suggests using hybrid solar PV/T collection technology to improve energy efficiency per unit area. The performance analysis of the combined PV and thermal systems into a single device is covered in this study. The experimental results demonstrate a significant improvement in the electrical performance of the PV module using the PV/T approach. Results indicated that the electric and heat output of the PV/T system together is significantly higher than that of PV alone. An original In this study, maximum power point tracking is presented as a way for solar photovoltaic systems to achieve maximum output. The maximum power point system's dynamic nature is explained by this research. The study covers both the theoretical and the real-world applications of the conventional and soft computing techniques that have been applied to the development of maximum power point algorithms. A CSA algorithm has been created for monitoring power consumption to the maximum. Thorough examination of the proposed algorithm in complex, normal, and partially shaded modes of operation shows the algorithm's effectiveness in improving the solar system's operational efficiency under these conditions. When compared to conventional methodologies, the enhanced cuckoo search optimization technique increased the tracking speed and tracked the maximum power point under complex operating conditions, enhancing the system's operational efficiency

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