




Modeling of Partial Shading PV System to Predict and Achieve the Peak Power Point using Advance Control Technique

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Received: 10 January, Revised: 23 January, Accepted: 03 February

Abstract— Photovoltaic System (PV) is one of the abundant sources of renewable energy available on the earth. The PV system plays a vital role to cope with electric power demands without affecting the environments; as it is one of the green energies. To get the maximum power from the available PV system and to utilize its maximum efficiency; the control techniques of the maximum power point have a great contribution. But the Partial shading condition makes it more challenging because of the local and Global maximum power points. The first challenge to cope with: is to find those maxima and minima which can be done by having a variable voltage source across the load to achieve a varying voltage. In the same way, while varying the voltage from zero to a maximum limit; there were two different maximum points of the power observed i.e., local and global maximum points. The Conventional control techniques (Incremental Conductance and Perturb and Observe) were applied to the PV system for maximum point achievement. The Incremental conductance has achieved the power near the local maximum point while P&O has improved this Power comparatively more than IC but still, it has been stuck to the local maximum point. Cuckoo search algorithm was able to bypass the local maximum point and successfully achieved the global maximum Power Point. Moreover, the Cuckoo control technique has a better transient response as compared to IC and P&O technique.

Keywords— Incremental conductance, Perturb and Observe, Partial shading.

I. INTRODUCTION

Renewable energy sources are becoming more and more important to meet energy demand for the future and assess the environmental harm caused by fossil fuels. They are easily accessible, require little maintenance, and are completely free of pollution. Sun energy is the main energy source of energy resources worldwide, which has a natural fusion reactor [1]. The rising and falling of the Earth's atmosphere cause the differential heating of the surface of Earth. From this, an airflow comes in, pushing wind. In essence, wind forced by the waves moves into the ocean, creating ocean tidal energy. The sun is responsible for the water's evaporation from the oceans and rivers that feed into the mountain streams, giving rise to hydraulic power, which makes rain and gives rise to lakes and

rivers. Plants use water as their energy source, carbon dioxide as their fuel source, and photosynthesis mechanism. The plants do photosynthesis to grow and prepare their food. Biosolids are plants and other biological molecules that are generally referred to as biomass. Solar energy might be harnessed either through the building's construction (through the heat collection of the building's design) or through photovoltaic cells.

The photovoltaic cell's current in the conduction band depends on the number of electrons concentrated in the semiconductor band. This is proportional to the supply of solar radiation that is absorbed by the photovoltaic cell. Increasing the photovoltaic cell's current can be increased by increasing the cell area, or it can be increased by increasing the amount of solar radiation that hits the cell. The photovoltaic module's power rating is usually given as the module's power output when the incident solar radiation is 1000 watts per square meter and the temperature is 25 degrees Celsius. . A single square meter module can generate 150 watts, which can be concluded that 150 watts can be produced from a single square meter of solar modules.

II. METHODOLOGY

Before we get into MPPT Control Technique, there are a few topics that will help us understand the MPPT concepts.

A. Photo-Voltaic System

Since solar energy systems are entirely dependent on the radiation and temperature factor, these variables decrease efficiency even when the irradiance level drops below 150 W/m² on cloudy days. Therefore, by using MPPT controllers the system needs to increase the overall efficiency of solar energy with the help of a boost converter. The energy obtained by PV cells varies due to variations in the environment, including irradiation and temperature. Therefore, the controller is important to adjust the solar cell energy to adapt the environmental changes to the nonlinear voltage and current that is a characteristic of solar cells.

B. Photovoltaic Single diode Model

The single-diode model has been considered for the estimation of electrical model parameters [3]-[4]. A solar PV is usually modelled with an inverted diode as the current source,

as shown in Figure 1. Resistance R_s , as can be seen in Figure 1, reflects the resistance between the bulk material and the interaction with the metal, while R_{sh} reflects the recombination of pairs of electron-holes. For the single-diode model, the relationship between the output current I_L and voltage V_L is given as follows:

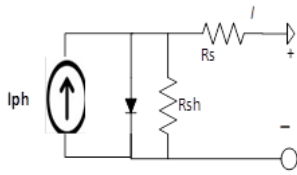


Figure 1 Single diode Model

$$I_L = I_{ph} - I_0 \left[\exp\left(\frac{V_L + I_L R_s}{V_t}\right) - 1 \right] - \frac{V_L + I_L R_s}{R_{sh}} \quad (1)$$

where $V_t = nKT/nq$ Here, n is the diode ideality factor

T represents the temperature of the solar cell in Kelvin

K represents the Boltzmann constant which is

$$K = 1.3806 \times 10^{-23} \text{ J/K}$$

q represents the charge of an electron

$$q = 1.6021 \times 10^{-19} \text{ Coulomb}$$

I_0 represents the diode saturation dark current

I_{ph} represents photon current

- *Open-circuit State*

This is the state where the PV module output terminals are not connected, and the voltage is at its peak and equal to the V_{oc} open-circuit voltage across the PV module terminals. In the output, there is no current flowing, and therefore

$$I = 0 \quad (2)$$

- *Short-circuit condition*

This is the state where the PV module output terminals are attached (short-circuited) such that the voltage across the PV panel is zero. At this point, the highest value of current will flow through the PV module and is equal to the I_{sc} (short-circuit current). Besides, under the same condition, the current derivative is obtained from the slope of the I-V characteristic in the region closer to the short-circuit condition concerning voltage $dI/dV = -1/R_{sh}$, where R_{sh} is the effective resistance under short-circuit conditions.

- *Maximum PowerPoint*

The current flowing at the output of the PV module is equal to I_{mp} at full PowerPoint operation and the voltage through the PV module is equal to V_{mp}

Besides, at the highest PowerPoint, the derivative of power concerning voltage is zero.

- *Estimation Method A*

$$I_0 = \frac{I_{sc} R_{sh} + I_{sc} R_s - V_{oc}}{R_{sh} \exp\left(\frac{V_{oc}}{N_s V_t}\right)} \quad (3)$$

$$I_{ph} = I_0 \left[\exp\left(\frac{V_{oc}}{N_s V_t}\right) - 1 \right] + \frac{V_{oc}}{R_{sh}} \quad (4)$$

Table 1 Parameter Estimation

Parameter	Estimated Value
R_s	0.3085Ω
R_{shunt}	1.676k Ω
V_{ter}	0.02739V
I_0	1.207×10^{-9}
I_{ph}	4.85A
A	1.067

A. BOOST CONVERTER

The simplest type of switch-mode converter is a booster converter. It is obvious from its name that an input source voltage is needed, and it boosts or raises it. A semiconductor system switch (a MOSFET), a diode (to allow current in one direction), and a condenser switch (to allow current in one direction) are typically used in the circuit (whose energy storage adds up with the source) (To remove the fluctuations and to maintain a steady current across the load).

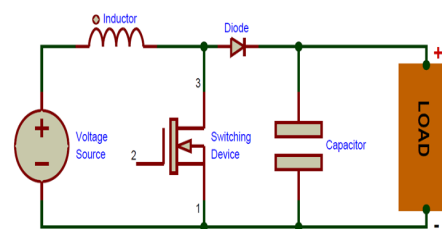


Figure 2 Boost Converter and its basic elements [5]

- *Converter Working Principle*

The role of the inductors, a switch such as MOSFETs, a diode, and capacitors must be understood to understand the functionality of a boost converter. The boost converter method is explained stepwise with the help of the below phases

Phase 1: Voltage drop across the capacitor

The capacitor output is charged to a level of voltage that is equal to the source voltage except for the drop across the diode. The diode drop will be subtracted from the source voltage. The voltage drop across the capacitor is shown in Figure 3 [5].

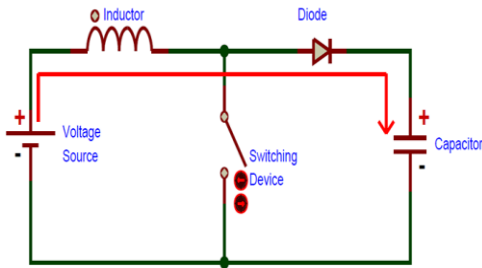


Figure 3 Voltage drops across the capacitor [5]

Phase 02: Turn-on the switch

Now turning the transistor (switch) on is a way to get a voltage drop across the inductor. The MOSFET will be turned on by the PWM source. The source current is channeled through the inductor by passing through the MOSFET. The capacitor remains charged parallel to the load because the diode does not discharge it through the source so it does not allow the backward path of current to flow while the switch is on/off. The switch is shown closed in Figure 4 and it shows the source voltage is dropped across the inductor.

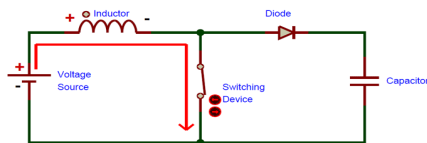


Figure 4 Storage of energy in an inductor [5]

Phase 03: Switch turn off

The switch is turn-off at this point, and the source current is stopped by the inductor to pass through the inductor alone. The purpose of the inductor is to store the energy in its magnetic field and to integrate the electromotive force of the source to the inductor voltage drop and increase the voltage across the load. The voltage across the inductor would be such that the polarity of the inductor is opposite to the polarity of the source. The voltage drop across the capacitor is now greater than before, which suggests that it has successfully increased the low DC voltage to a higher voltage. The power store is given by the inductor

$$P_L = \frac{1}{2} L_1 I_1^2 \tag{5}$$

The voltage drop across the inductor is also indicated by the equation.

$$V_L = L_1 \frac{di}{dt} \tag{6}$$

When the anode has a higher potential than the cathode, the diode is forward biased while it was reversed in Phase 2 as mentioned before, because the cathode had greater potential than the anode. In this process,

The output voltage is step up through the capacitor, which will discharge through the load, due to the voltage of the source and inductor acting as the source.

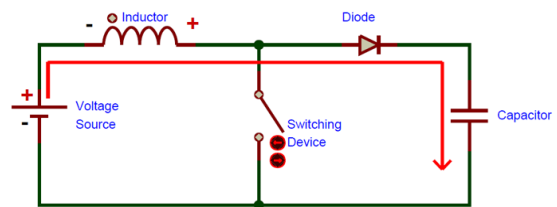


Figure 5 Boosted voltage across the Capacitor [5]

• *Step in the Boost converter design*

STEP-01

It is always important to know the specifications of the DC load connected to the boost converter. Since it is strongly suggested (from experiments) that when connecting the source and inductor, the output voltage and current must be first measured for the load, which results in our output power for the circuit.

STEP-02

The power calculated from step one is divided by the input voltage and is increased by 40 per cent to determine the peak current value. Additionally, the average input current is multiplied by 0.8 to get the minimum current. The minimum current must be subtracted from the maximum to determine the average current, which is the overall current.

STEP-03

Duty cycle of the PWM generator

$$Duty\ Cycle = (V_{out} - Input) / (V_{out}) \tag{7}$$

STEP 04

The oscillatory frequency is also a very critical parameter, and this may be anything like a 555 timer or a generator for PWM. Frequency-inverse often results in the time period and when it multiplies with the duty cycle it provides the switch-on time.

STEP 05

The inductance can be calculated by multiplying the voltage V with the dt (on time) which is then divided by change in current as shown in eq 8

$$L1 = (Vsource * dt) / dI \tag{8}$$

The equation illustrates that Vs is the voltage of the source, dt is the time when the switch (MOSFET) is on and dI is the current that can be determined from the current instantaneous and previous values

- Inductor value calculation

The inductance of the inductor is directly proportional to the following equation

Inductance ripple = slope of inductor current into(duration) as shown in eq 9

$$\Delta i_l = \frac{V_{in}}{L} \times D_{cyc} \times T_s \tag{9}$$

$$L = \frac{V_{in}}{\Delta i_l} \times D_{cyc} \times T_s \tag{10}$$

$$L = \frac{4 D_{cyc} V_m}{\Delta \times I_m \times f_s} \tag{11}$$

In equation 11, Δi_l is the product of Δ and i_l and i_l is $\frac{I_{in}}{4}$ and f_s is the frequency of switch and Δi_l is the inductor currents peak-to-peak ripple of I_{L1} to I_{L4}

- The calculation for the capacitor in the Boost converter

From the capacitor mathematical model

$$\frac{dV_o}{dt} = \frac{I_o}{C_o} \tag{12}$$

To calculate the output capacitor ripple voltage, it must be equal to the slope \times duration given in equation 13

$$\Delta v_o = \frac{I_o}{C_o} \times (1 - D_{cycle}) T_s \tag{13}$$

$$C_o = \frac{I_o \times (1 - D_{cycle}) T_s}{\Delta v_{out}} \tag{14}$$

$$C_o = \frac{I_o \times (1 - D_{cycle}) T_s}{\Delta \times V_{out}} \tag{15}$$

Where Δv_o is the peak-to-peak output voltage ripple and Δ is the per cent of the output voltage V_o

III. MPPT CONTROL TECHNIQUES

A. Perturb and Observe Method

For the better outcome (maximum Power) many researchers have contributed to enhancing the efficiency. MPPT algorithms are widely used in Perturb and observe (P&O), and incremental (IC) control techniques. In [2], and [12], an analysis of the different MPPT schemes was carried out. The principle behind the Perturb and Observe technique is to interrupt the PV voltage by adding or subtracting the duty cycle when there is a slight increase or decrease in the Power so that to track the resulting electrical power. It is interesting to note that MPPT structures operate under evolving conditions, which have been highlighted by several researchers [8],[9],[10]. The challenges face by the Incremental Conductance and Perturb and Observe method has been addressed to smoothly and rapidly track the MPP [11]. In MPPT literature, this problem is also known as drift. A perfect approach to eliminating steady-state oscillations in P&O is the implementation of variable intervals. The flow chart diagram of P&O is given Figure 6.

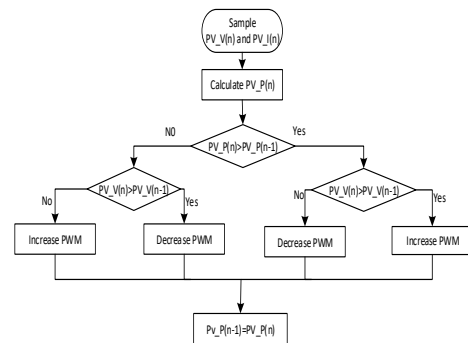


Figure 6 Perturb and Observe Flow Chart

B. Incremental Conductance Technique (MPPT)

Another technique for maximum PowerPoint achievement is the incremental conductance method, which is considered in the early stages of the study. This technique is used to control the voltage of the solar array power systems through a boost converter [12]. As the PV operates at optimal PowerPoint-related irradiation and temperature, the optimum efficiency is achieved. A PV control system (incremental conductance (IC) process) that can control the maximum power point to produce more electrical power compared to normal operation without

MPPT, because irradiation and temperature often change with time. To control the duty cycle of the Buck-Boost converter and to ensure the maximum efficiency of the MPPT process, the IC algorithm method has been developed. In a Simulink setting, the system output of the IC algorithm has been compared with the widely used Perturb and Observe (P&O) algorithm and it is concluded that the IC method shows better simulation results and also has lower oscillations.

The mathematical model of incremental conductance is derived from the power formula that is the product of voltage and current after taking the derivative of voltage shift with respect, as shown in equation 14

$$P = I \times v \tag{14}$$

$$\frac{dP}{dV} = I \times \frac{dV}{dV} + V \times \frac{dI}{dV} \tag{15}$$

The flow chart of the Incremental Conductance (IC) is shown in Figure 7

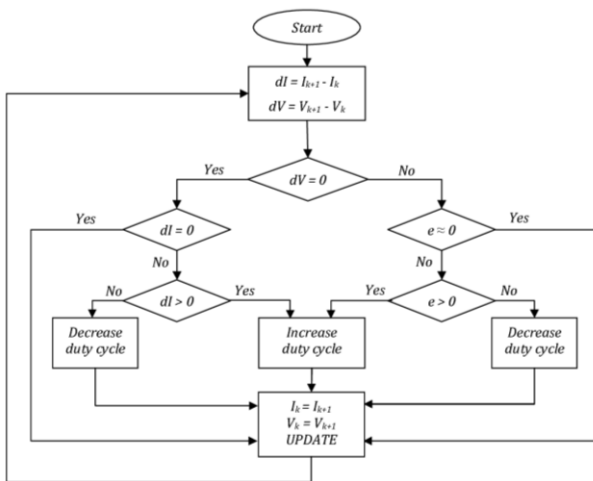


Figure 7 Incremental Conductance Method Flow Chart

C. Maximum Power Point Technique (CUCKOO Search)

Cuckoo is a bird, which has strange breeding and lay the egg in the nest of the other bird. Ani and Guiro are the birds that don't make their own nest and lay the egg in the host nest. These birds neither lay their egg silently but also kick out the egg of the host nest so that there is no possibility of hatching the host's egg [4]. Cuckoo birds always searching before they lay their egg in the host nest, and this process is also very important in their breeding. Levy flight, which is a statistical technique for selecting something like choosing walk or direction. The input to this mathematical function is the worst and best possibility which can return the outcome near the best always. Levy's flight steps are spread with time and each step is according to the period of the step. The Power-law of distribution can calculate the steps of the which is the Cuckoo search length [6]. The exponential function is a long tail of the power-law distribution in which the steps taken are randomly processed [7].

- Rules of Cuckoo Search Algorithm

- The egg lay by the cuckoo in the nest which is randomly picked is one at a time.
- The best egg can be passed to the next generation.
- The number of nests available must be determined and the host species, where Pa is located [0, 1], must be labelled with the cuckoo egg. If the cuckoo eggs are found by

The flow chart of the Cuckoo search is applied to the PV device is shown in Figure 8 to achieve maximum power. The flow chart is shown in Figure 8 to achieve the MPPT condition using the cuckoo method.

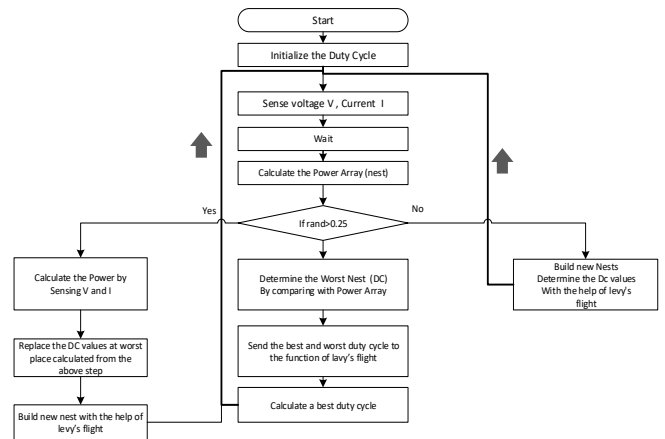


Figure 8 CUCKOO Search Flow Chart

IV. SIMULATION AND RESULT

A. Photovoltaic System and Partial Shading

Irradiance 1000 w/m2 and temperature 25 for the solar PV array whose open-circuit voltage, short circuit current, MPPT Power and current are shown in figure 9.

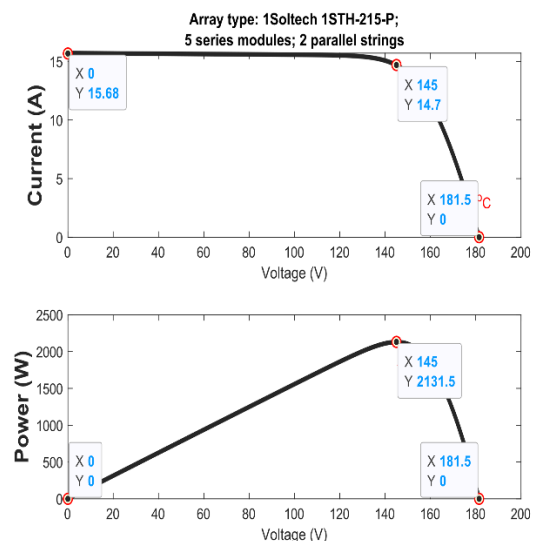


Figure 9 Five Series module and 1 Parallel String of the PV Array showing maximum current and Power for the specific voltage

B. Local and Global Maxima

The partial shading condition is created on the PV system by having different irradiance i.e., 1000 W/m² and 500 W/m² on the two different PV array. The setup for the Partial shading condition was set by varying the voltage across the load so that variation in the Power can be observed in fig 10.

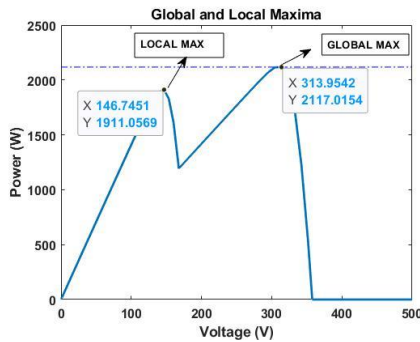


Figure 10 Global and Local Maxima

The local Maxima is achieved at 1911W while the global maxima which the highest peak under the partial shading condition is 2117W.

C. PV only connected to the load

Figure 10 is Simulink model consist of the PV arrays having a partial shading condition due to the 1000 and 500 W/m² of

irradiance.

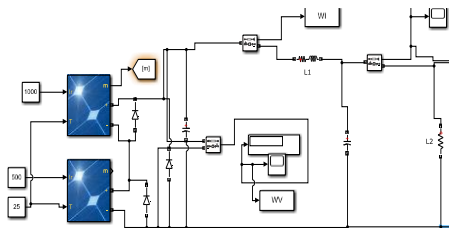


Figure 11 Simulink block Connecting Two PV Array with the Load

Power achieved from the PV Array shown in Figure 10 is demonstrated with the help of figure 12

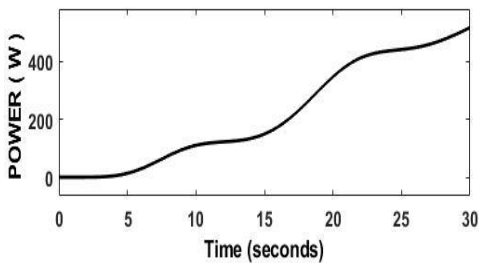


Figure 12 power achieved with no control technique

Load voltage curve is shown in Figure 13 with no boost control technique.

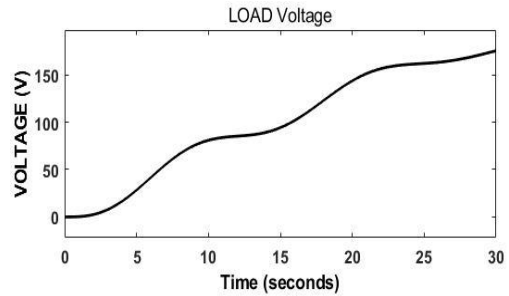


Figure 13 Load Voltage with no control technique

D. Power Improvement using IC Method

Figure 14 shows that the Power 1751W is achieved with the help of the IC method and hence it is improved from the power achieved without any control technique used above.

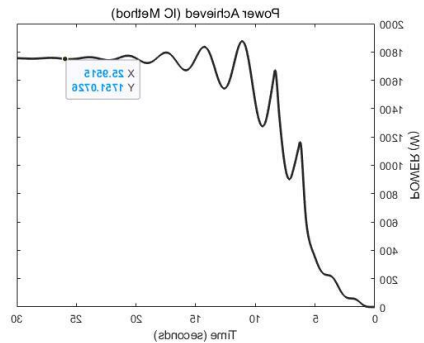


Figure 14 Power Improvement using IC Method

E. Power Improvement using P&O Method

Figure 15 shows that the Power 1833W is achieved with the help of the P&O method and hence it is improved from the power achieved without any control technique used above.

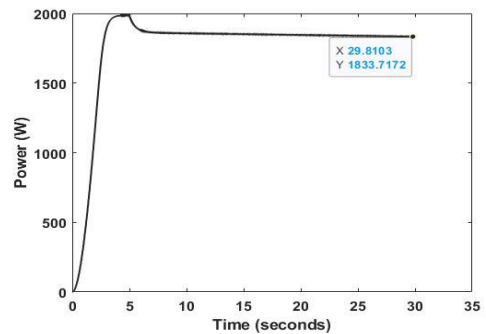


Figure 15 Power Improvement using P&O Method

F. Power Improvement using CUCU Search Control

Figure 16 Shows that the Power 2116W is achieved with the help of the CUCU method and hence it is improved from the power achieved without any control technique used above.

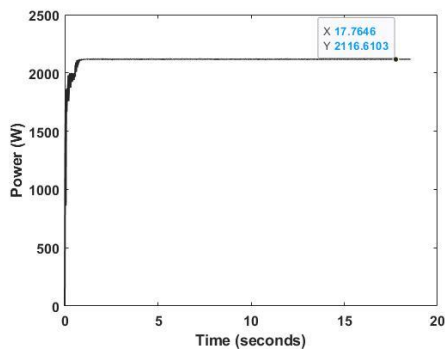


Figure 16 Power Achieved using CUCU Method

Figure 17 shows the PV terminal and boosted voltage which is done with the help of boost converter and PWM control signal through the CUCU control technique

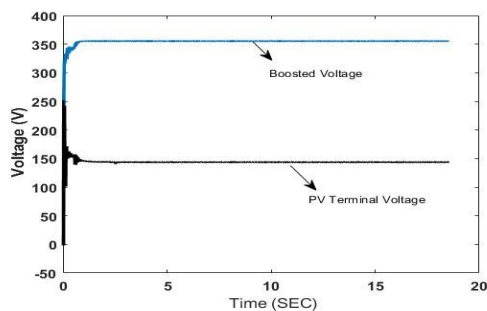


Figure 17 PV terminal and Boosted voltage using CUCU Control Method

Power Comparison of control techniques

The first waveform shows the power (2116W) achieved using CUCU Search, the second waveform (1840W) is the P&O, while 1751W is the IC and 430W is the power observed in the absence of control technique under partial shading condition respectively as in fig 18.

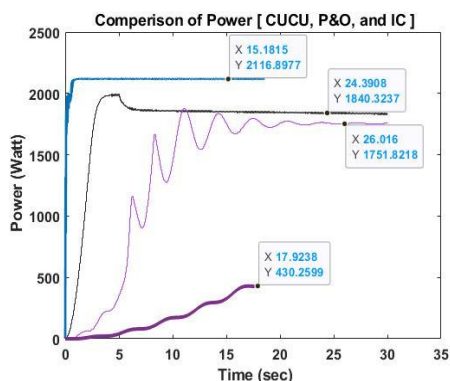


Figure 18 Comparison of Power using MPPT control Techniques

CONCLUSION

The Incremental conductance has achieved the Power of 1751W while the P&O has improved this Power to 1840W. The Cuckoo search algorithm was able to bypass the local maximum point and successfully achieved the global maximum power

point at 2116W. Moreover, the Cuckoo control technique has a better transient response of almost 1sec from the P&O (21sec) and IC 8.6 sec.

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How to cite this article:

Amjad Ali , Amjad Ullah Khattak, Ahmad Jamal "Modeling of Partial Shading PV System to Predict and Achieve the Peak Power Point Using Advance Control Technique", International Journal of Engineering Works, Vol. 9, Issue 02, PP. 32-38, February 2022, <https://doi.org/10.34259/ijew.22.9023238>.

