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INTRODUCTION

One of the major concerns in the power sector is the day-to-day increasing power demand but the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming.

Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever wherever necessary.

In order to tackle the present energy crisis one has to develop an efficient manner in which power has to be extracted from the incoming solar radiation. The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and material science has helped engineers to come up very small but powerful systems to withstand the high power demand. But the disadvantage of these systems is the increased power density. Trend has set in for the use of multi-input converter units that can effectively handle the voltage fluctuations. But due to high production cost and the low efficiency of these systems they can hardly compete in the competitive markets as a prime power generation source.

The constant increase in the development of the solar cells manufacturing technology would definitely make the use of these technologies possible on a wider basis than what the scenario is presently. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy.

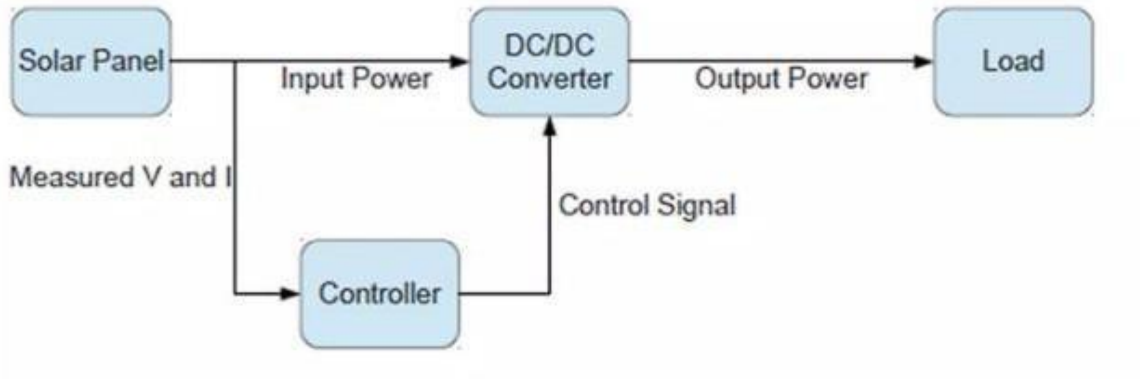


Fig.1: MPPT block scheme

SOLAR CELL MODELING

2.1 MODELLING OF SOLAR CELL

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available.

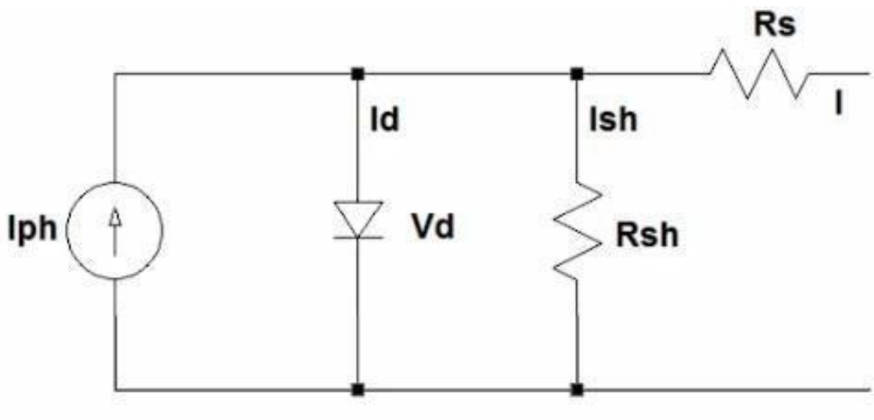


Figure 2: Single diode model of a solar cell

The characteristic equation for a photovoltaic cell is given

$$I = Ilg - Ios * \left[\exp\left\{q * \frac{V+I*Rs}{A*k*T}\right\} - 1\right] - \frac{V+I*Rs}{Rsh} \quad (1)$$

Where,

$$Ios = Ior * \left(\frac{T}{Tr}\right)^3 * \left[\exp\left\{q * Ego * \frac{\frac{1}{Tr} - \frac{1}{T}}{A*k}\right\}\right] \quad (2)$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * lambda \quad (3)$$

I & V: Cell output current and voltage;

Ios: Cell reverse saturation current;

T: Cell temperature in Celsius;

k: Boltzmann's constant, 1.38*10-19 J/K;

q: Electron charge, 1.6*10-23 C;

Ki: Short circuit current temperature coefficient at Iscr;

lambda : Solar irradiation in W/m^2;

Iscr: Short circuit current at 25 degree Celsius;

Ilg: Light-generated current;

Ego: Band gap for silicon;

A: Ideality factor;

Tr: Reference temperature;

Ior Cell saturation current at Tr;

Rsh: Shunt resistance;

Rs: Series resistance;

The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance .

$$I = Np * Ilg - Np * Ios * \left[\exp\left\{q * \frac{\frac{V}{Ns} + I * \frac{Rs}{Np}}{A * k * T}\right\} - 1\right] - \frac{V * \left(\frac{Np}{Ns}\right) + I * Rs}{Rsh} \quad (4)$$

The I-V and P-V curves for a solar cell are given in the following figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

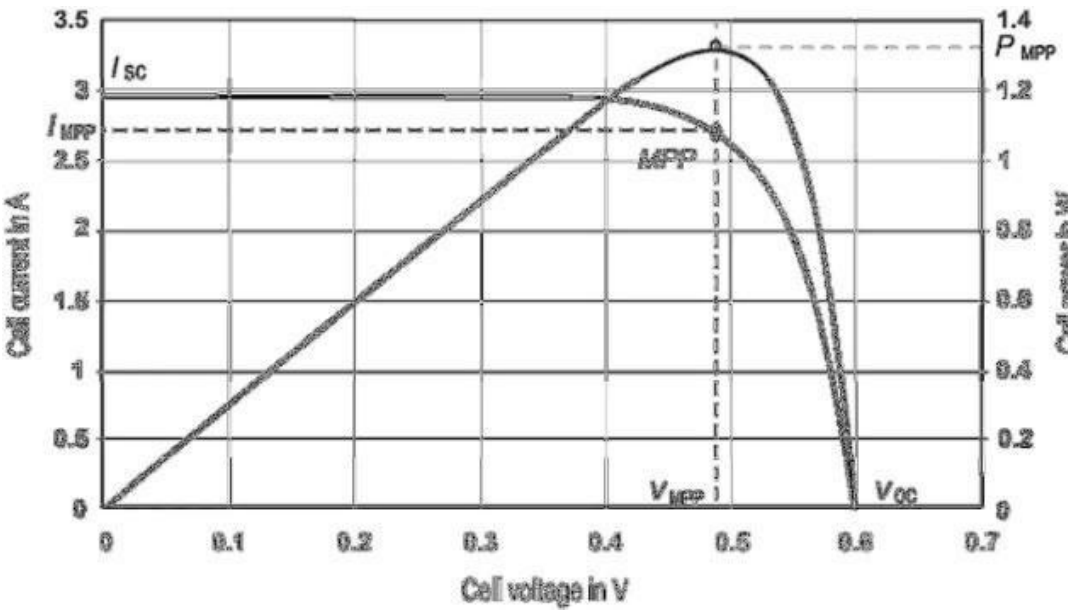


Figure 3: P-V I-V curve of a solar cell at given temperature and solar irradiation

2.2 EFFECT OF VARIATION OF SOLAR IRRADIATION

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. Higher is the solar irradiation, higher would be the solar input to the solar cell and hence power magnitude would increase for the same voltage value. With increase in the solar irradiation the open circuit voltage increases. This is due to the fact that, when more sunlight incidents on to the solar cell, the electrons are supplied with higher excitation energy, thereby increasing the electron mobility and thus more power is generated.

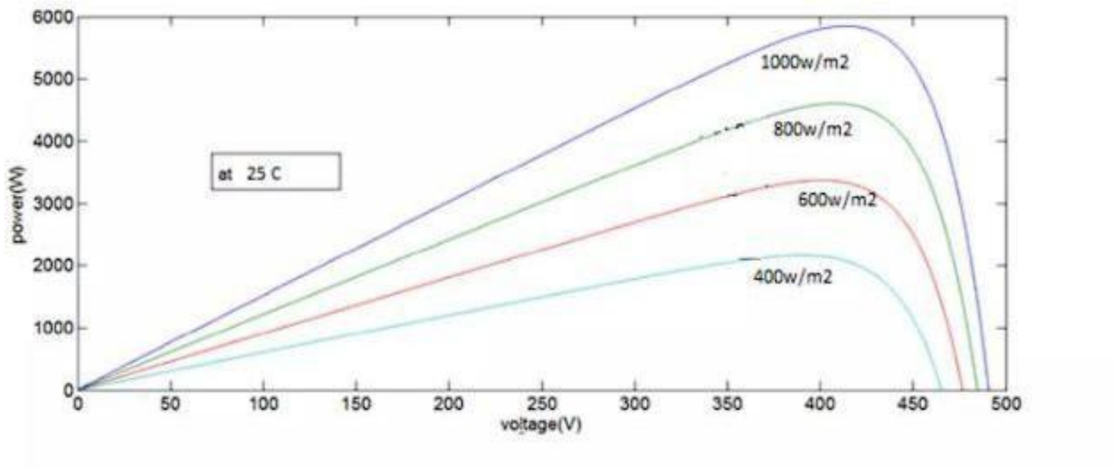


Figure 4: variation of P-V curve with solar radiation

2.3 EFFECT OF VARIATION OF TEMPERATURE

On the contrary the temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus the efficiency of the solar cell is reduced.

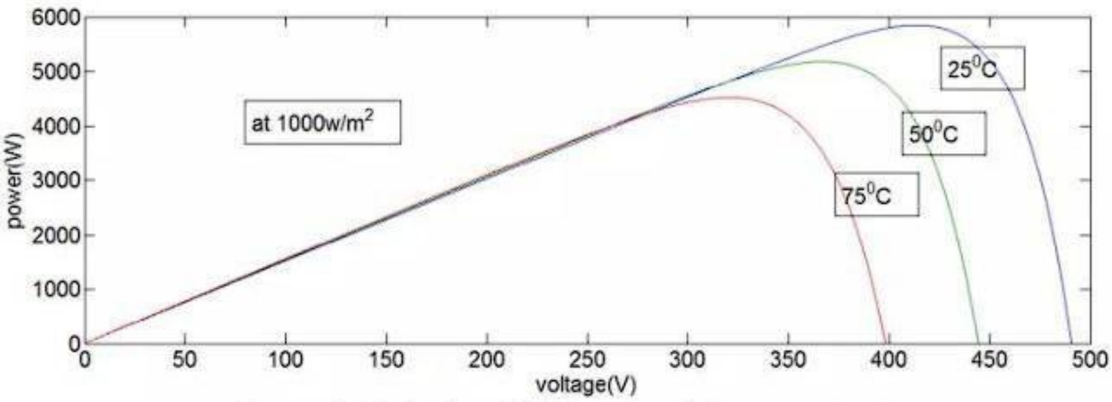


Figure 6: Variation of P-V curve with temperature

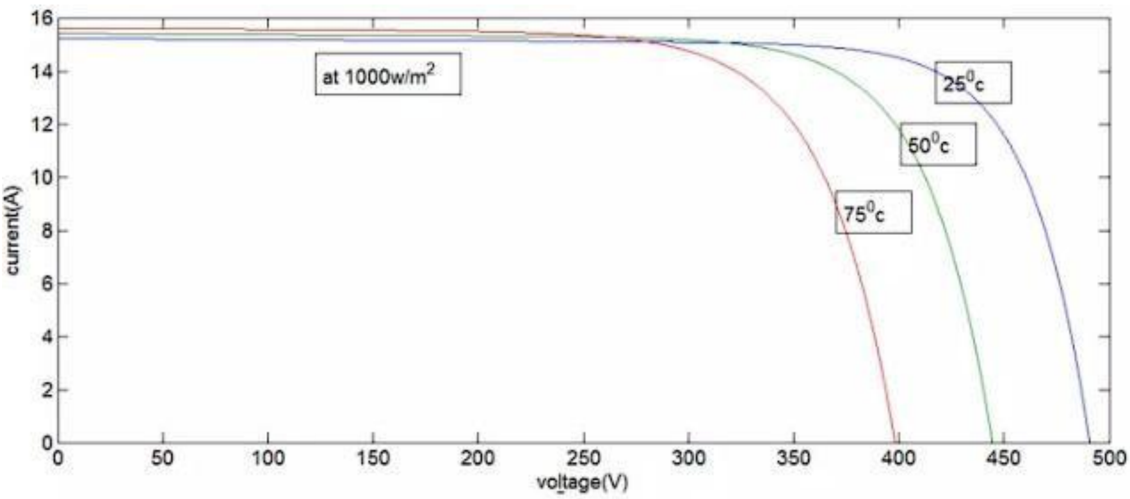


Figure 7: Variation of I-V with temperature

BOOST CONVERTER

3.1 BOOST CONVERTER

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co- ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change .

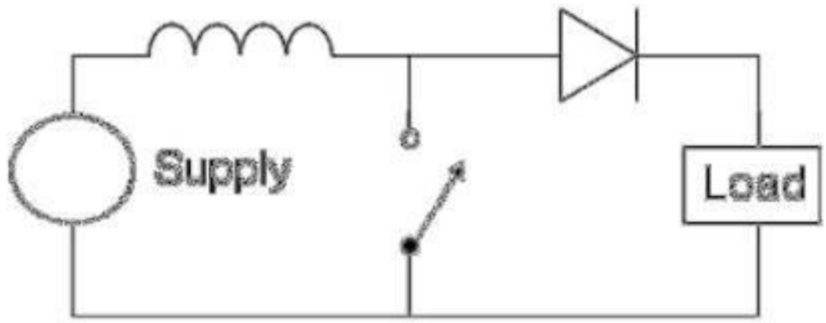


Figure 8: A boost converter

3.2 MODES OF OPERATION

There are two modes of operation of a boost converter. Those are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation .

3.2.1 Charging Mode

In this mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying . The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

3.2.2Discharging Mode

In this mode of operation; the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

3.3 WAVEFORMS

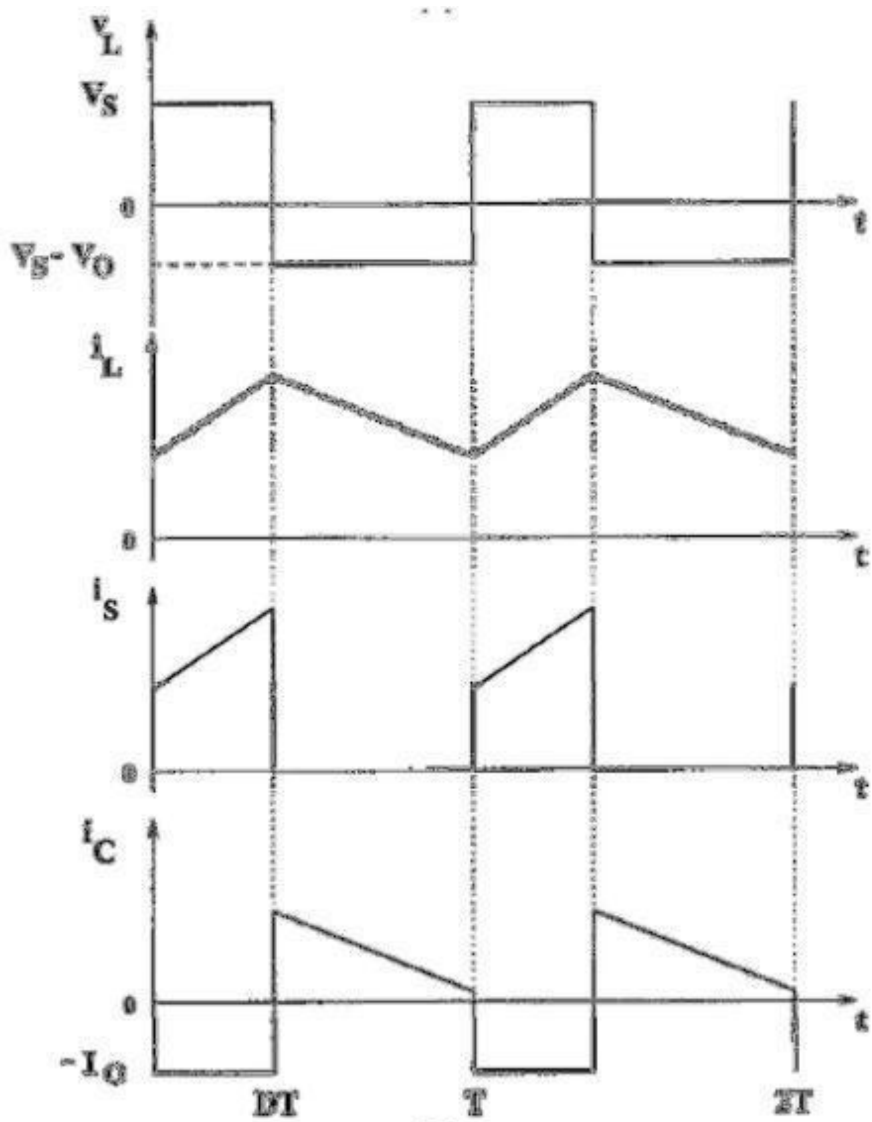


Figure 9: Waveforms of boost converter

MAXIMUM POWER POINT TRACKING

4.1 MAXIMUM POWER POINT TRACKING

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is varied by using a mppt algorithm. Few of the many algorithms are listed below.

A boost converter is used on the load side and a solar panel is used to power this

converter.

4.2 METHODS FOR MPPT

There are many methods used for maximum power point tracking a few are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

4.2.1 Perturb and Observe method

This method is the most common. In this method very less number of sensors are utilized [5] and [6]. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples dP/dV. If dP/dV is positive, then the algorithm increases the voltage value towards the MPP until dP/dV is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP).

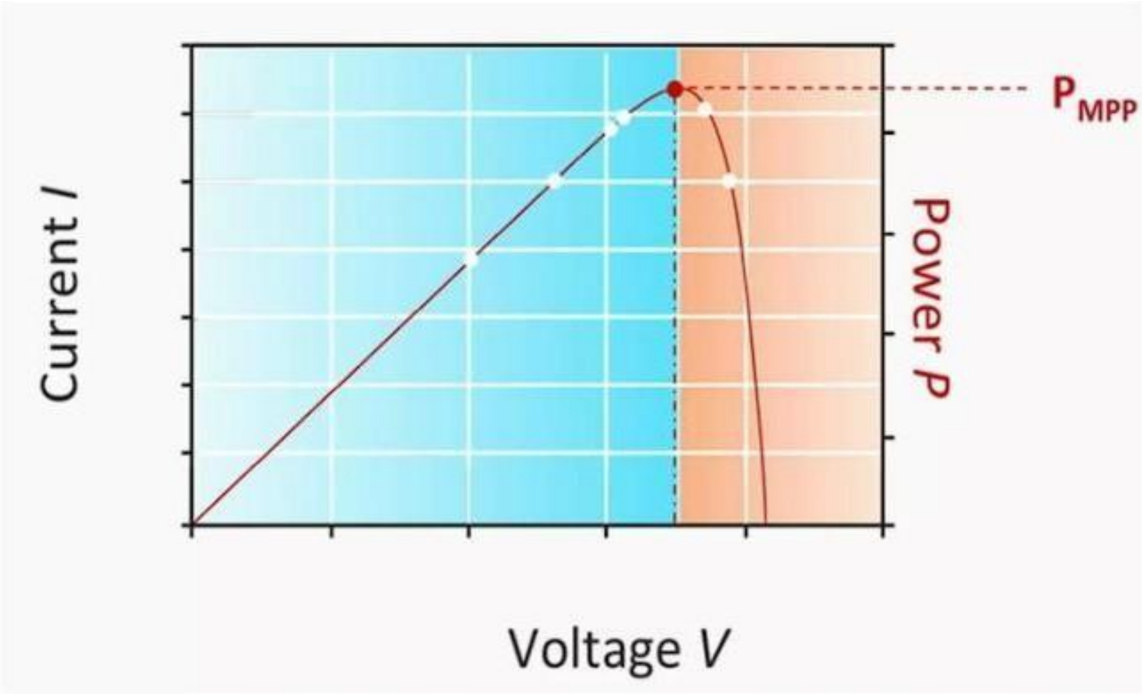


Figure 10: P-V curve of a solar cell in Perturb and Observe method

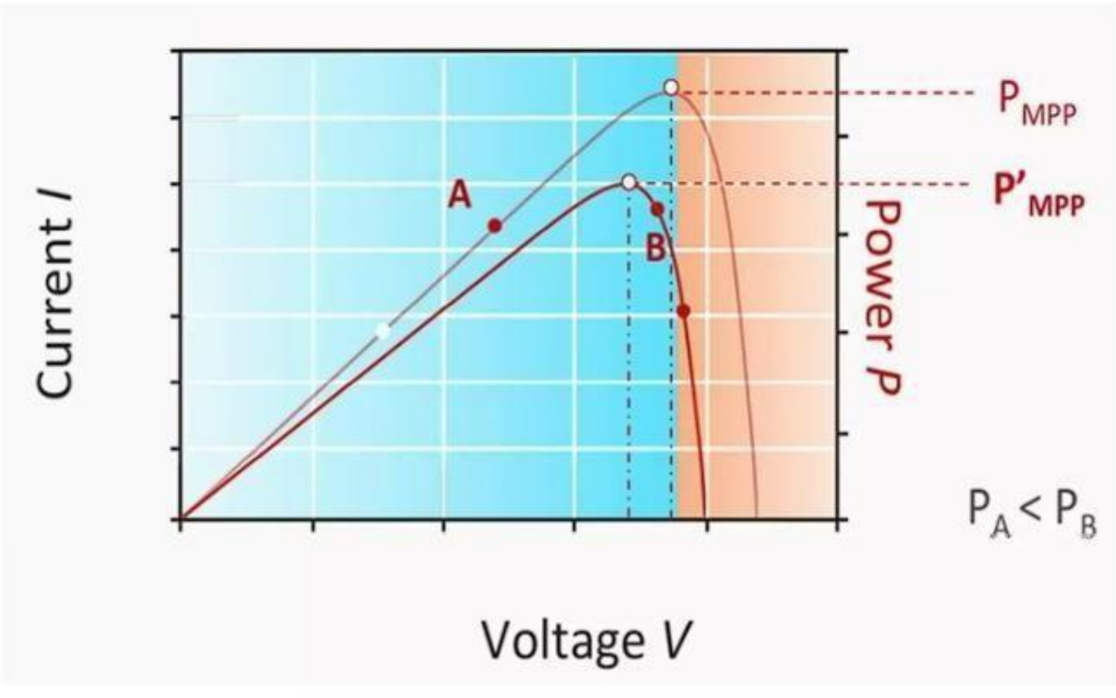


Figure 11: P-V curve of a solar cell in Perturb and Observe method

4.2.2 Incremental Conductance

This method uses the PV array's incremental conductance dP/dV to compute the sign of dP/dV. When dP/dV is equal and opposite to the value of I/V (where dP/dV =0) the algorithm knows that the maximum power point is reached and thus it terminates and returns the corresponding value of operating voltage for MPP. This method tracks rapidly changing irradiation conditions more accurately than P&O method. One complexity in this method is that it requires many sensors to operate and hence is

economically less effective [5] and [6].

P=V*I

Differentiating w.r.t voltage yields;

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} \tag{5}$$

$$\frac{dP}{dV} = I*\left(\frac{dV}{dV}\right) + V*\left(\frac{dI}{dV}\right) \tag{6}$$

$$\frac{dP}{dV} = I + V*\left(\frac{dI}{dV}\right) \tag{7}$$

When the maximum power point is reached the slope $\frac{dP}{dV} = 0$. Thus the condition would be;

$$\frac{dP}{dV} = 0 \tag{8}$$

$$I + V*\left(\frac{dI}{dV}\right) = 0 \tag{9}$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{10}$$

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V} \quad \text{At MPP}$$

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V} \quad \text{To the left of MPP}$$

$$\frac{\Delta I}{\Delta V} < -\frac{I}{V} \quad \text{To the right of MPP}$$

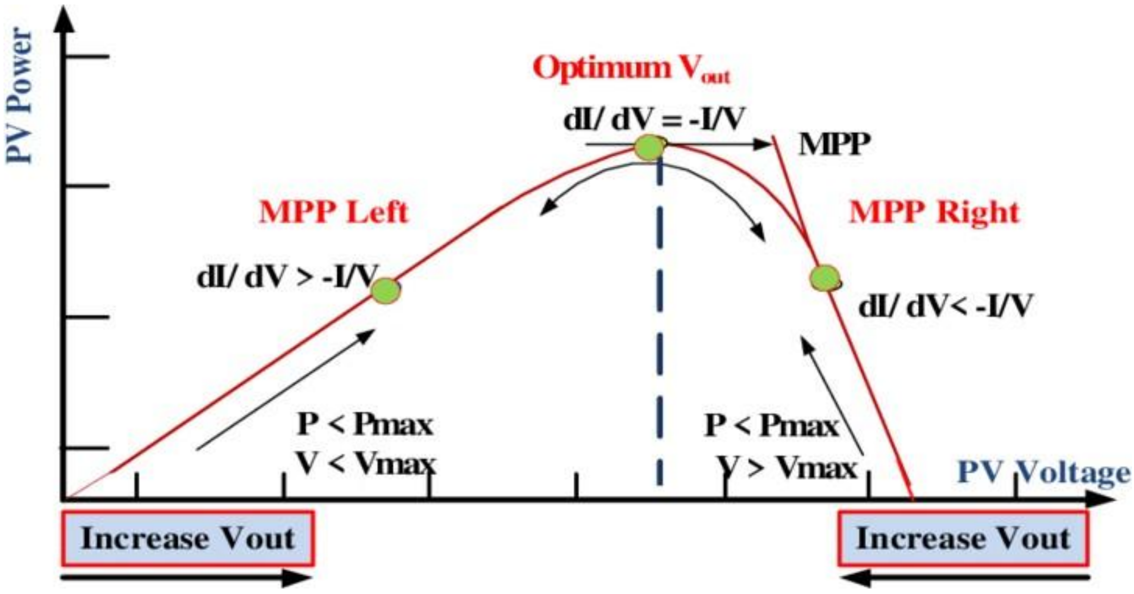


Figure 12: Power-Voltage curve of a solar cell in Incremental Conductance method

4.2.3 Parasitic Capacitance method

This method is an improved version of the incremental conductance method, with the improvement being that the effect of the PV cell's parasitic union capacitance is

included into the voltage calculation.

4.2.4 Constant Voltage method

This method which is a not so widely used method because of the losses during operation is dependent on the relation between the open circuit voltage and the maximum power point voltage. The ratio of these two voltages is generally constant for a solar cell, roughly around 0.76. Thus the open circuit voltage is obtained experimentally and the operating voltage is adjusted to 76% of this value .

4.2.5 Constant Current method

Similar to the constant voltage method, this method is dependent on the relation between the open circuit current and the maximum power point current. The ratio of these two currents is generally constant for a solar cell, roughly around 0.95. Thus the short circuit current is obtained experimentally and the operating current is adjusted to 95% of this value.

The methods have certain advantages and certain disadvantages. Choice is to be made regarding which algorithm to be utilized looking at the need of the algorithm and the operating conditions. For example, if the required algorithm is to be simple and not much effort is given on the reduction of the voltage ripple then P&O is suitable. But if the algorithm is to give a definite operating point and the voltage fluctuation near the MPP is to be reduced then the IC method is suitable, but this would make the operation complex and more costly.

4.3 FLOW CHART OF MPPT ALGORITHMS

Two of the most widely used methods for maximum power point racking are studied here. The methods are

1. Perturb & Observe Method.

2. Incremental Conductance Method.

The flow charts for the two methods are shown below.

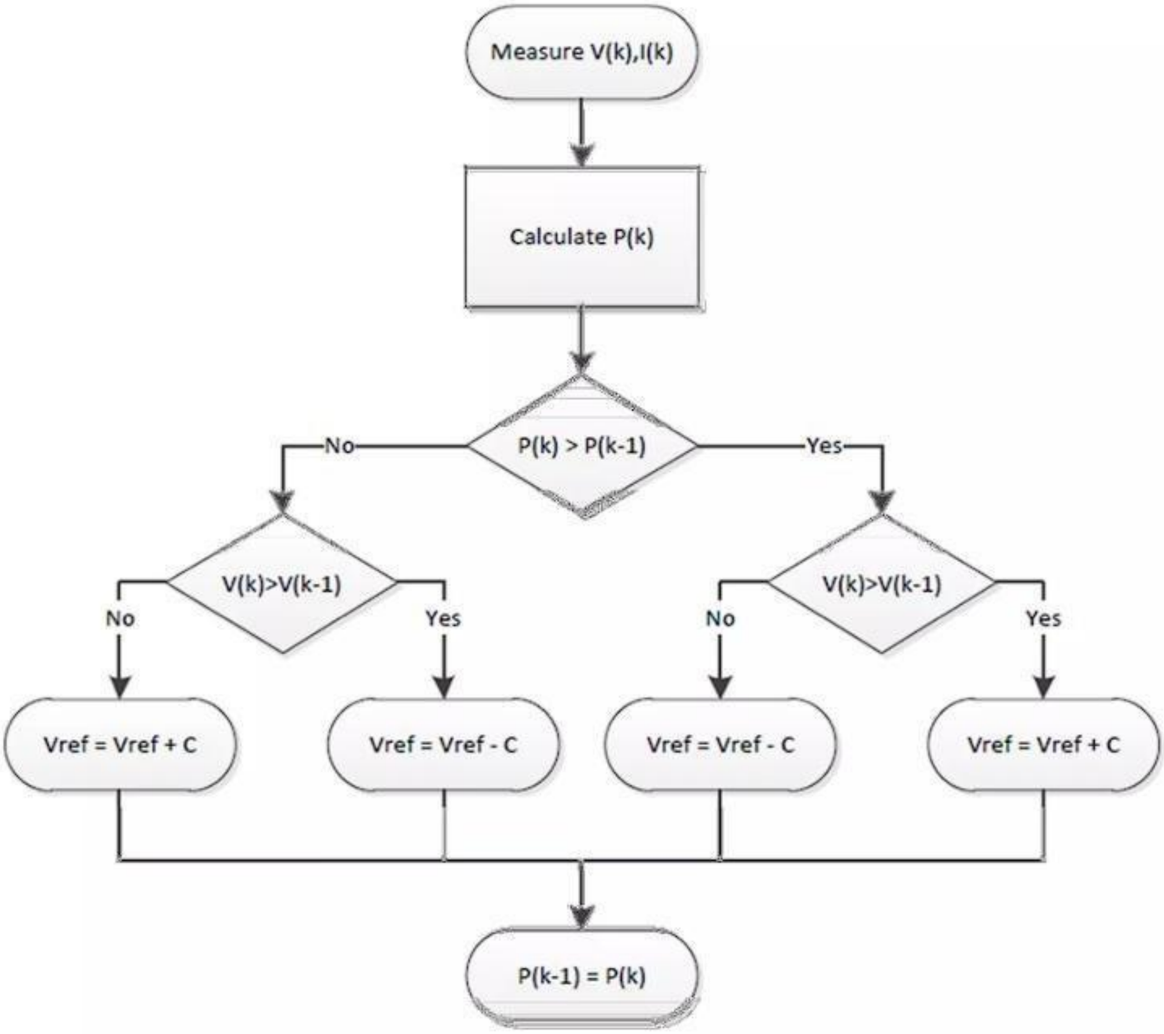


Figure 13: Flow chart for perturb & observe

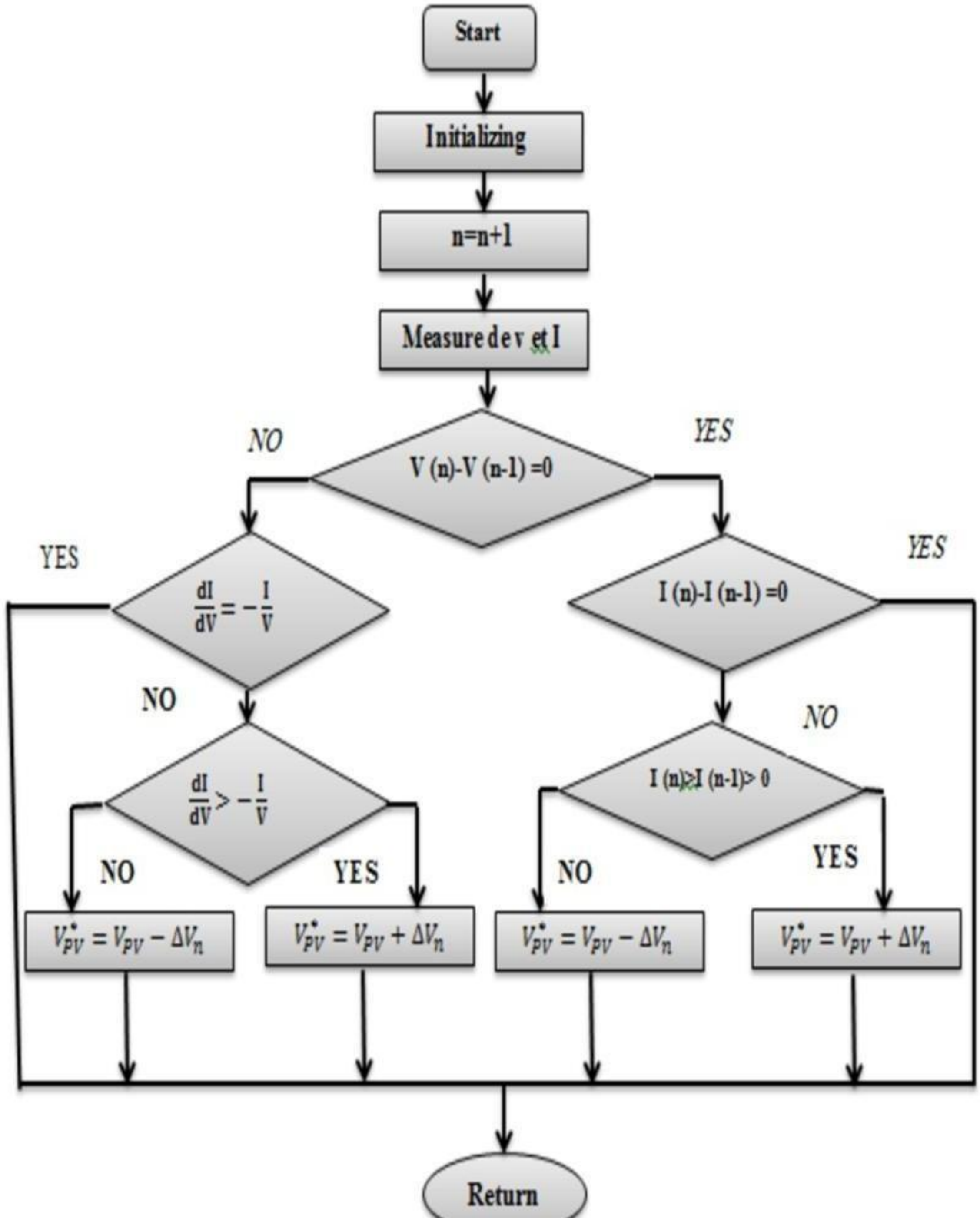


Figure 14: Flow chart of Incremental Conductance

Simulation of MPPT Using Incremental Conductance Algorithm with Boost Converter

Objective:

The project aimed to simulate and analyze the performance of a Maximum Power Point Tracking (MPPT) system using the Incremental Conductance algorithm in MATLAB Simulink. The system employed a Boost Converter and was tested with an Aleo Solar S18Y250 module rated for 250 W under standard test conditions.

MPPT Implementation:

- The Incremental Conductance algorithm was implemented to monitor the change in power relative to the change in voltage (dP/dV) and dynamically adjust the duty cycle of the Boost Converter.
- Key tracking condition:

  $dI/dV + I/V = 0$

Parameter Configuration:

- **Solar Module:** Aleo Solar S18Y250, with standard values:
  - Maximum Power (W) :249.672
  - Cells per module (Ncell): 60
  - Open circuit voltage Voc (V) :37.5
  - Short-circuit current Isc (A): 8.76
  - Voltage at maximum power point Vmp (V): 30.3
  - Current at maximum power point Imp (A) : 8.24
  - Temperature coefficient of Voc (%/deg.C) : -0.314
  - Temperature coefficient of Isc (%/deg.C): 0.043995

  Boost Converter: Optimized for high efficiency during MPP tracking.

- **Environmental Inputs:** Variations in irradiance (200 W/m² to 1000 W/m²) and temperature (25°C to 50°C) were simulated for real-world adaptability.

Matlab Code:

```
function D = MPPT_IC(Vpv,Ipv)


del=0.00001;

do=0;

dmin=0;

dmax=1;


persistent Vold Dold Iold;


if isempty(Vold)

   Vold=0;

   Iold=0;

   Dold=do;

end

dv=Vpv- Vold;

di=Ipv- Iold;


if dv == 0

   if di== 0

      D= Dold;

   else

      if di > 0

         D = Dold - del;

      else

         D = Dold+del;
```

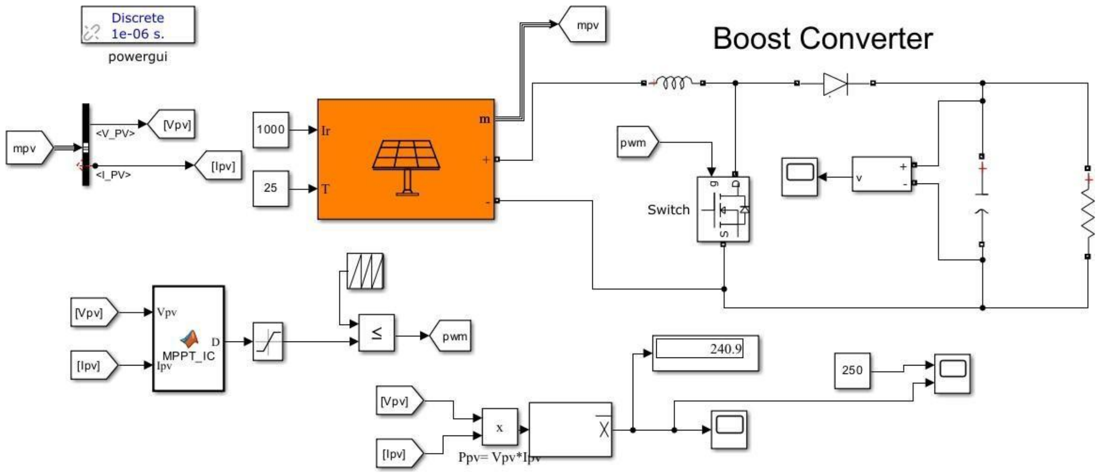
```
        end
    end
else
    if di/dv == -(Ipv/Vpv)
        D=Dold;

    else
        if di/dv > -(Ipv/Vpv)
            D=Dold-del;
        else
            D=Dold+del;
        end
    end
end

% if D >dmax || D <= dmin
%     D=Dold;
% end

% data store
Dold=D;
Vold=Vpv;
Iold=Ipv;
end
```

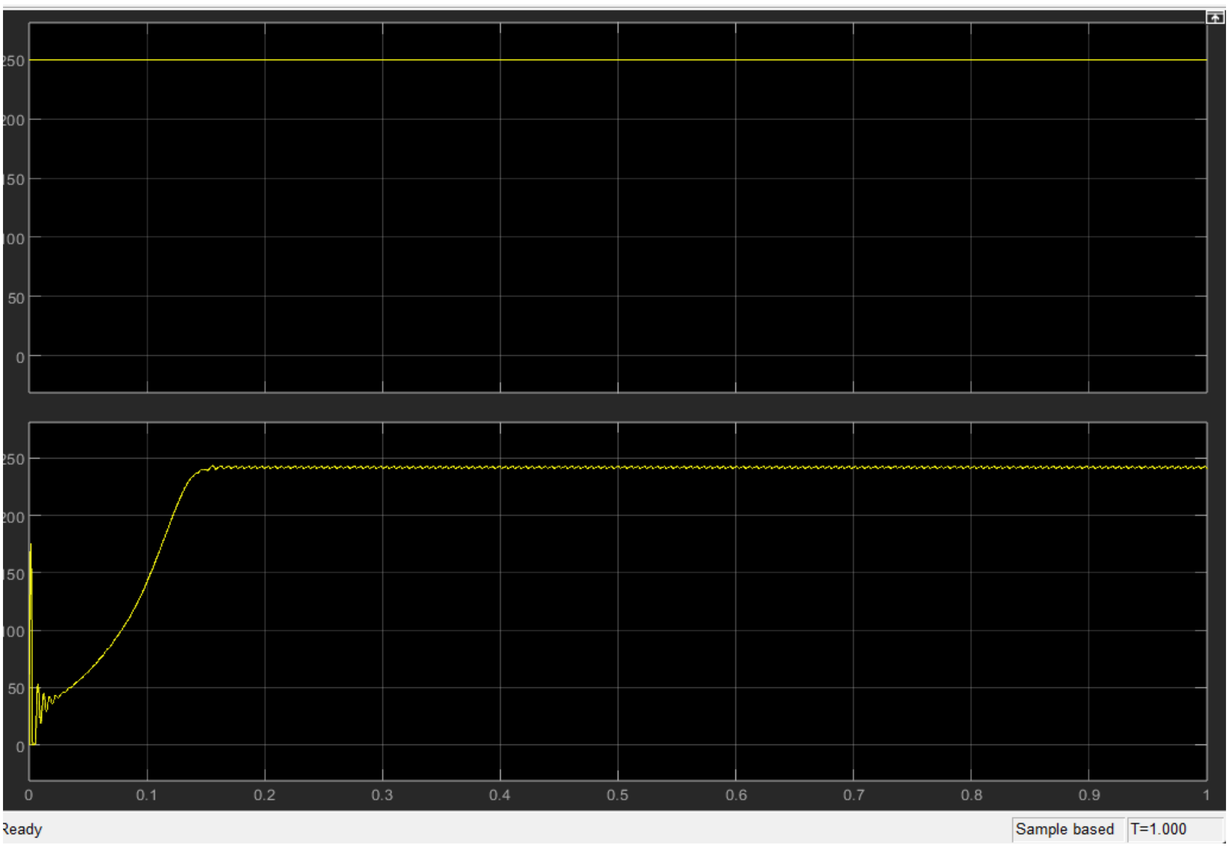
Circuit Model :



Results and Observations:

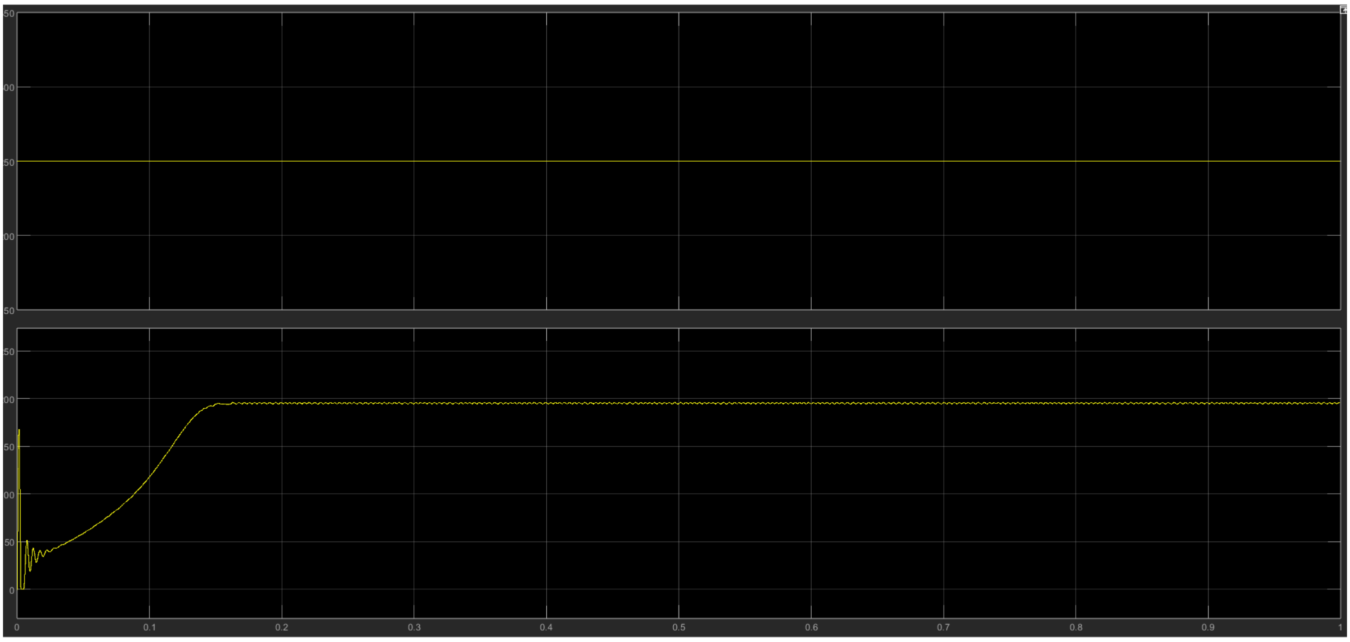
1. **Graphical Outputs:**

   Irradicance at 1000W/m2



Max Power 240.9W

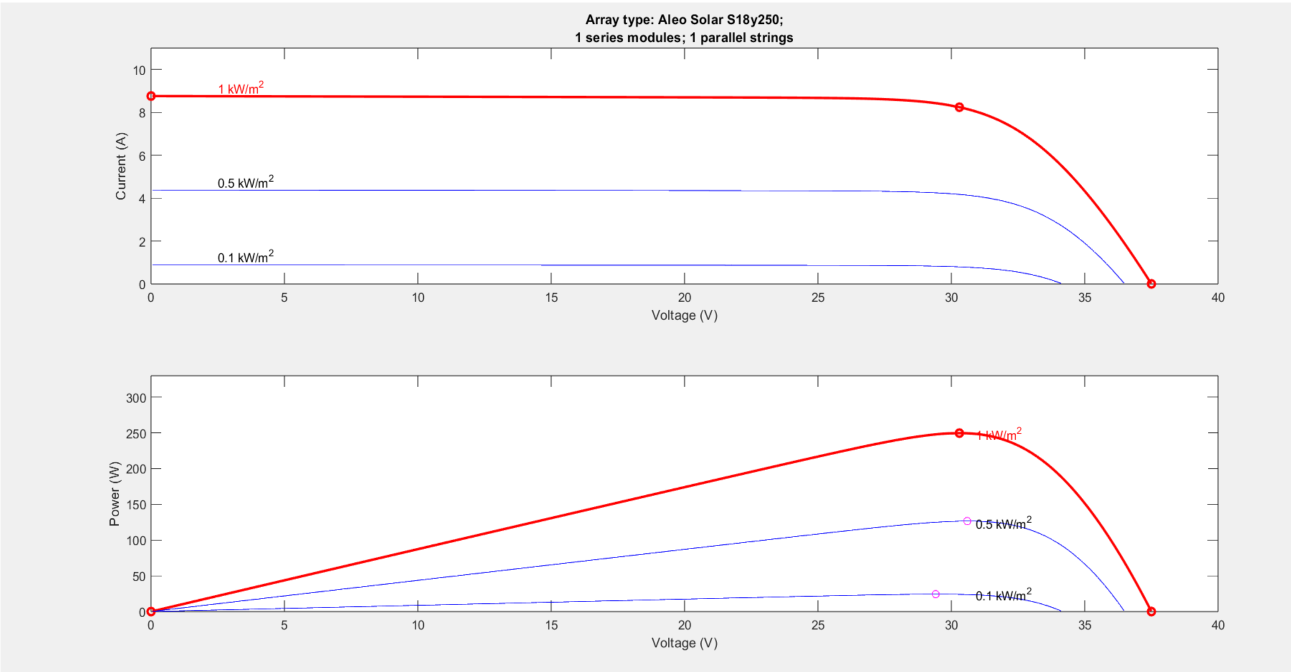
Irradiance at 800W/m2



Max power 200.42 W

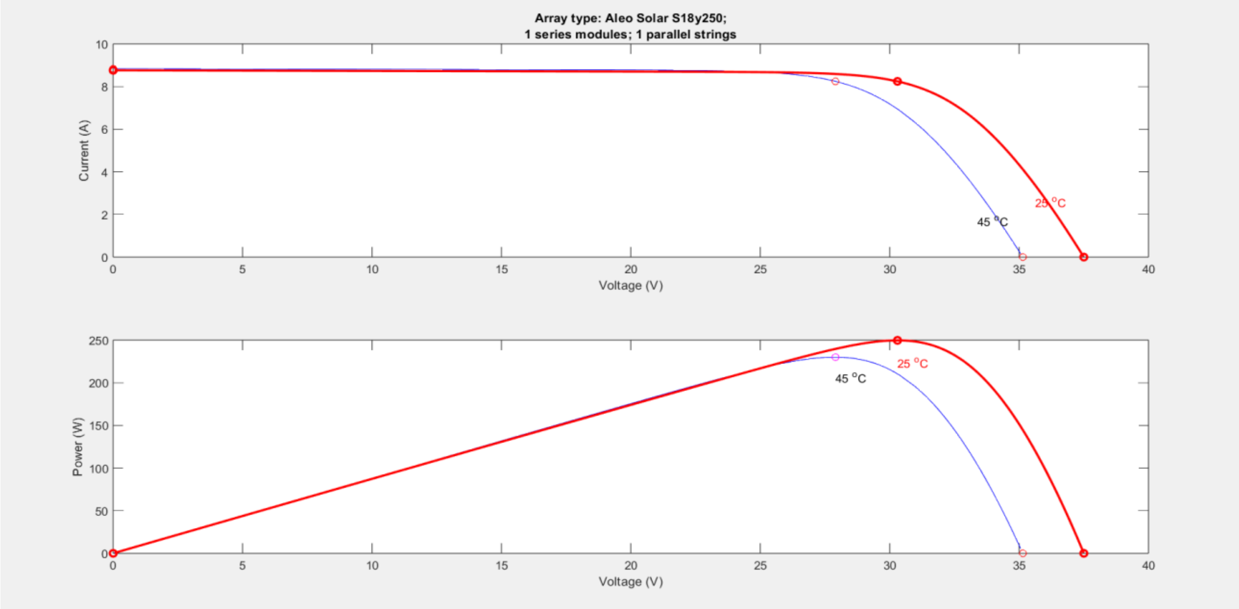
Array @25 deg.C and specific irradiancesIrradiances

(W/m2) = { 1000, 500, 100}



I-V curve and P-V curve for Aleo Solae S18y250

Array @1000 W/m2 and specified temperature



Array @1000 W/m2 and specified temperature

2. Performance Metrics:

- Maximum Power Point (Pmax): ~240.9 W (at standard conditions: 1000 W/m² and 25°C).
- Voltage at Maximum Power (Vmp): ~30.4 V.
- Current at Maximum Power (Imp): ~7.93 A.
- Efficiency: The Boost Converter achieved an overall efficiency of 96.3% during the conversion process.

CONCLUSION

5.1 CONCLUSION

In this report a detailed analysis of various maximum power point tracking algorithms were carried out. Incremental Conductance algorithm which holds good performance than any other methods under normal and varying atmospheric conditions. Power output obtained from incremental conductance method is high us compared to other methods under varying atmospheric conditions. Maximum Power Point Tracking algorithm which place a major role for a grid connected Photo voltaic system. A most suitable MPPT technique is chosen based on the implementation cost, number of sensors required, complexity. So for residential and industrial purposes INCREMENTAL CONDUCTANCE ALGORITHM performs better results.

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