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The Effect of Different Mppt on the Linear Load and Non-Linear Load in Pv System

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Abstract - The output power of a PV array is dependent on environmental factors such as solar irradiation and temperature. So, it has a non-linear I-V characteristic. Maximum Power Point (MPP) is a point on the I-V, P-V characteristic curve of a PV array where the PV device generates maximum output power. The location of MPP shifts as the climate changes. MPPT's aim is to keep the solar operating voltage as similar to MPP as possible under changing environmental conditions. They must run at their MPPT considering the inhomogeneous shift in environmental conditions in order to continuously gather the full power from the PV array. Here the most commonly used MPPT algorithms for PV applications are illustrated because they are easy to implement which are Perturb and Observe (P&O), Hill Climbing (HC) and Incremental Conductance (INC). In this paper, the applications of those three MPPT algorithms in PV systems at linear and nonlinear loads have been investigated. Comparative analysis has been done and the efficient one based on different testing scenarios has been determined based on output results.

Key Words: *MPPT, PV System, linear load, non-linear load*

1. Introduction:

Nowadays the hot topic in the world is climate change. One of the main causes of climate change is using fossil fuels. One of the most widely used effective ways to tackle climate change issues is the installation of renewable energy sources including PV systems. [1]It is clean, free, and renewable. There are two types of photovoltaic systems: standalone and grid-connected PV

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systems. Stand-alone photovoltaic systems are used for locations that are not connected to the electrical grid. The performance of the PV system in these systems is determined by the operating conditions. The maximum power point (MPP) PV source can be affected by three factors: radiation, load characteristics, and temperature. A grid-connected PV system is used in locations with easy access to the connected electrical network.

To generate the maximum power by the solar module, it is essential to find the point on the I-V characteristic where the current and voltage are at their maximum value continuously. This point is called the maximum power point (MPP). PV model is able to extract maximum available power if it is working on MPP point. Therefore, it is essential to use a maximum power point tracker (MPPT) with PV system to ensure the operation of the PV module at MPP. The two main dependent parameters in solar power are irradiance and temperature, which are not remaining stable due to continuous changes in the weather condition. At satisfying weather conditions, when the temperature and irradiance are good the PV model can generate maximum power efficiently while an effective MPPT algorithm is used with the system. There are many MPPT algorithms developed by researchers all over the world such as Differential method, Incremental Conductance (INC), Perturb and Observe (P & O) Fuzzy logic, Hill Climbing (HC). In this paper the focus will be on the application of P&O, (HC), and (INC). In PV system. The main contributions of this paper are:

- The application of the three mention MPPT at linear and non-linear load.
- Comparative analysis between them in terms of input and output Current, Voltage, and Power.
- The effect of changes in Irradiance and Temperature in the application of the proposed MPPTs at both sinarios (PV connected to linear load and PV connected to non-linear load.

The efficiency of solar power generation can be directly affected by the following factors:

- ✓ Irradiance and temperature
- ✓ PV panel cell.
- ✓ DC-DC converter
- ✓ Maximum Power Point Tracking (MPPT) algorithm.

2. Equivalent Circuit of a Solar Cell

The solar cell is a diode, and the diode is a p-n junction semiconductor. When the solar cell is exposed to the sunlight, a dc current is generated. The amount of current generated is proportionally varies with the solar irradiance. The performance of the pv module we can describe by a single standard diode model. Shown in figure(1) [2].

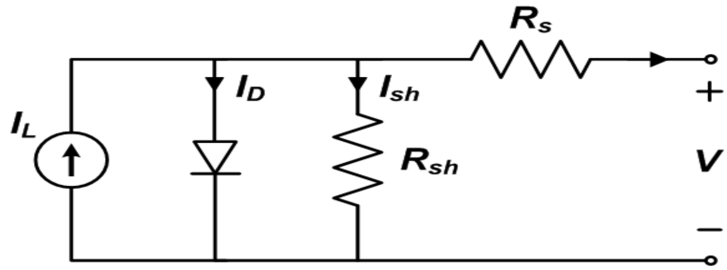

Figure 1: Equivalent circuit of a solar cell

The output current of the solar cell is can be represented by the following equation:

$$I = I_L - I_0\left(e^{\frac{q(V-IR_S)}{AKT}}\right) - \frac{V-IR_S}{R_{sh}} \quad (1)$$

Where:

V = the output of the solar cell voltage.

I = the current output by the solar cell.

I_0 = a dark current saturation.

q = the number of electronic charge constant (1,602.10-19 Coulomb).

A = the ideality diode factor.

k = Boltzmain constant (1,38. 10-23 J/K).

Rsh = shunt resistance.

Rs = is the series resistance of the solar cell.

T = temperature of the cell [Kelvin].

The working of the shunt resistance (Rsh) is hard to explain. This is due to the imperfect nature of the p - n junction and the presence of inclusions near the edges of the cell providing a short junction path around the junction [1]. RS will be zero and RSH would be infinite in the ideal cell. But this is not possible in practice but in product we will try to minimize the effect of both resistances.

To simplify the solar cell in calculation (model) in we assume that the RSH is infinite, and we can neglect the effect of this resistor. Equation (1) could be simplified.

$$\boldsymbol{I \approx n_p I_L - n_p I_0 \left(e^{\frac{q(V-IR_S)}{AKTn_s}} - 1\right)} \tag{2}$$

Where:

np → number of solar cells in parallel

ns → number of solar cells in series

In any photovoltaic panel, many solar cells have been used, they are connected in a series and parallel as needed. In the end, the output voltage and current are large enough to connect with the grid or used by the equipment. By considering the simplification talked about above, we can show the characteristic of output voltage and current by equation (2) [8].

3. Irradiance & Temperature Effects

In the solar module, two factor irradiation and temperature directly effecting on the working of the panel. These two main reasons directly affecting on the working of the solar panel which is irradiation and temperature. As a result of any change in the irradiance and temperature affecting the output power of the panel, the MPPT is working to find the maximum available power in the panel and any change of radiation and temperature.

As was previously mentioned, the photo-generated current is directly proportional to the irradiance level, so an increment in the irradiation leads to a higher photo-generated current. Moreover, the short circuit current is directly proportional to the photo-generated current; therefore, it is directly proportional to the irradiance.

In normal operation of PV cell, the power generated an affected by irradiance of the cell as it is illustrated in eq (1), eq (2).

From the figure (2) it can be noticed the effect of changing temperature on the open voltage is very large but effect on current can be neglected theoretically. But, changing in irradiance on the PV panel on the short circuit (current) characteristic curve is logarithmic as shown in figure (4), eq (3) shows this relation the characteristic, carve bellow shows that in any change in irradiance directly affecting on the current generation by the panel. Any increase in current generation means an increase in power generated by the panel proportionally.

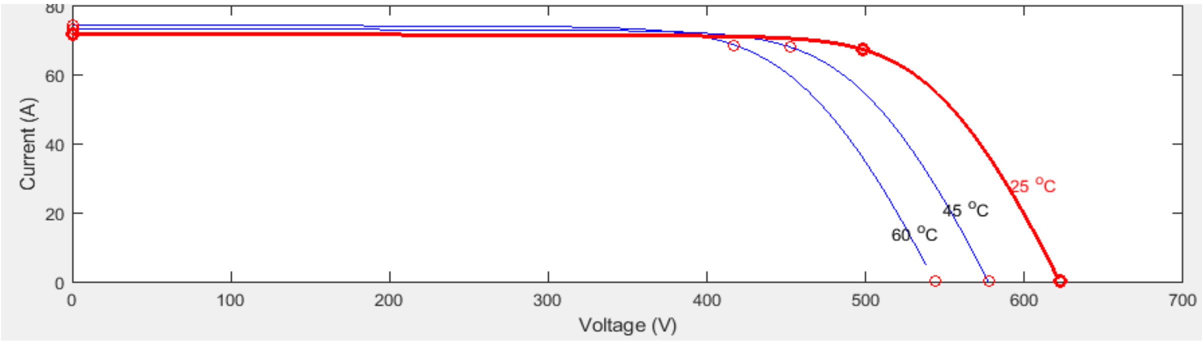

Figure 2. MPP changes with Temperature (I-V Curves)

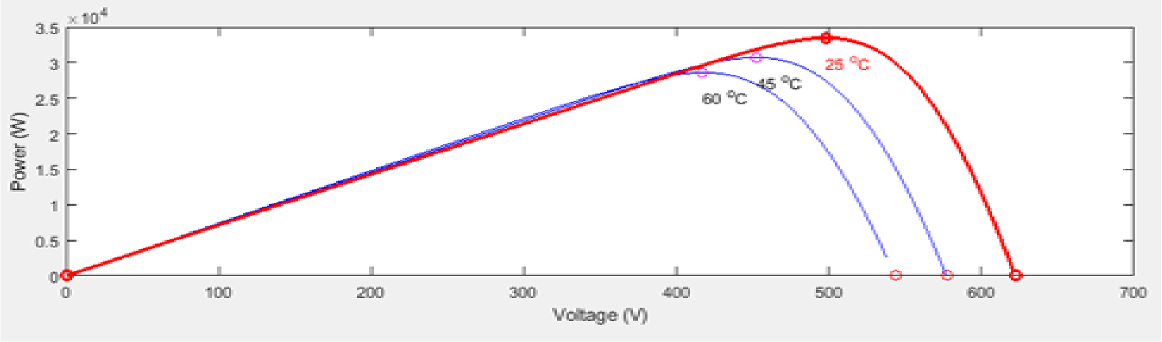

Figure 3. MPP changes with Temperature (P-V Curves)

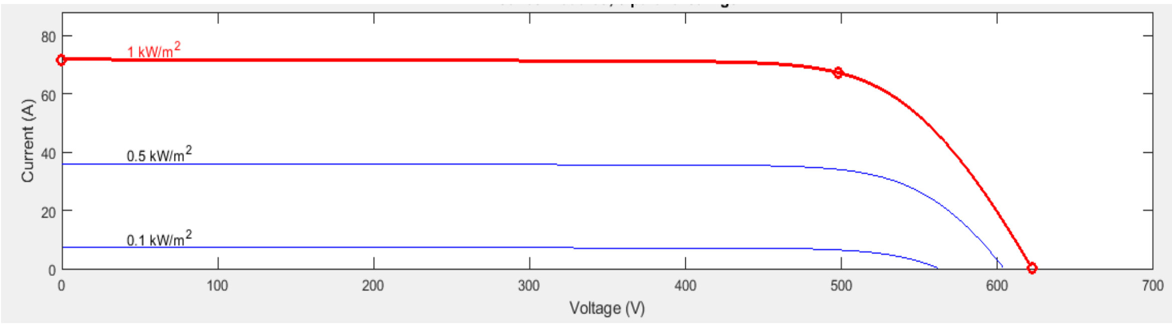

Figure 4. MPP changes with Irradiance levels (I-V Curves)

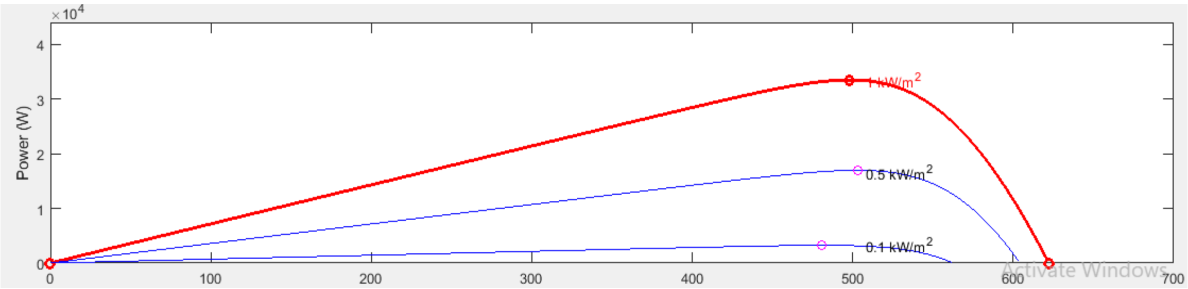

Figure 5. MPP changes with Irradiance levels (P-V Curves)

The effect of irradiance on the current is very bigger than the effect on the voltage as shown in figure (2,3,4,5), for that reason, the change in voltage by irradiance is neglected [6], when the irradiance is increasing the power generated is increase because voltage and current generated in this change are positive.

On the other hand, the voltage change is directly proportional with the temperature if the temperature is increasing the voltage generated is decrease, this equation is illustrating the effect of temperature on the V_{OC}.

$$\boldsymbol{V_{OC}(T) \approx V_{OC}^{STC} + \frac{K_{V\%}}{100}(T - 273.15)} \qquad \textbf{(3)}$$

As stated earlier, the effect temperature on both voltage and current is a different increase in temperature means a decrease in voltage much more than increasing in current so the power generated when the temperature is increase is smaller, figure (8) shows the effect of temperature on the generation of power and current.

During PV generate power, the power generation that PV is generating has changed with changing weather (temperature and irradiance), use MPP to monitor the new peak power produced as a result of the change. If the MPPT is slow in finding the peak power, the power losses are high, and vice versa. A good MPPT is needed to collect the power that the PV cell can generate.

4. DC-DC Converters

A DC-DC converter is a type of power transformer that is an electronic circuit, by temporarily storing input energy and then releasing that power to the output but with different voltages, converts a direct current (DC) power source from one voltage level to another. By using the characteristic of Magnetic fields in (inductors, transformers) or electric field storage elements may be contained in any of the storage components (capacitors) [4].

The output power and input power can be controlled by controlling the duty cycle (ratio of turn on/off time) between the input and output. The benefit of duty cycle uses to control output voltage, the input current, the current of the output, or to maintain constant power. Isolation between the input and output can be provided by transformer-based converters. For certain topologies, the key disadvantages of switching converters include difficulty, electronic noise, and high cost. In the literature, several different kinds of DC/DC power converters are suggested [2].

In this paper, the DC-DC converter used is boost which is using as step-up voltage(step-down current) the principle working is opposite to the buck converter, in the PV system using boost converter to increase the voltage to desire value that needed, the figre shows the circuit diagram of DC-DC boost converter [5].

It can represent the operation of boost converter by the equation (4).

$$V_{in}.t_{on} + (V_{in} - V_0).t_{off} = 0 \qquad (4)$$

V_0 = the output voltage

V_{in} = input Voltage

t_{on} = the peride time on

t_{off} = the peride time off

From equation (4) it can show the effect of duty cycle on the output voltage :

$$\frac{Vin}{V_0} = \frac{t_{on}+t_{off}}{t_{on}} \qquad (5)$$

From equation (5) $T = t_{on} + t_{off}$, T is the period of the switch, the duty cycle is calculated by the ratio of T and t_{on} . so we can control the output voltage very easily by the control duty cycle.

5. Maximum Power Point Tracking Algorithms

Maximum Power Point Tracking (MPPT) is a photovoltaic (PV) transducer algorithm that continuously modifies the impedance seen by the solar array to preserve the variable efficiency of the PV device at the peak power of the PV panel. Conditions, such as sunshine, temperature, and battery alterations [2].

MPPT algorithms are implemented by engineers designing solar inverters to optimize the power produced from photovoltaic systems. Algorithms regulate voltage to ensure that the device runs on the power voltage curve at the "maximum power point" (or maximum voltage), figure (6)shows how MPP change with changing irradiance [7].

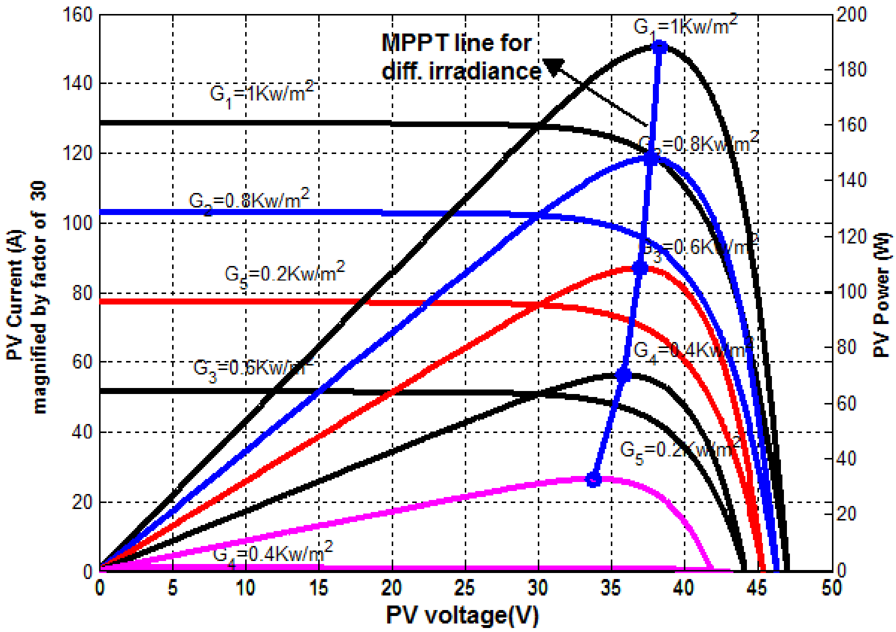

Figure 6: changing MPP with changing irradiance [11]

For PV systems, MPPT algorithms are widely used in controller design. In order to ensure optimum photovoltaic device power generation at all times, these algorithms take into account variables such as variable radiation and temperature.

In this paper most popular MPPT algorithms are discussing which is P&O and INC:

5.1. Perturbation and Observation P&O Algorithm

Perturb and Observation is one of the conventional methods to find MPPT and the most popular method, in P&O to calculate the MPP randomly choosing a point then makes incremental changes to the voltage and monitors changes in power. Figure (7) shows operation of P&O algorithm, if the change in voltage increase the power output of the solar panel the next perturbation will be in the same direction, if the change in the voltage decrease the power output of the panel then the next perturbation will be in the opposite direction. Till the difference between the previous power and new power equal to zero means ΔP is equal to zero, this point is MPP, but in P&O never stay even in best MPP because the Algorithm continuously searching the better power this is causing the oscillation around MPP and loss power and that's the biggest disadvantage of this method.

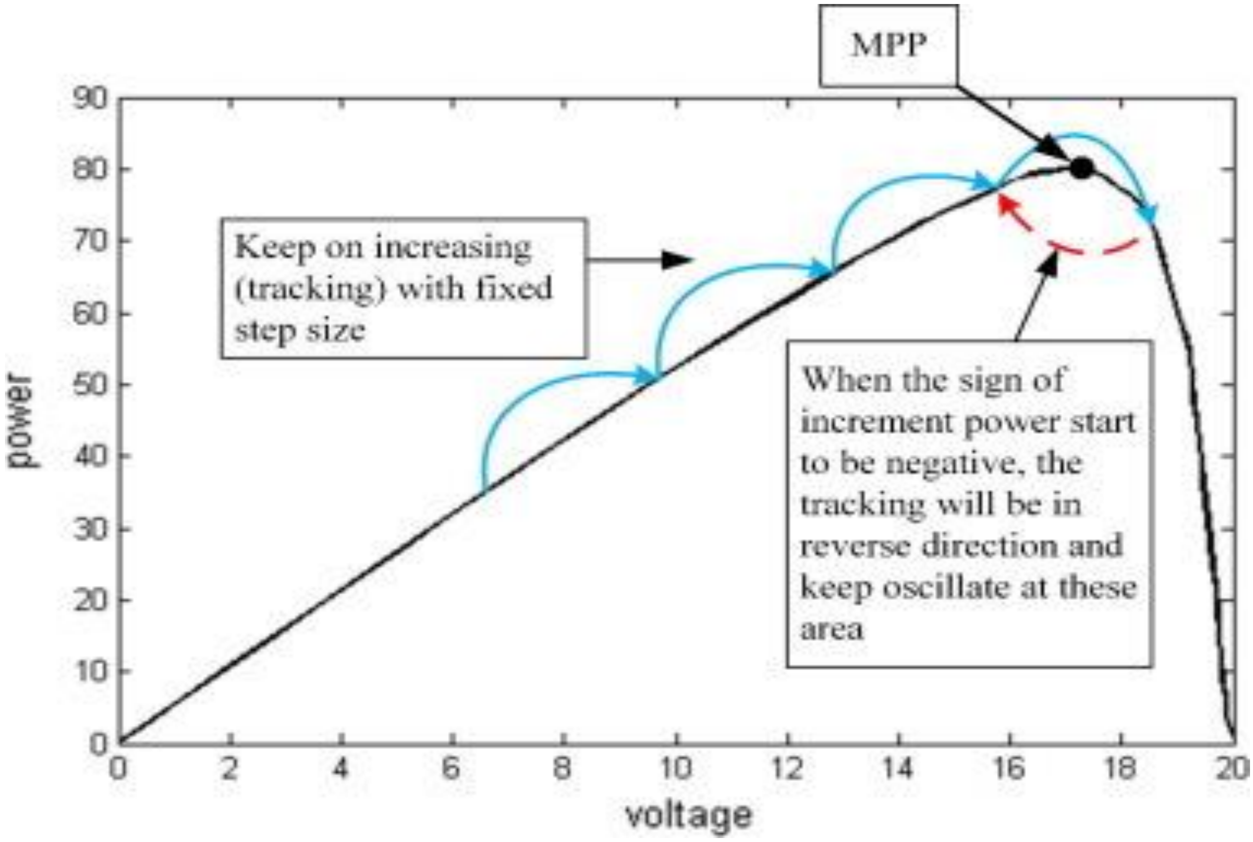

Figure 7: illustrate the operation of the P&O algorithm [12]

The table(1) shows all possibilities in the P&O algorithm. P&O have ability to find voltage V_{MPP} and current I_{MPP} automatically under change in weather condition (irradiance and temperature)for the PV panel or array [3].

Table 1. Shows all possibility in P&O algorithm

Prior perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

The following flowchat is illustrate the operation of P&O Algorithm

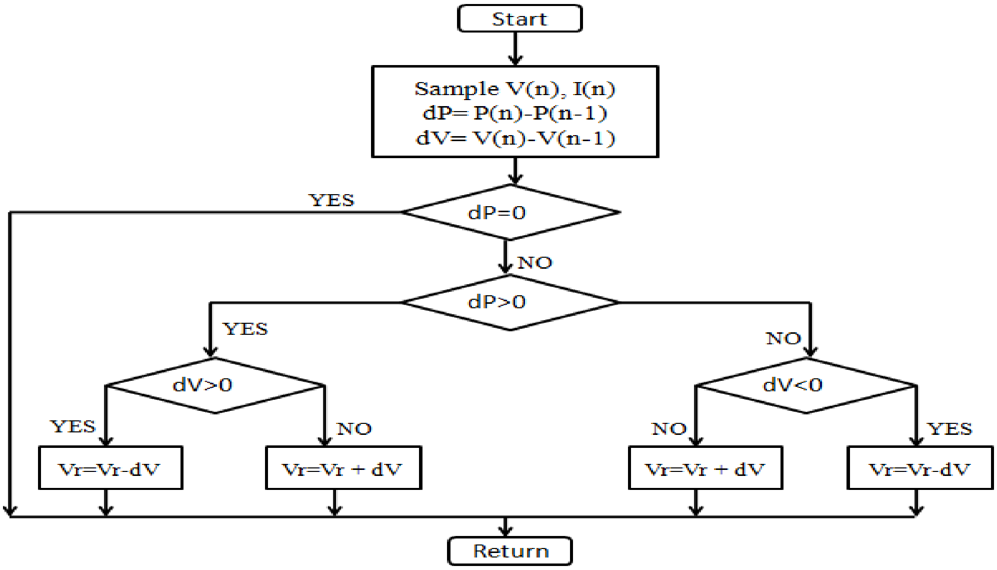

Figure 8: the flowchat of P&O algorithm [13]

5.2. Incremental and Conductance (INC) Algorithm

The incremental conductance method (INC) technique is one of the hill claim methods which is a direct technique, some of the drawbacks in P&O can be solved by using (INC) conductance like rapid change environmental. The basic idea of the incremental conduction (INC) method on the Ppv - Vpv curve of the PV module. The slope of the PV curve is zero at MPP, it decreases to the right of MPP and increases on the left side of MPP and this is shown in Figure (9).

The MPP in the PV module occurs when $\frac{dP}{dV} = 0$ and

$\frac{dP}{dV} > 0$ then $V_P < V_{mpp}$ at left of MPP

$\frac{dP}{dV} = 0$ then $V_P = V_{mpp}$ at the MPP

$\frac{dP}{dV} < 0$ then $V_P > V_{mpp}$ at right of MPP

From the description above we can write equation (6):

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I\frac{dV}{dP} + V\frac{dI}{dV} \tag{6}$$

$$= I + V\frac{dI}{dV}$$

Also, the MPP can be found by the ratio of changing current and voltage:

$\frac{\Delta I}{\Delta V} > -\frac{1}{V}$ then, at left of MPP

$\frac{\Delta I}{\Delta V} = -\frac{1}{V}$ then, at the MPP

$\frac{\Delta I}{\Delta V} < -\frac{1}{V}$ then, at right of MPP

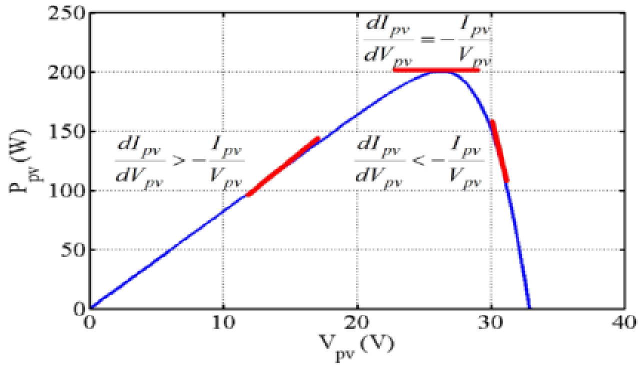

Figure 9: the flowchat of INC algorithm

The operation of incremental conductance can be illustrated by the following flowchart.

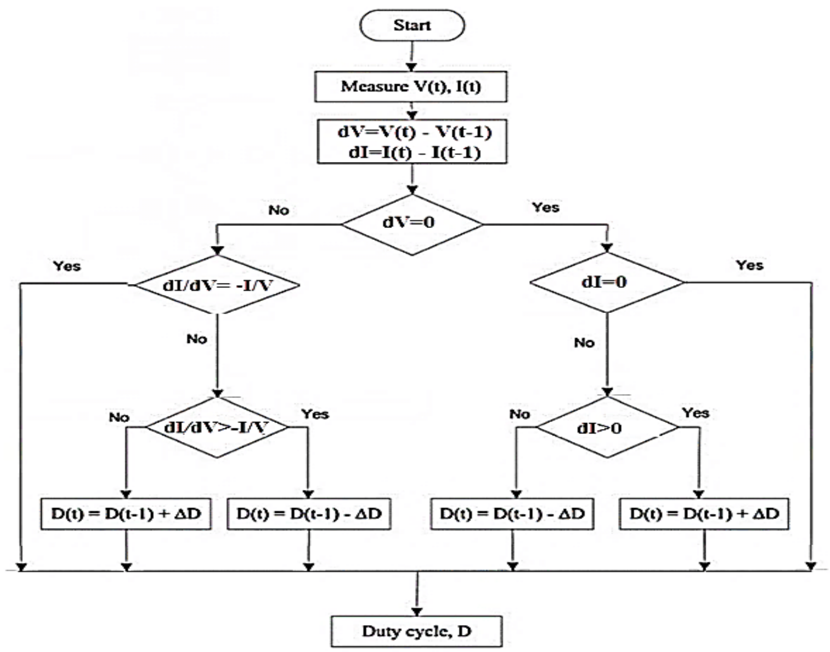

Figure 10: the flowchat of INC algorithm [14]

5.3. Hill Claim

As previously mentioned Maximum power point tracking used to extract the maximum power that the PV module can generate when the weather is changing, for this application, the Hill Claim algorithm uses a charge controller. At a certain point, the current and voltage can generate the maximum PowerPoint. This point (MPPT) is changed when the weather changes which are Irradiance and temperature. Hill Claim algorithms Use on a large scale in the PV systems in the process because of their simplicity and it does not require a study or source modeling features and can explain the properties of the drift because of the statute of limitations and shading other operational irregularities [9].

The basic operation of this algorithm first memorized the previous value of current I (k-1) and voltage V (k-1) for voltage and current and then calculate the power P (k-1). Then calculate the strength of P (k) current from the current-voltage and current. If the power is greater than the previous value, then the next step goes forward, and if the next step is less than the previous power, then maybe the maximum power point (MPP) or (local maximum) as shown in Figure(11.B) This is biggest a drawback to this algorithm. So it is normal for the power output in this way to be smaller than the other method. The operation of hill climb algorithm can be shown by the flowchat in Figure (11.A).

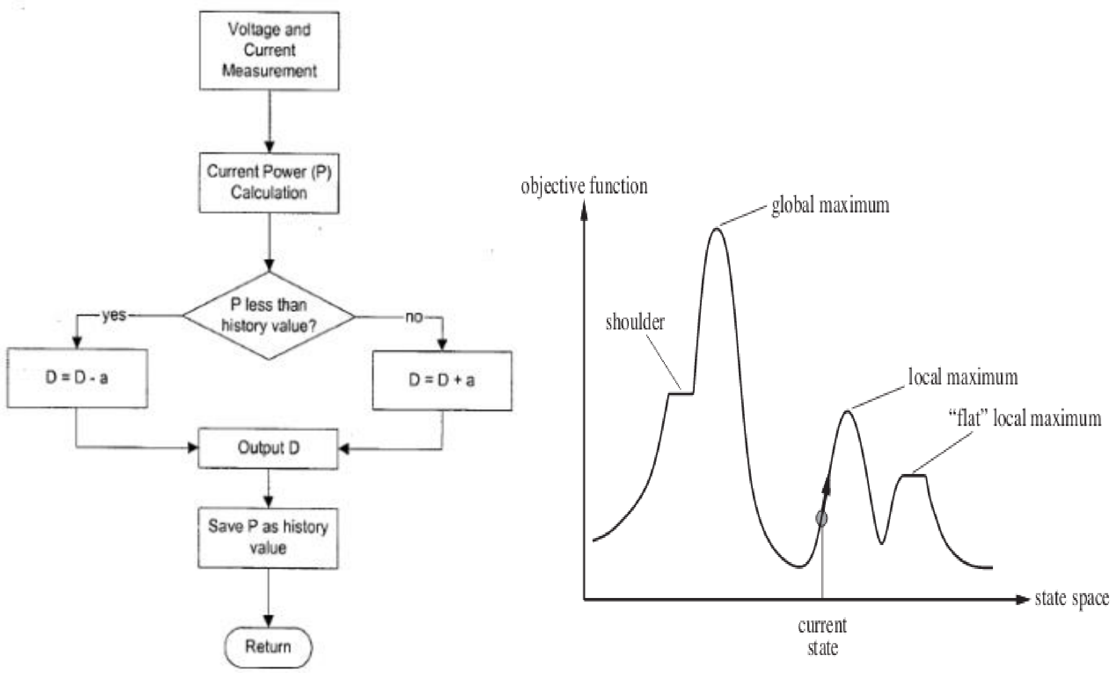

Figure 11:

A) Flowchart of the hill-climbing algorithm. B) State Space diagram for Hill Climbing

6. Linear and non-Linear load

Depending on how they draw current from the main power supply waveform, electrical loads can be are classified as linear or non-linear loads.

In terms of Linear loads, the voltage and current waveforms are sinusoidal, and the current is proportional to the voltage at all times (Ohm's law). However, in a DC system, a Linear load is a purely resistive load in which there is a linear relationship between the values of Current and Voltage. Most of the conventional lighting systems are accounting for linear loads [9].

Regarding non-linear loads, on the other hand, the current is not proportional to the voltage and fluctuates according to the alternating load impedance. Non-linear loads are usually connected to the electrical source via electronic devices. This means there will be a non-linear relationship between the values of the voltage and current. All capacitive, inductive, and motors are accounting for non-linear loads.

7. Simulation and design:

In this article simulation PV array working in a stand-alone system, PV system doesn't connect to the grid because the MPPT algorithm operation is identical, since MPPT control works through DC/DC converter. Therefore, an inverter is not required and only a DC/DC converter is connected between the PV array and the load. The PV system model used in Simulink can be seen in Figure (10).

In all PV systems, two inputs to the PV array variable which is are irradiance and temperature. These values temperature and irradiance in the daytime changing between 50 to 500, 200 to 1000 W/m2 respectively. Then, the PV array model consists of 9 Parallel strings and 17 Series-connected modules per string.

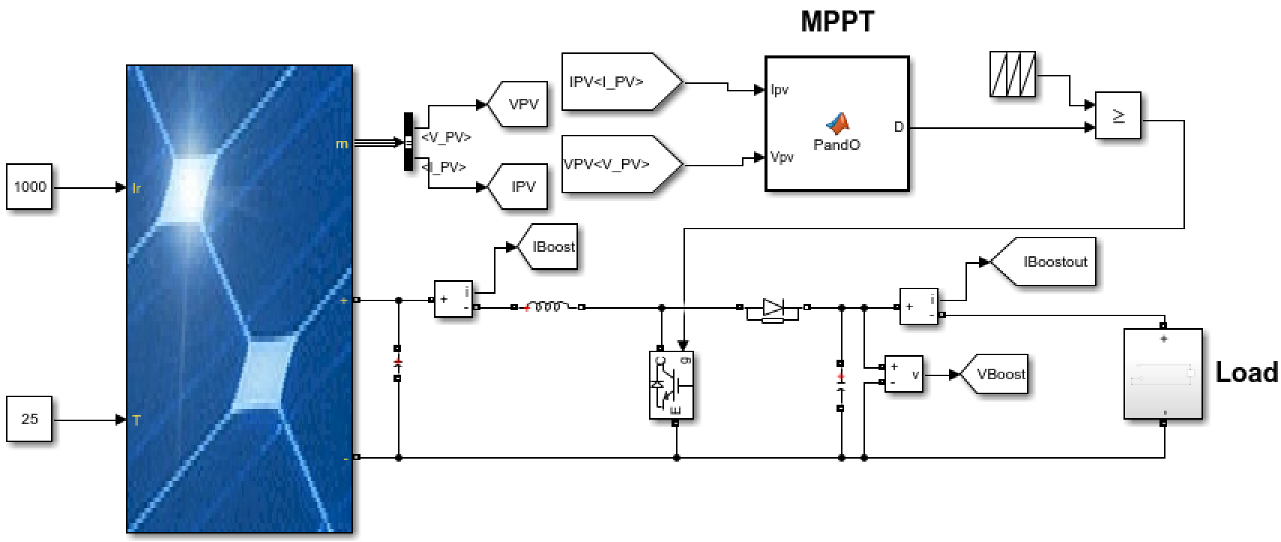

Figure 12: MATLAB Simulink Model PV System

- $I_{sc} = 7.97$ A
- $V_{oc} = 36.6$ V
- $I_{mpp} = 7.47$ A
- $V_{mpp} = 29.3$ V
- $P_{mpp} = 33.49$ kW

The value compound DC-DC Boost converter used in the model.

(L = 4.5 mH),
(C = 5000 μF)

(LC) functions as a low pass filter.

The MPPT algorithm will control duty ratio (D) and thus PV voltage (Vpv) in this converter. Furthermore, the DC battery maintains a constant voltage that must be maintained unless the MPPT algorithm changes the converter's duty ratio (D). In this converter, the MPPT algorithm to control the PV power (P_{pv}) working in maximum voltage and current point it should MPPT can control the duty ratio (D). The DC battery generates a constant voltage that must remain constant unless the MPPT algorithm changes the operating ratio converter (D).

In the end, the MPPT algorithm model block comprises. The MPPT use the voltage (Vpv) and current (Ipv) of PV are used as inputs, which are altered by a low pass filter to obtain true signal values free of noise. As a result, D is obtained and updated to the converter after their review.

8. Results and discussion:

In this part, The results of simulating for all algorithm methods are shown, first of all, the effect of variation solar irradiance, in the second part, the effect of changing temperature is discussed. This article focused on the power input and output power for both linear and non-linear load because the power is a result of voltage and current. all the figures collected the power of PV and output power for the linear and non-linear load to illustrate the comparison.

**** Note: Because the load for linear (resistor) and non-linear (DC-Motor) loads is constant in all cases, the effect of different MPPTs on output power simulation is very clear.***

8.1. Under Variable Solar Irradiance

8.1.3. P&O Algorithm

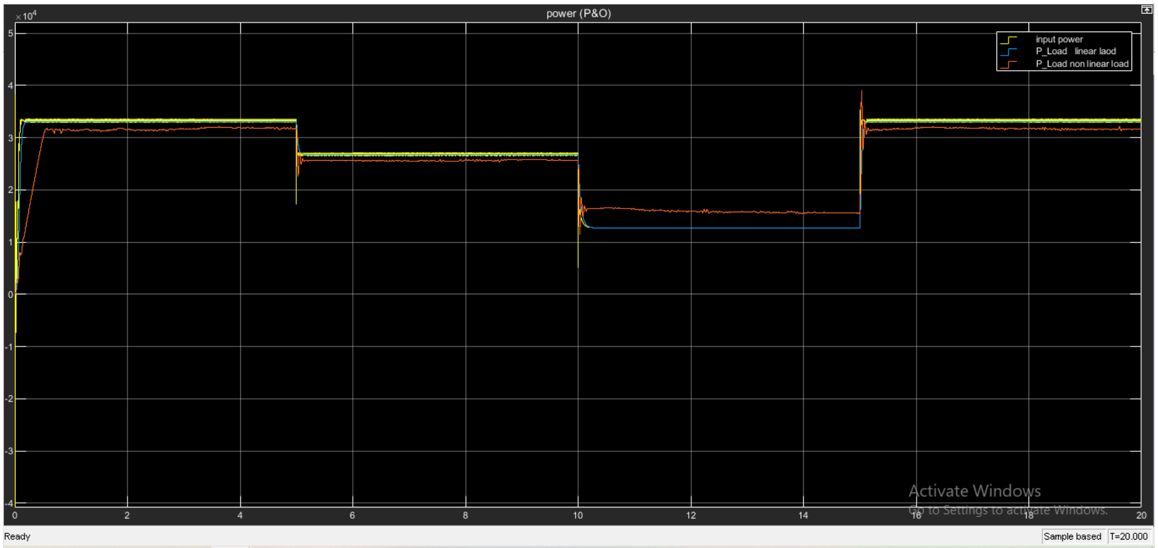

Figure 13: The output powers for perturb & Observation (P&O) under changing irradiance (1000, 800, 500, 1000)

Figure (13) shows the results of the power P&O algorithm under changing temperature from (1000,800,500,1000) W/m2, the yellow line shows the power input with more oscillation compare to the blue line which is the power of linear load, but in non-linear load (DC Motor) the output power is lower with more oscillation. For the non-linear load (DC Motor) witch shows the time need to get a steady-state is very high compare to the power linear load. The power generation by PV in both linear and non-linear loads is nearly the same. Because we have different loads, the output power level is very different. Also, the non-linear load affected the power generation and made the oscillation was high.

For each irradiance changing the P&O could find MPPT that is mean the algorithm working properly.

The rising time of the P&O Algorithm needed to reach the steady-state is smaller than INC Algorithm, but the oscillation of P&O is greater than INC Algorithm.

8.2.1. Hill Climbing (HC) Algorithm

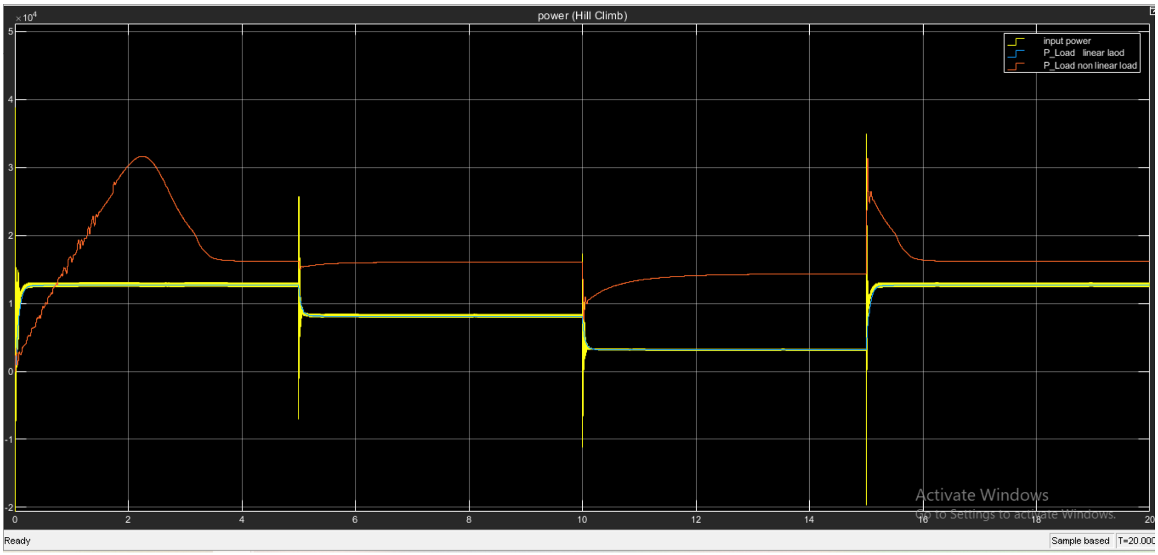

Figure 14: The output powers for Hill Climbing (HC) under changing irradiance (1000, 800, 500, 1000)

In Hill Climb (HC) algorithm opposite to P&O, INC algorithm the output power of the PV is very low as mentioned before for HC algorithm, it is normal because it cannot find the best power that the panel can generate. Also, we note that the time needed to rich steady state for non-linear load is more than the linear load.

8.1.3. INC Algorithm

In the case of a sudden shift in solar irradiance, the INC algorithm takes longer to hit the new MPP in non-linear load, as shown in Figure (14). As a result, the system's performance under variable solar irradiance is poor.

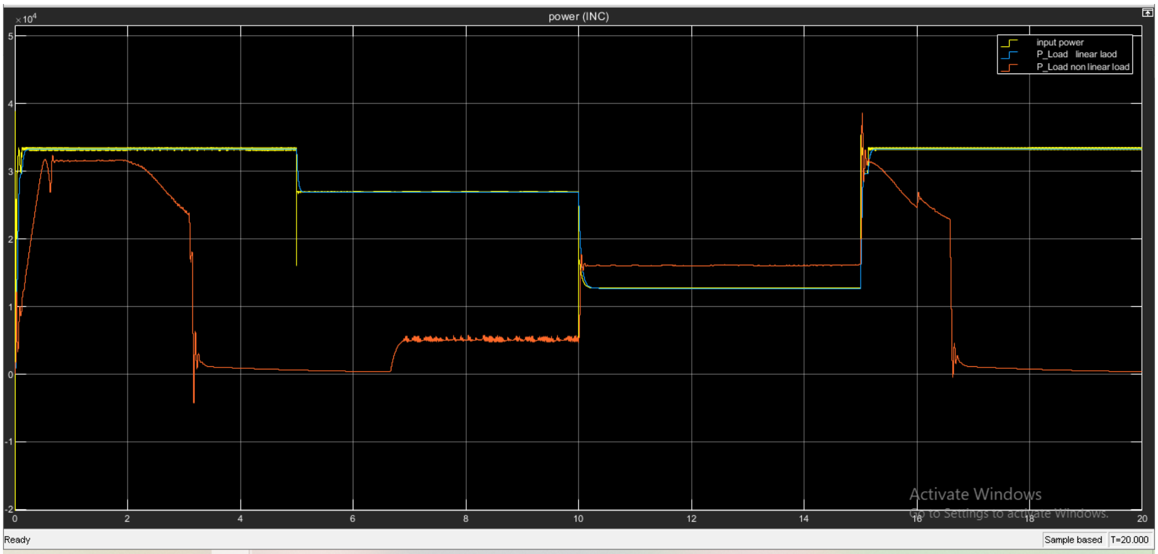

Figure 15: The output powers for Incremental Conductance (INC) under changing irradiance (1000, 800, 500, 1000)

The three figures(13,14,15) shows the effect of changing irradiance on power generation and output power for a linear and non-linear load like all the case the oscillation in non-linear load is high and affect of change irradiance is very clear in non-linear load the rising time needed to saturation is higher than non-linear.

In general, when irradiance change directly affected output power, P&O is better than the two other algorithms in order to reach steady-state, oscillation and output power for the linear and non-linear load.

8.2. Under variable solar temperature

8.2.1. P&O Algorithm

The Figure (16) shows the effect of variable temperature Change in temperature (25, 35, 45, 25) at 0, 5, 10, 15.

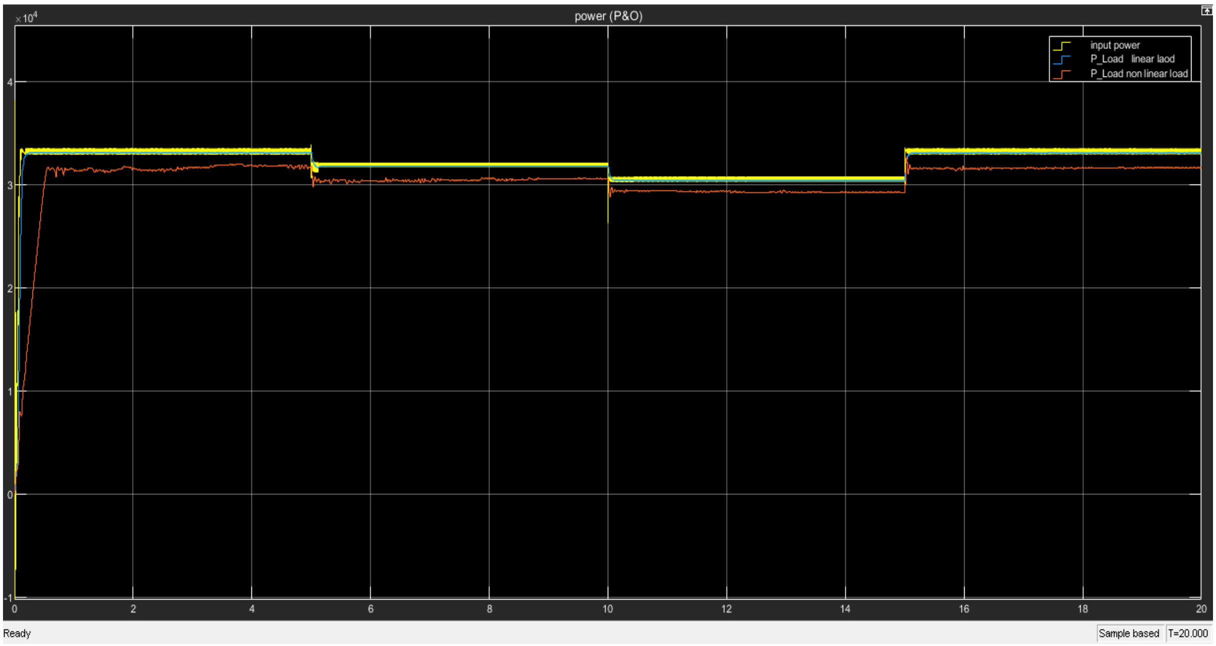

Figure 16: The powers output for P&O algorithm under variable temperature after (25, 35, 45, 25) at 0, 5, 10, 15 seconds, respectively.

In the P&O algorithm for changing temperature the output power is changing, the algorithm can find the MPPT in all cases of changing temperature. But in non-linear load, the oscillation is higher than the linear load. Also, the rising time is greater than the linear load.

8.2.2. Hill Climb (HC) Algorithm

The Figure 17), shows the effect of variable temperature on the output power for linear and non-linear load.

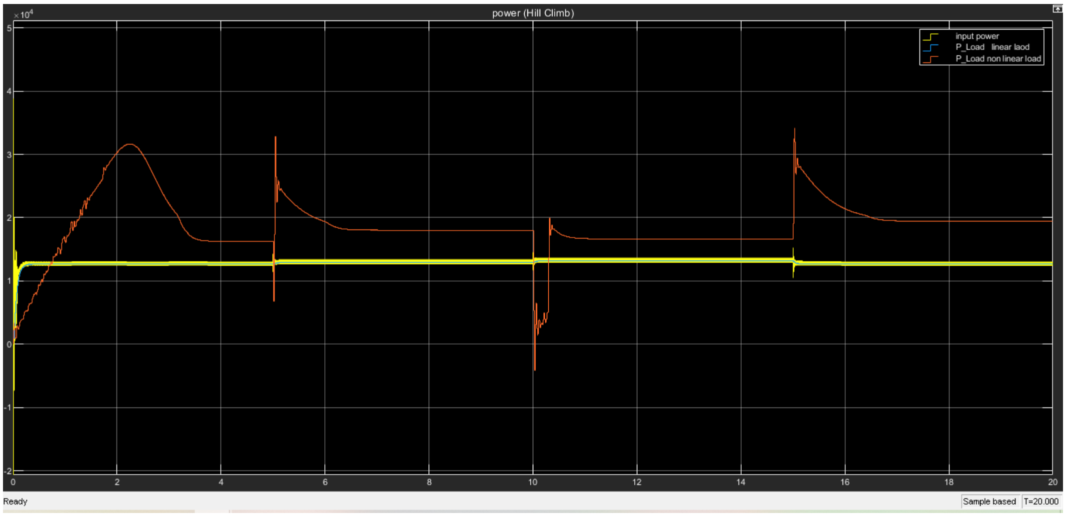

Figure 17: The powers output for Hill Climbing (HC) algorithm under variable temperature after 5 seconds (25, 35, 45, 25)

The change in temperature shows that in P&O and INC the time needed to saturate is very small compared to the HC algorithm. In HC algorithm for changing temperature the output power is changing, the algorithm cannot find the MPPT any case of changing temperature. In non-linear load the oscillation is higher than the linear load. Also, the rising time is greater than the linear load.

8.2.3. Incremental Conductance (INC) Algorithm

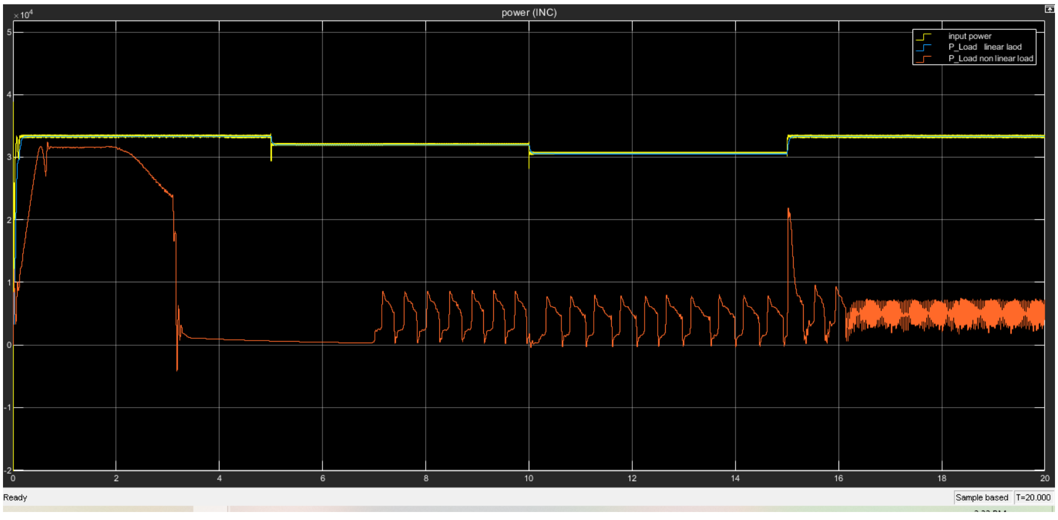

Figure 18: The powers output for Hill Climbing (HC) algorithm under variable temperature after 5 seconds (25, 35, 45, 25)

Figure (18) shows the power of nonlinear load has a very large oscillation. The INC algorithm has the ability to find MPPT when the temperature is changing in all cases.

9. Conclution

In this article to compare the effect of linear and non-linear load The two most popular MPPT algorithms, P&O, HC, and INC, those algorithms were selected their performance and dynamic MPPT efficiencies were examined. Both (P&O, INC) algorithms could find the MPP properly, but Hill Climb (HC) algorithm mostly couldn't find the actual MPPT because of their property described above.

The effect of linear load and nonlinear load on PV power and output power is shown. oscillation in output power and the rising time to MPPT is a large difference. in the simulation, it can notice that all algorithms have the advantage and disadvantage. The load connected to the output is not the same so it can not compare the power between linear load and non-linear load very well.

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