1- Draw the PV panel equivalent circuit diagram and explain clear what each element represents (in your own words).

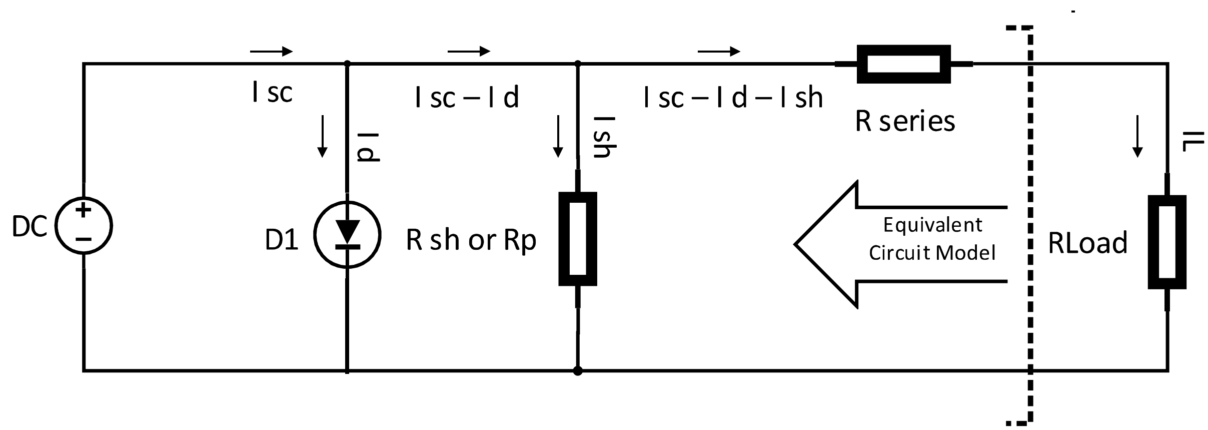

Fig.1: Equivalent circuit of PV panel.

The equivalent circuit includes the following elements:

1- Current source which depends on irradiance. Also, there are slightly impact on the value of Current source because of temperature.
2- Shunt Diode which represents the diffusion current through P-n junction.
3- Series Resistance which represents fingers resistance (internal resistance) and should be small values as possible.
4- Shunt resistance which represents Resistance of the leakage current path, and it is very high.

2- Explain briefly the principle of the Newton-Raphson method and the criterion for terminating the iteration.

Consider a function *f(x)* whose zeros are to be determined numerically. Let r be a zero (I) of f and let x *(Voc)* to be an approximation to r. If f'' exists and is continuous, then by Taylor's theorem,

$$0 = f(r) = f(x+h) = f(x) + hf'(x) + O(h^2)$$

where $h = r - x$ If h is small (that is, x is near r), then it is reasonable to ignore the $O(h^2)$ term and solve the remaining equation for h. If we do this, the result is

$$f(x) + hf'(x) = 0 \quad \Rightarrow h = -f(x)/f'(x)$$

If x is an approximation to r, then $x - f(x)/f'(x)$ should be a better approximation to r.
Newton's method begins with an estimate x_0 of r and then defines iteratively

$$x_{n+1} = x_n - f(x_n)/f'(x_n) \qquad\qquad n \geq 0$$

3- Draw your program flowchart and explain the procedures of the program.

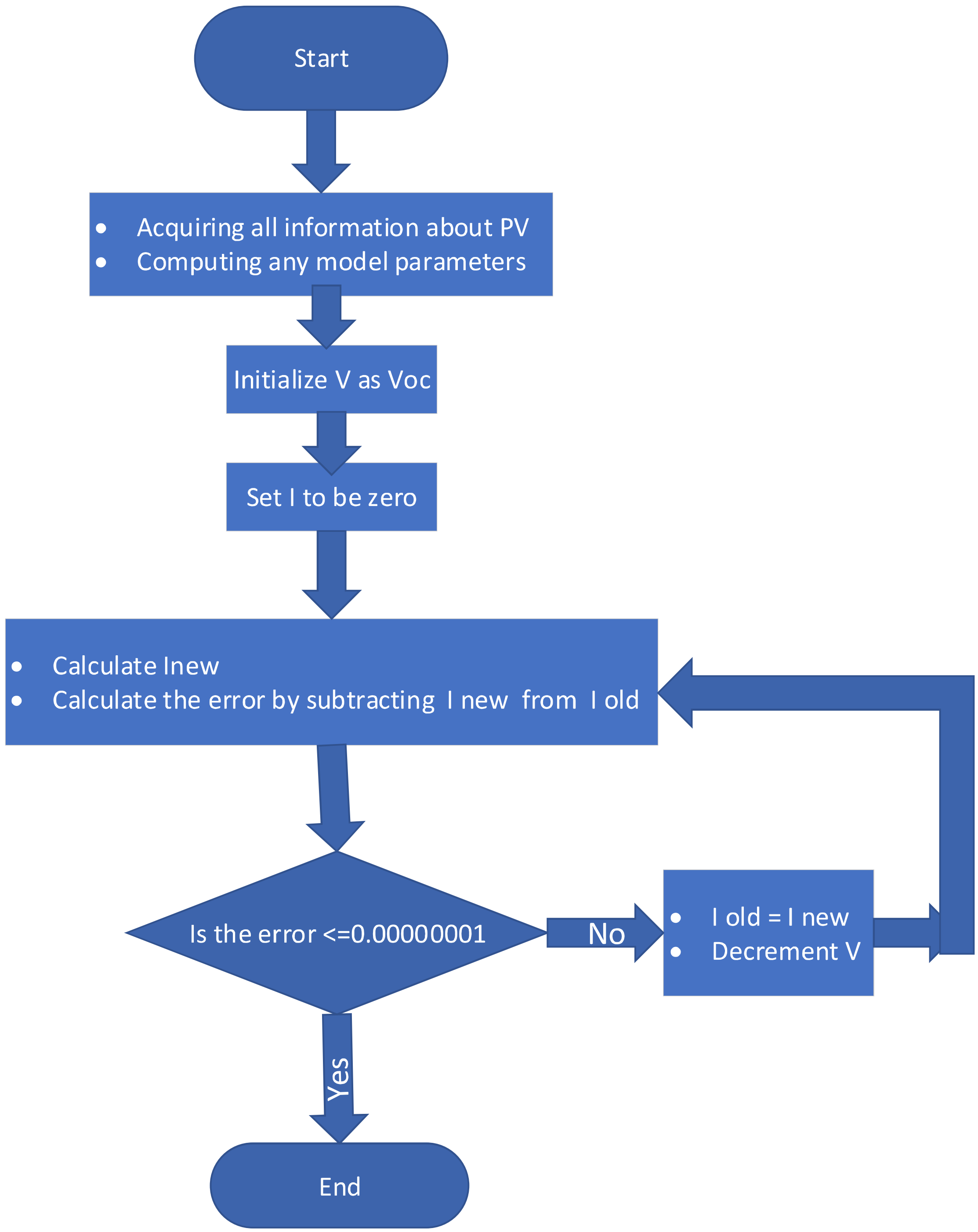

Fig.2: Flow chart of PV model.

MATLAB

```
clc
clear
G=1.0;              %irradiance
ior=19.9693e-6;
tr=301.18;          %Normial or referance temperature
iscr=3.3;
eg=1.1;ki=1.7e-3;a= 1.72e+00;k=1.380658e-23;
q=1.6e-19;
rs=5e-05;       %series resistance.
rsh=5e+05;      %parallel resistance rsh=rp
ns=40;          % No of series cells.
np=2;
ta=25;
tc=ta+0.2*G+273.18;
isc=(iscr+ki*(tc-tr))*G;    %short circuit current.
is=ior*(tc/tr)^3*exp(q*eg*((1/tr)-(1/tc))/(k*a));
IL=isc;
I=zeros(250,1);
i=1;
I(1,1)=0;
for v=25:-0.1:0;
 I(i+1)=np*isc-
(is*np*((exp(q*(v/ns+(I(i,1)*rs)/np)/(a*k*tc)))-1))-
((v*np/ns+(I(i,1)*rs))/rsh);
v1(i)=v;
    p(i)= v*I(i);
    error=abs(I(i+1)-I(i,1));
   if error<=0.00000001;
    break
   end
    i=i+1;
end
v1(i)= v1(i-1);
p(i)=p(i-1);
plot(v1,I);
ylim ([0 10])
plot(v1,p);
ylim ([0 105])
```

4- Plot the I-V and P-V characteristics for G=0.5 ,0.7 and 1.0 kW/m^2 at the ambient temperature T=25 °C, annotate the maximum power point for each case on the graphs.

Firstly: I- V characteristics.

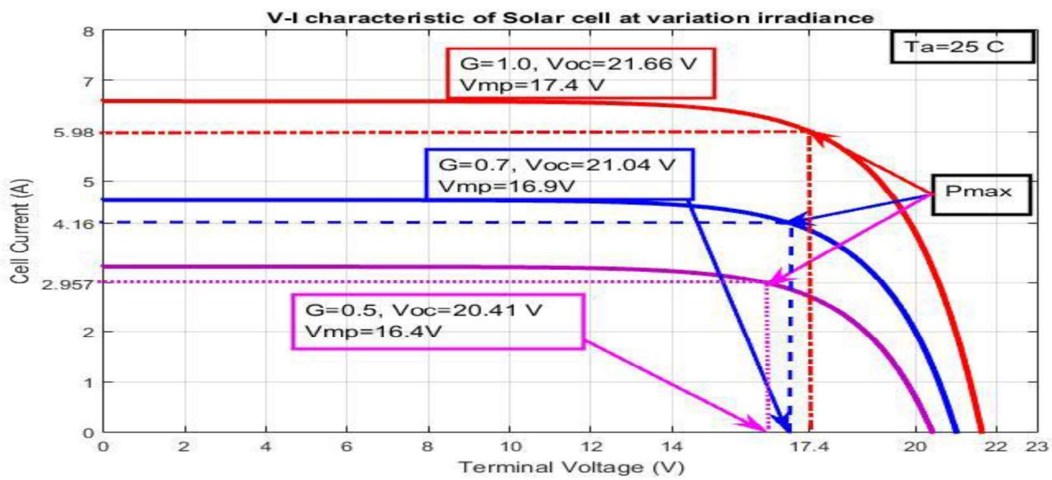

Fig.3: I-V characteristics at varying irradiance.

From above figure, terminal voltage (whether Voc or Vmp) and cell current (whether Isc or Imp) are proportional with irradiance power as shown in Fig.3. At increasing G, both Isc, IL, Voc and Vmp will be increased. As seen in the figure, high performance at max irradiance.

secondly: P- V characteristics.

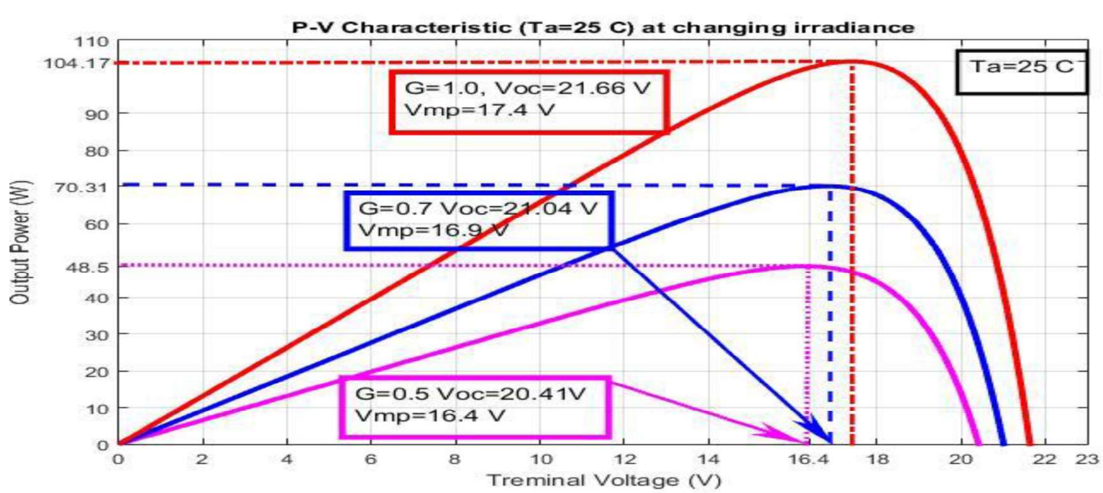

Fig.4: P-V characteristics at varying irradiance.

Fig.4. shows the relevance of increasing the irradiance levels, where at low levels of irradiance the MP is small (G=0.5, MP=48.7 W), but at high levels the MP has been extracted is very high (G=1.0, MP=104.17 W). Therefore, it's important to get high irradiation all the day.

Result(Irradiance):

- ***The MP is proportional with irradiance.*** $P_{MAX}\ \alpha\ G$
- ***The terminal voltage or the cell current is proportional with irradiance.*** V_T ***or*** $I_{Cell}\ \alpha\ G$

5- Plot the I-V and P-V characteristics for the ambient temperatures T_a of 25, 40 and 60 °C, at G=1.0 kW/m² and annotate the maximum power point for each case on the graphs.

Firstly: I- V characteristics.

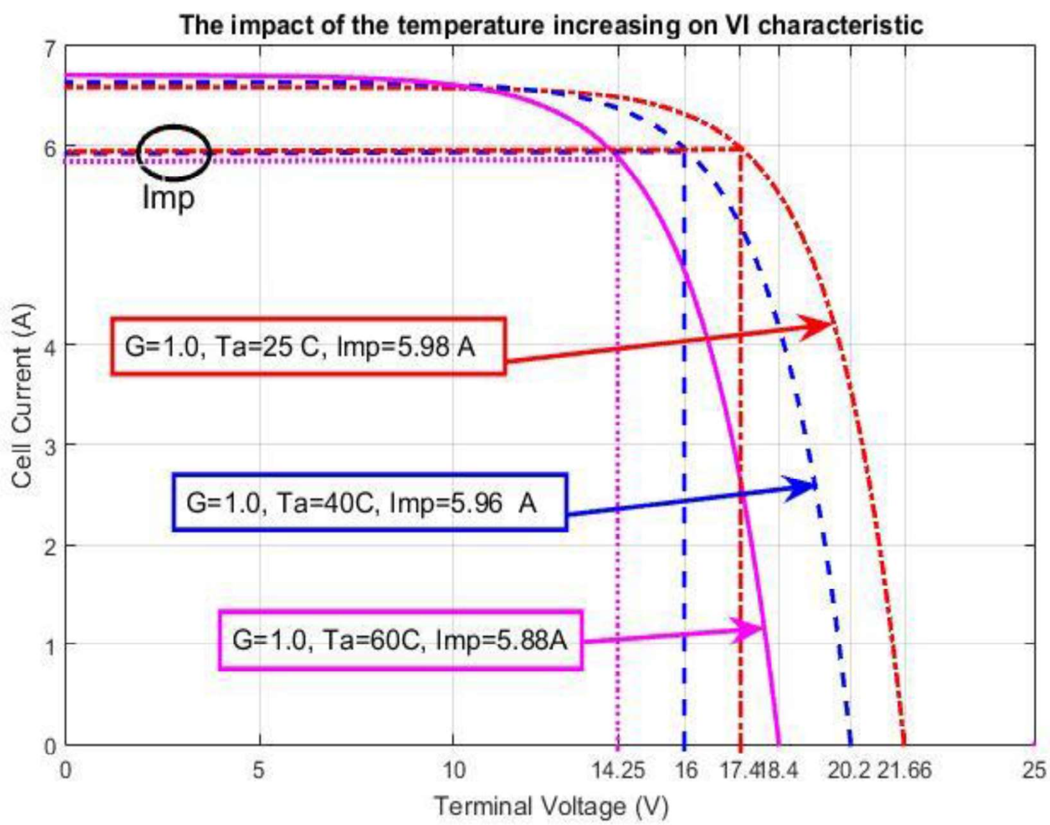

Fig.5: I-V characteristics at varying temperature.

- **Terminal voltage:**

  At increasing temperature, both Voc and Vmp are decreased as depicted in Fig.5. where at Ta=25, Voc and Vmp equal 21.66 V and 17.4 V respectively whereas at Ta=40, Voc=20.2 V and Vmp=16 V. So, the temperature has a detrimental impact on terminal voltage if it's increased.

  Calculations:

  $V_{40\ C} = V - (\Delta Ta * 0.0024 * ns)$=21.66-(15*0.0024*40)= 20.2 V

  $V_{60\ C} = V - (\Delta Ta * 0.0024 * ns)$=21.66-(35*0.0024*40)= 18.4 V

  The results from calculations are exactly the same results from figure.

- **Max. Current Imp:**

  There are a slightly impact on the Imp at increasing temperature as illustrated in Fig.5. where the current decreases from 5.98 A to 5.88 A when the temperature increases from 25 C to 60 C.

- **Short Circuit Current Isc:**

  Isc is greatly affected at increasing temperature. In order to observe this, let's take a closer look as indicated in the below figure.

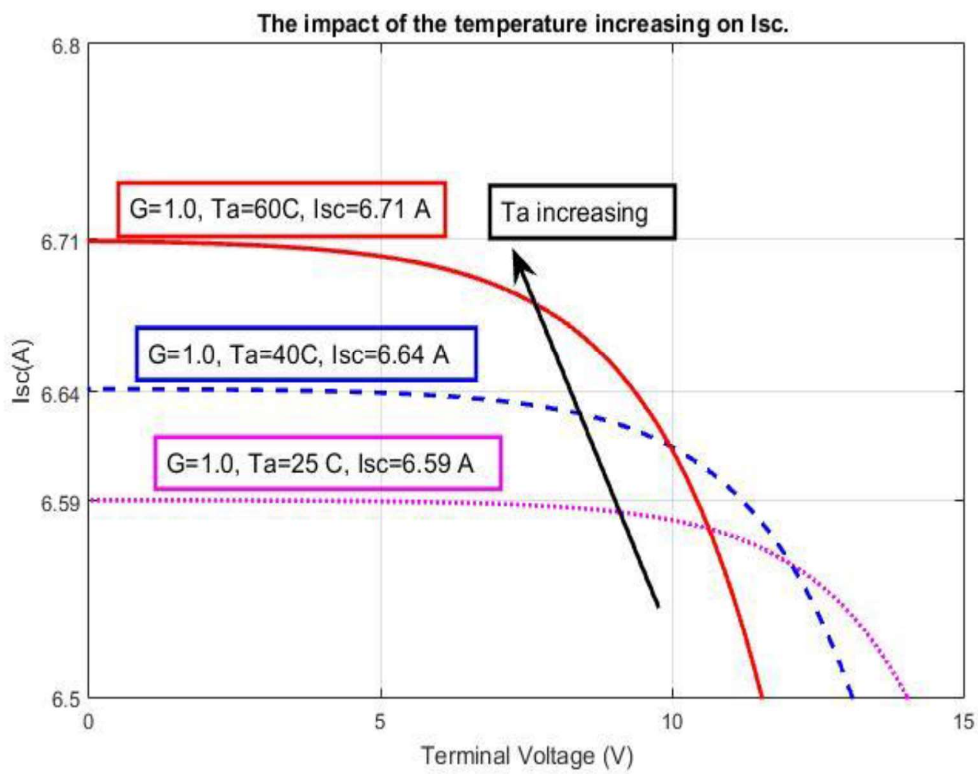

Fig.6: The impact of increasing temperature on Isc.

The magnitude of the Isc at increasing temperature can be obtain as following:

Isc(40 C)=Isc((25)+(40-25) = 6.59+(0.004*15)=6.65 A

Isc(60 C)= Isc((25)+(60-25) = 6.59+(0.004*35)=6.71 A

The calculations consistent with the results that are shown in the previously figure.

Secondly: P- V characteristics.

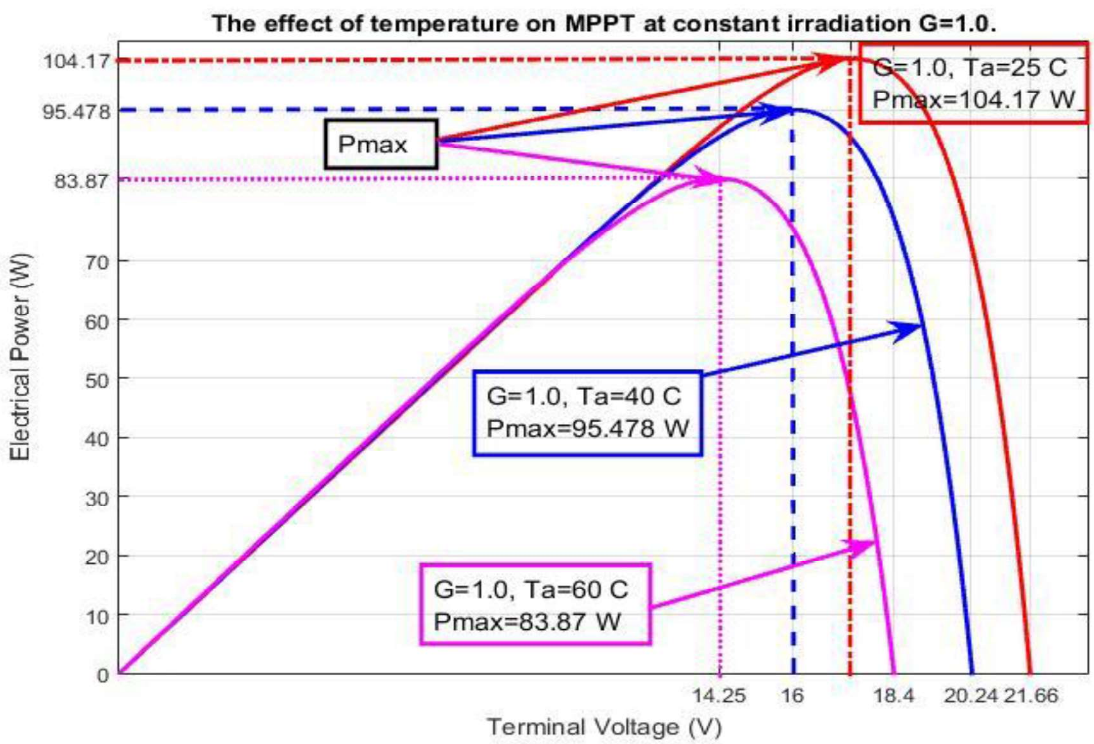

Fig.7: The impact of increasing temperature on MP.

It is obvious from Fig.7.that max temperature, will leads to minimum MP. When the temperature is increased from 25 C up to 40 C, the MP is decreased from 104.1 W to 95.47 W. Therefore, there are adverse influence on MP at increasing temperature.

Results (Temperature):

- ***MP as well as terminal voltage are inversely proportional with temperature, whereas Isc is proportional with temperature.***
- ***There is slightly effect on Imp (decreases at increasing temperature)***

6- Make adequate comments on the dependence of P_{max} (at MPP) on T and G.

- ***The MP is proportional with irradiance.*** $P_{MAX}\ \alpha\ G$
- ***The terminal voltage or the cell current is proportional with irradiance.*** V_T **or** $I_{Cell}\ \alpha\ G$
- ***MP as well as terminal voltage are inversely proportional with temperature, whereas Isc is proportional with temperature.***
- ***There is slightly effect on Imp (decreases at increasing temperature)***

7- Calculate FF in all 6 cases (in questions 1 and 2) and comment on the findings.

Firstly: the impact of varying irradiance on FF.

Table 1: The impact of varying irradiance on FF.

Ta=25^0 C				
Irradiance	**Pmax**	**Vo.c**	**Is.c**	**FF**
1.0	**104.17**	**21.66**	**6.5905**	**0.7297**
0.7	**70.31**	**21.04**	**4.6132**	**0.7243**
0.5	**48.5**	**20.41**	**3.2951**	**0.7211**

From table 1. the FF is proportional with irradiance but this is *slightly changing* in FF.

Secondly: the impact of varying temperature on FF.

Table 2: The impact of varying temperature on FF.

G=1.0 KW/m^2				
Temperature	**Pmax**	**Vo.c**	**Is.c**	**FF**
25	**104.17**	**21.66**	**6.5905**	**0.7297**
40	**95.478**	**20.24**	**6.6415**	**0.7102**
60	**83.87**	**18.4**	**6.71**	**0.6793**

As illustrated in Table.2. the FF is inversely proportional with temperature as well as the FF is Significantly affected at varying temperature.

8- Using three points (the MPP point and two neighbouring points) on one I-V characteristic curve, work out three values of V/I and the corresponding slope resistance dV/dI . (This is the slope of the tangent to the I-V curve at that point.) Explain what these values represent. Comment on the characteristics of the PV panel. At which point is V/I equal to – dV/dI? Why is this?

Table 3: The calculation of V/I and slope.

Voltage (V)	Current (A)	Resistance(Ω)	Slope	Power(W)
(A) 16.9	6.133	2.755	2.91	103.65
(MP) 17.41	**5.98**	**2.91**	**2.91**	**104.11**
(B) 17.9	5.79	3.09	2.91	103.65

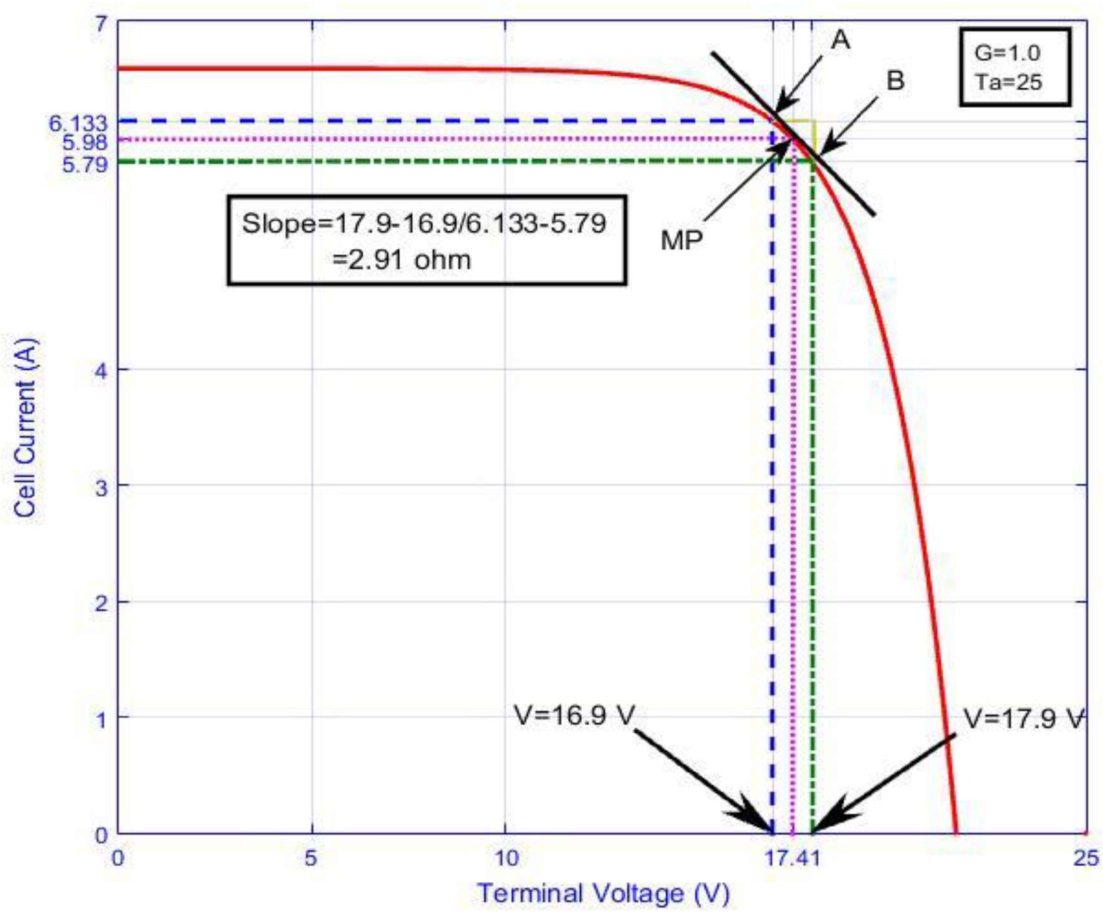

Fig.8: I-V characteristic with tangent for MPP.

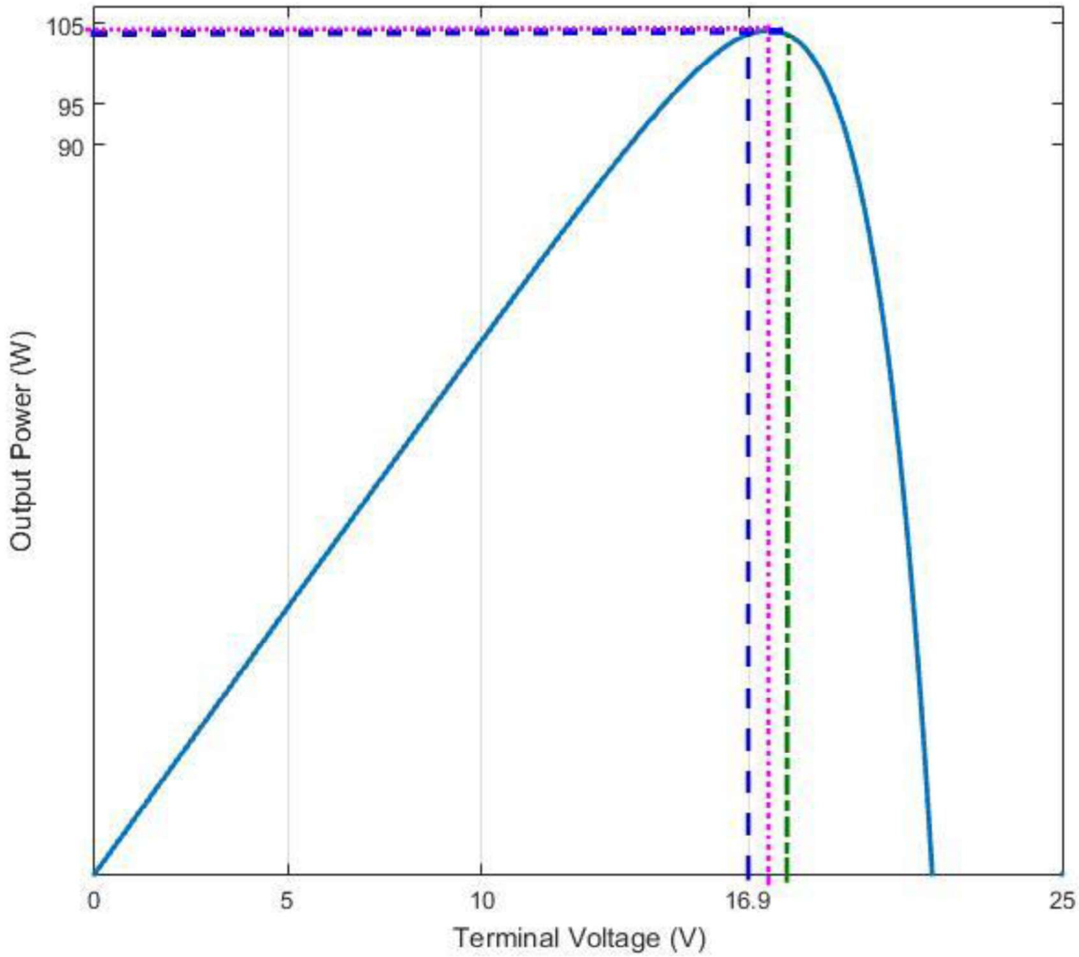

Fig.9: P-V characteristic with tangent for MPP.

From Fig.8,9, it is obvious that MP point (the middle point) represents the best point for operation where the extract power is max value, whereas two neighbour points for MP point represents the limits of the voltage and current (±3%) or the operating range. In case of MPP V/I is equal slope as shown in Table 3, since the tangent passes only through one point MPP (this is a curve) only one point will equal slope.

From these figures, the MPP is one point, whereas the limitations has one value for power (103.65 w) but at different values for current and voltage.