# EE4170 :
# Power Systems and Renewable Energy Laboratory

INDIAN INSTITUTE
OF TECHNOLOGY
PALAKKAD

# Post Lab Report

Experiment 1 :

## Solar PV Model and Characteristics


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# Question 1,2,3,4

This section covers the design of the PV module and the setup necessary for measuring the output voltage and current. The code below is used to automate the process of measuring the PV module output voltage and current.

```
T = 21;
data_points = 40;
Voltage = linspace(0,45,data_points);

vpv = zeros(1,data_points);
ipv = zeros(1,data_points);
pout = zeros(1,data_points);

% This is to find out the o/p voltage and current values.
for i=1:data_points
    V = Voltage(1,i);
    sim('Exp_1.slx');
    pause(1);
    vpv(1,i) = (ans.v.Data(end));
    ipv(1,i) = (ans.i.Data(end));
end

pout = vpv .* ipv; % This is the output power.
```

As we have used the bus selector for our simulink model, thus we can directly get the current and voltage values , to measure the variables instead of using separate voltmeters and ammeters .

The implemented Simulink model is shown below:

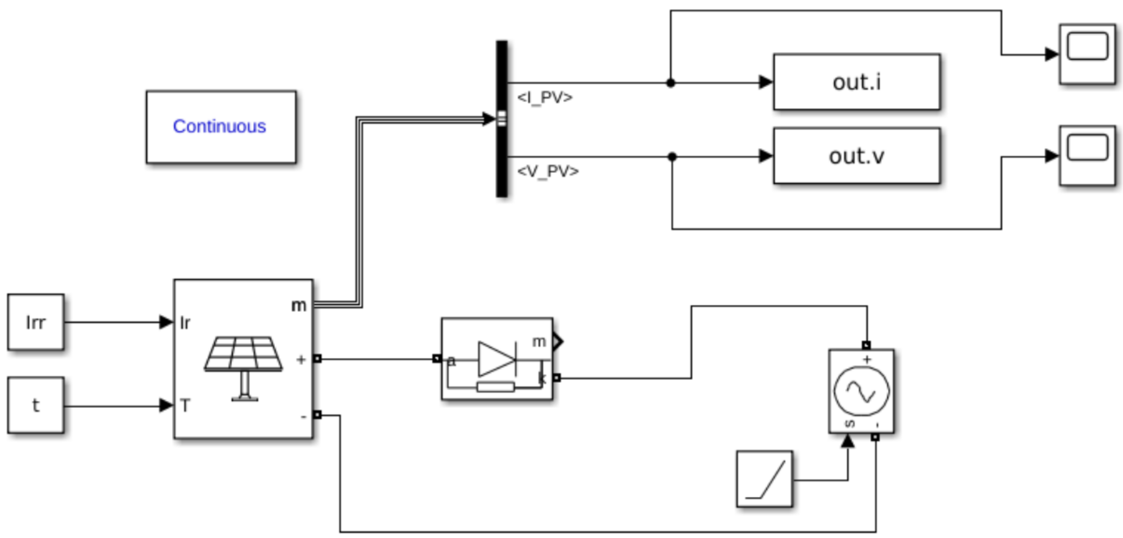


Figure 1: The required simulink model

# Question 5

The I-V and P-V plots for various irradiation values (W = 1000 , 600 and 200 ) are shown below:

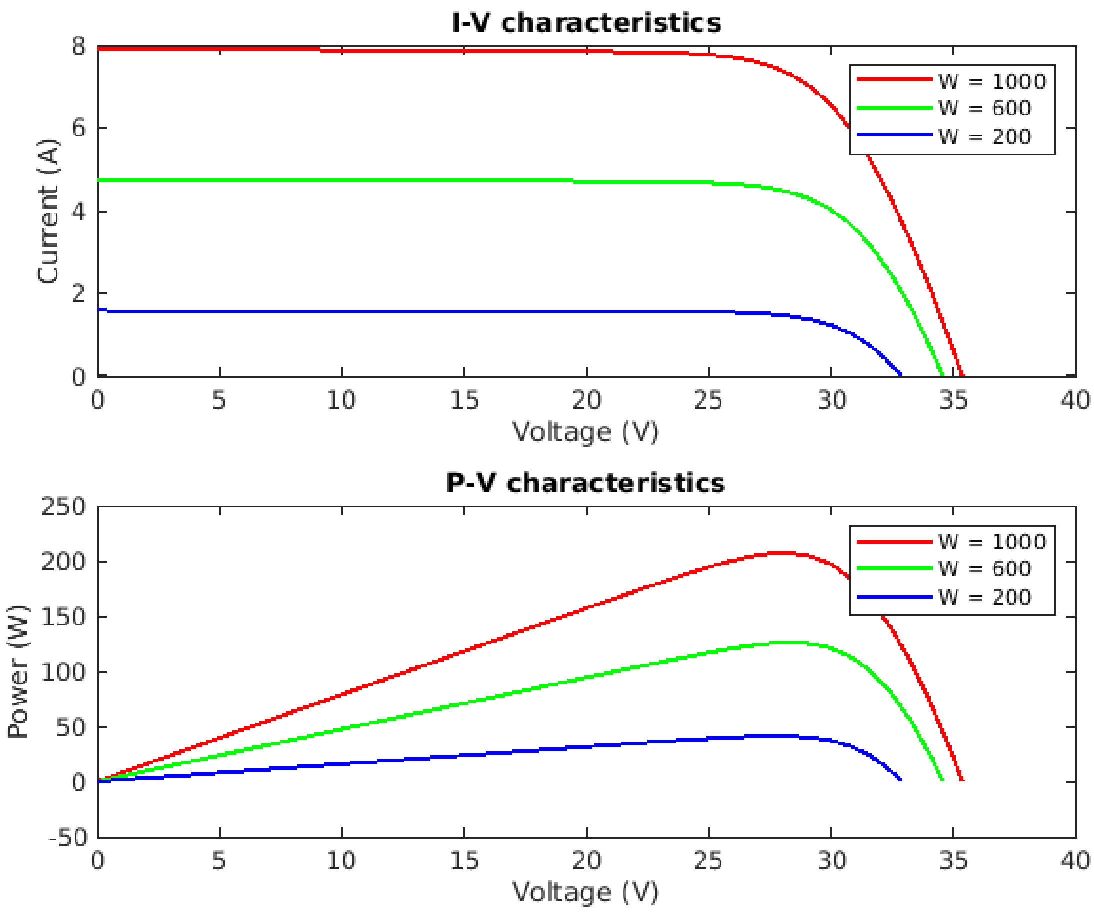


Figure 2: I-V and P-V plots for various irradiances

From Figure 2, we observe that as the irradiation decreases from the standard value of 1000 $W/m^2$, the change in open-circuit voltage is minimal, but there is a significant drop in the short-circuit current. Consequently, the maximum output power obtained also decreases with reduced irradiance.
**Note:** The temperature here is considered to be 32°C (20 + 12).

Here is the required code :

```
% Ques 5

W = [1000, 600, 200]; % Fixed the indexing issue
c = ['r','g','b'];
% Create a new figure
figure;

for i = 1:length(W) % Adjusted loop to start at 1 and iterate correctly
    Irr = W(i);
    t = 32;
```

```
    % Ensure the Simulink model and variables are set correctly
    sim('Exp_1.slx');

    % Plot data
    subplot(2,1,1);
    plot(ans.v.Data, ans.i.Data, c(i), 'LineWidth', 1.5);
    % Add labels and title
    xlabel('Voltage (V)');
    ylabel('Current (A)');
    title('I-V characteristics');
    % Add a legend to the plot with labels
    legend(arrayfun(@(x) sprintf('W = %d', x), W, 'UniformOutput', false));
    hold on;

    subplot(2,1,2);
    plot(ans.v.Data, ans.v.Data .* ans.i.Data, c(i), 'LineWidth', 1.5);
    % Add labels and title
    xlabel('Voltage (V)');
    ylabel('Power (W)');
    title('P-V characteristics');
    % Add a legend to the plot with labels
    legend(arrayfun(@(x) sprintf('W = %d', x), W, 'UniformOutput', false));
    hold on;
end

% Release the hold to stop adding more lines
hold off;
```

# Question 6

Here is the required code :

```
%Ques 6

Temp =[32,52];
c = ['r','g','b'];
% Create a new figure
figure;

for i = 1:length(Temp) % Adjusted loop to start at 1 and iterate correctly
    Irr = 1000;
    t=Temp(i);
    % Ensure the Simulink model and variables are set correctly
    sim('Exp_1.slx',400);

    % Plot data
    subplot(2,1,1);
    plot(ans.v.Data,ans.i.Data, c(i),'LineWidth',1);
    % Add labels and title
    xlabel('Voltage (V)');
    ylabel('Current (A)');
    title('I-V characteristics');
    % Add a legend to the plot with labels
    legend(arrayfun(@(x) sprintf('T = %d', x), Temp, 'UniformOutput', false));
    hold on;
    subplot(2,1,2);
    plot(ans.v.Data, ans.v.Data.*ans.i.Data, c(i),'LineWidth',1);
    % Add labels and title
```

```
    xlabel('Voltage␣(V)');
    ylabel('Power␣(W)');
    title('P-V␣characteristics');
    % Add a legend to the plot with labels
    legend(arrayfun(@(x) sprintf('T␣=␣%d', x), Temp, 'UniformOutput', false));
    hold on;
end

% Release the hold to stop adding more lines
hold off;
```

The I-V and P-V plots for variations in temperature is shown below. Here, the two temperatures considered are 32°C and 52°C.

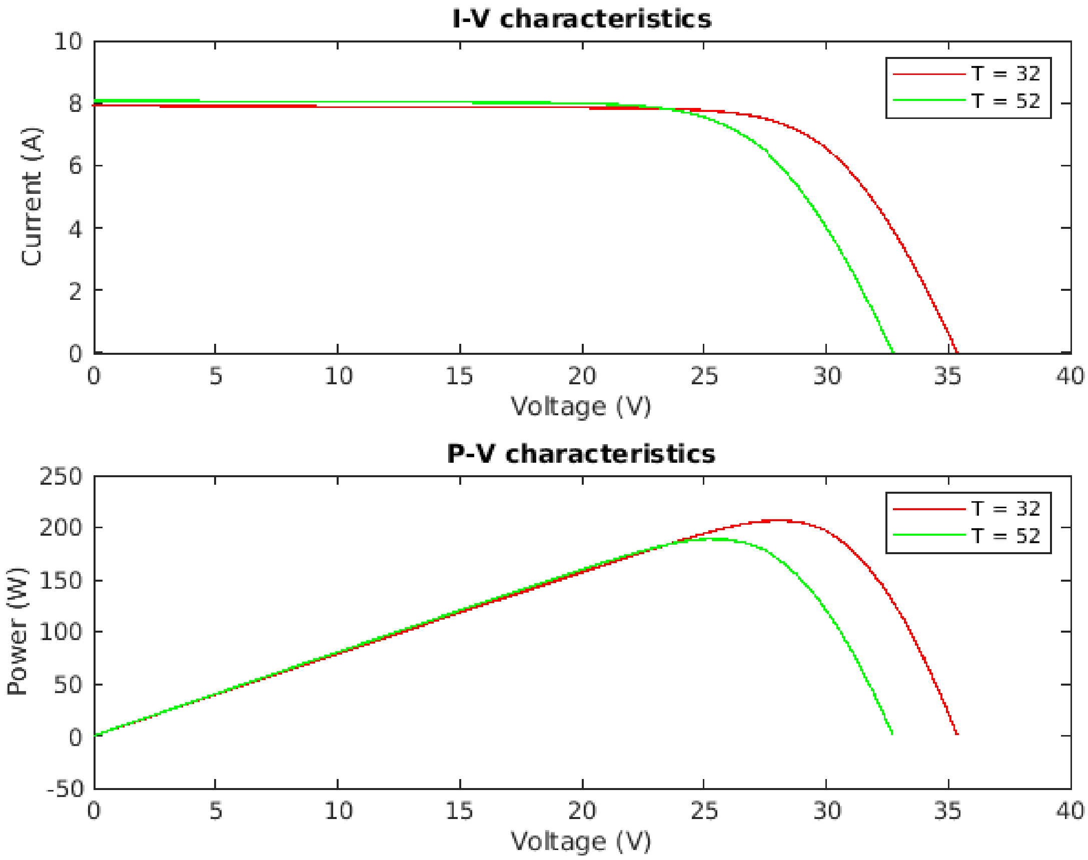


Figure 3: I-V and P-V plots for variations in temperature

Figure 3 shows that as the temperature rises, the open-circuit voltage decreases, while there is a slight increase in the short-circuit current. This increase in short-circuit current is due to the heightened thermal excitation of electrons. Additionally, the Maximum Power Point on the P-V curve also declines.

# Question 7

The I-V and P-V characteristics of the PV panel when irradiation is 1000 W/m2 and temperature is 32°C is shown below:

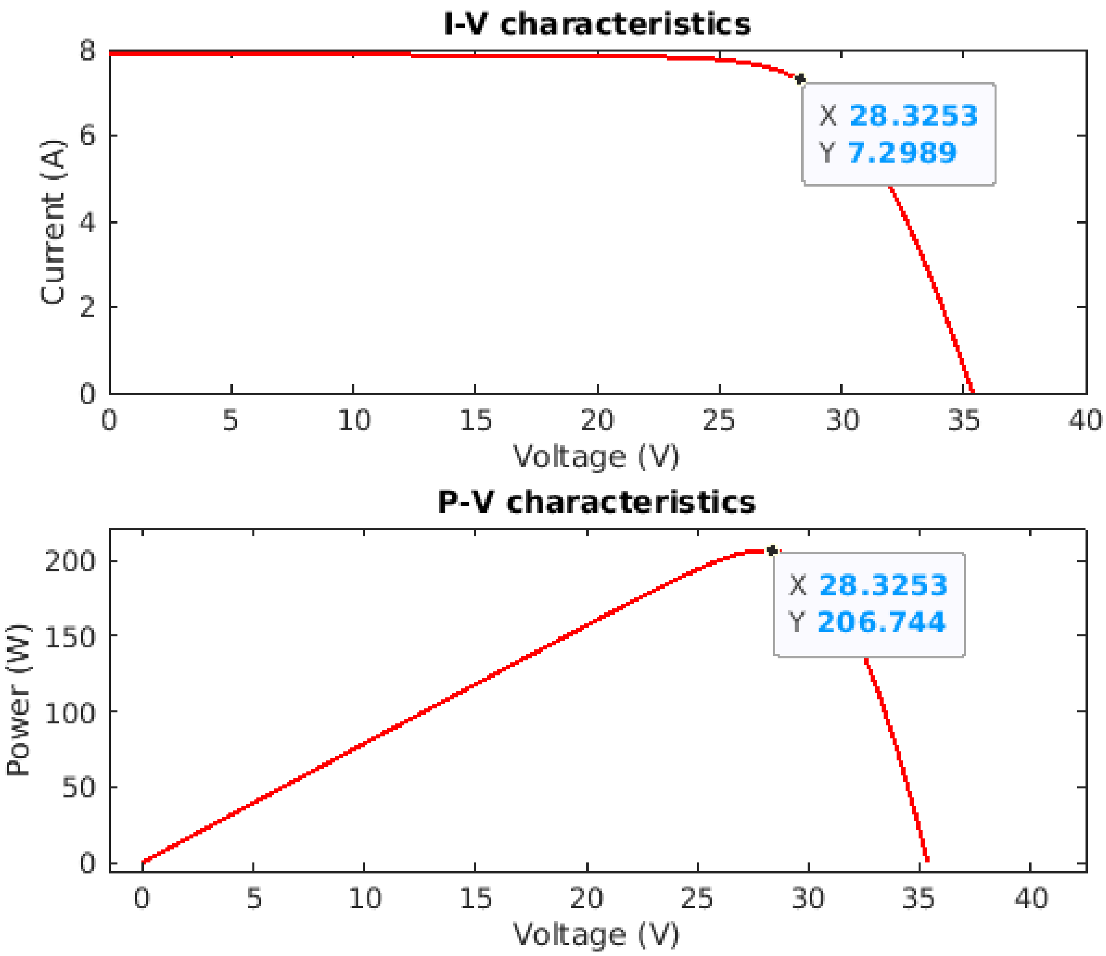


Figure 4: I-V and P-V plots

From Figure 4, we can say that the voltage and current values at the Maximum Power Point (MPP) are 28.3253 V and 7.2989 A. Thus, the load resistance required to get these values is:

$$R = \frac{V_{\text{MPP}}}{I_{\text{MPP}}} = \frac{28.3253}{7.2989} = 3.8808\,\Omega$$

The simulink model for the simulation is shown below:

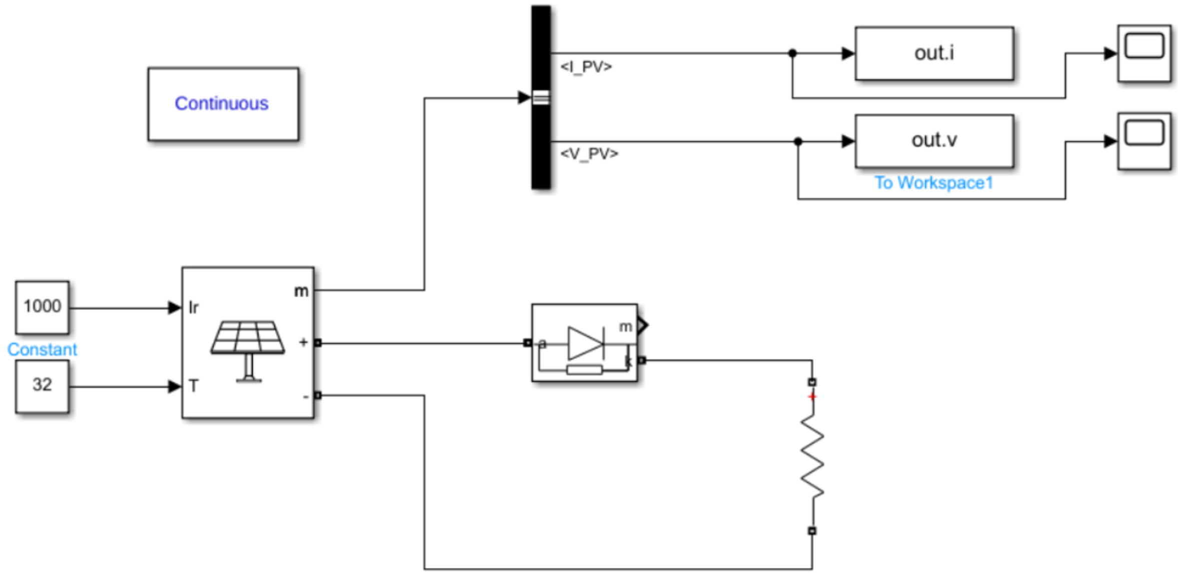


Figure 5: The required simulink model with resistance = 3.8808 ohm

```
%Ques 7

% Create a new figure
figure;

Irr = 1000;
t=32;
% Ensure the Simulink model and variables are set correctly
sim('Exp_1.slx');

% Plot data
subplot(2,1,1);
plot(ans.v.Data,ans.i.Data, 'r','LineWidth',1.5);
disp(max(ans.v.Data.*ans.i.Data));
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Current␣(A)');
title('I-V␣characteristics');

subplot(2,1,2);
plot(ans.v.Data, ans.v.Data.*ans.i.Data, 'r','LineWidth',1.5);
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Power␣(W)');
title('P-V␣characteristics');

%%
%Ques 7.1
% Create a new figure
figure;
Irr = 1000;
t=32;
```

```
% Ensure the Simulink model and variables are set correctly
sim('Exp_1.slx');

% Plot data
subplot(2,1,1);
plot(ans.v.Time,ans.v.Data, 'r','LineWidth',1.5);
% Add labels and title
ylabel('Voltage␣(V)');
xlabel('Time␣(s)');
title('Voltage␣Value␣for␣R=3.8807');

subplot(2,1,2);
plot(ans.i.Time, ans.i.Data, 'r','LineWidth',1.5);
% Add labels and title
ylabel('Current(A)');
xlabel('Time␣(s)');
title('Current␣Value␣for␣R=3.8807');
```

The current and voltage values obtained at the output is shown below:

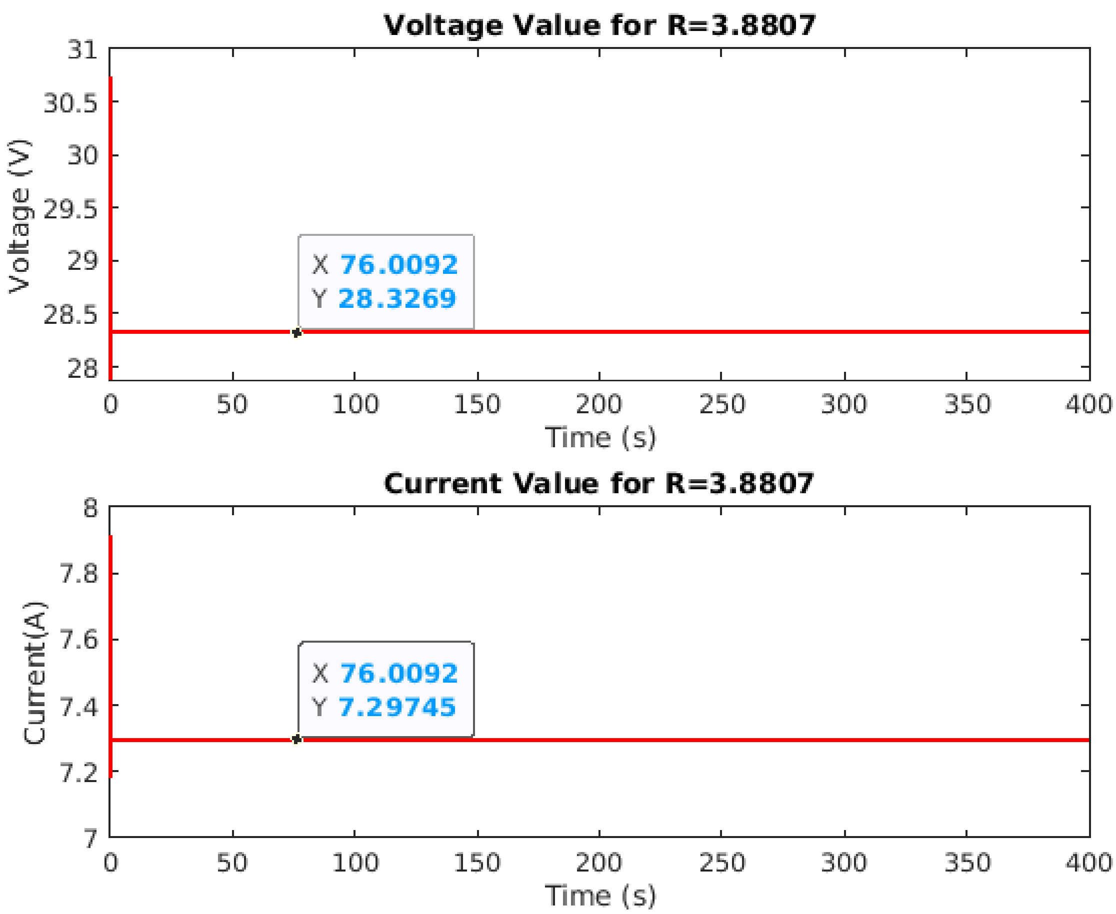


Figure 6: Plot showing the output current and voltage values when the load resistance, R = 3.8808 Ω.

From the plot shown in Figure 6, we can see that the **output voltage is 28.3269** and the **output current is 7.29745 A**. The **output power obtained is 206.714 W** which is very close to the value shown in Figure 4 (i.e. 206.744) .

# Question 8

Two identical PV modules having $V_{oc} = 36.3$ V and $I_{sc} = 7.84$ A are connected in parallel. The Simulink model has been shown below:

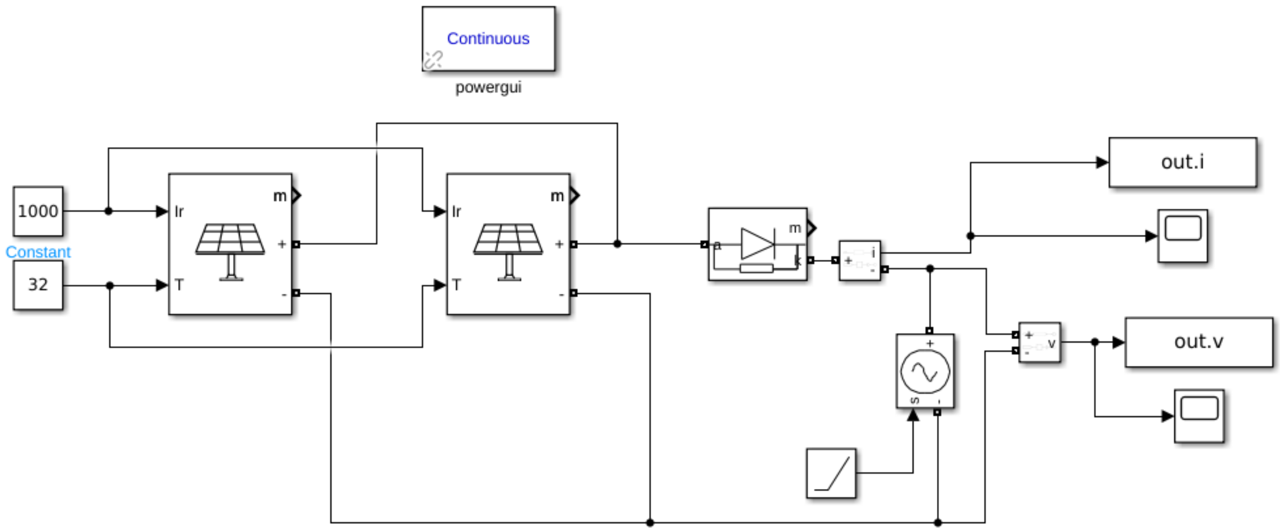


Figure 7: The required simulink model

```
%Ques 8

% Create a new figure
figure;

% Ensure the Simulink model and variables are set correctly
sim('Exp_1.slx');

% Plot data
subplot(2,1,1);
plot(ans.v.Data,ans.i.Data, 'r','LineWidth',1.5);
disp(max(ans.v.Data.*ans.i.Data));
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Current␣(A)');
title('I-V␣characteristics');

subplot(2,1,2);
plot(ans.v.Data, ans.v.Data.*ans.i.Data, 'r','LineWidth',1.5);
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Power␣(W)');
title('P-V␣characteristics');
```

The I-V and P-V plots for this model is shown below:

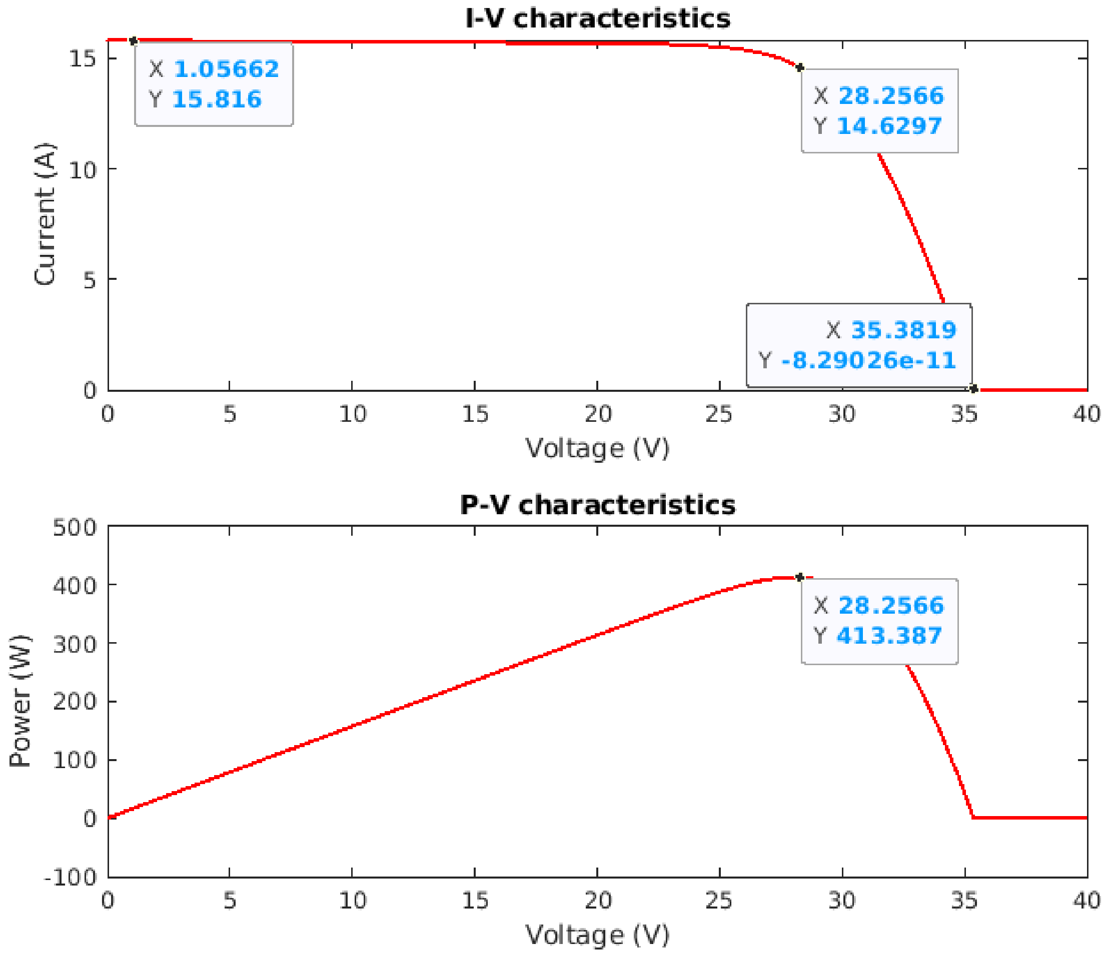


Figure 8: The required I-V and P-V characteristic plots for parallel PV Modules

The Short-Circuit Current in this case is $I_{sc} = 15.816$ A which is almost twice as the $I_{sc}$ obtained in Question 5. The Open-Circuit Voltage is $V_{oc} = 35.3819$ V which remains the same in Question 5 as well. Thus, we can say that the short-circuit currents will add up when PV Panels are connected in parallel. The open-circuit voltage of the PV panels connected in parallel will be the same as that of the individual panel (since the voltage across them remains the same). The output power has now increased to 413.387 W which is nearly twice the value obtained in Question 5.

# Question 9

Two identical PV modules having Voc = 36.3 V and Isc = 7.84 A are connected in series. The Simulink model has been shown below:

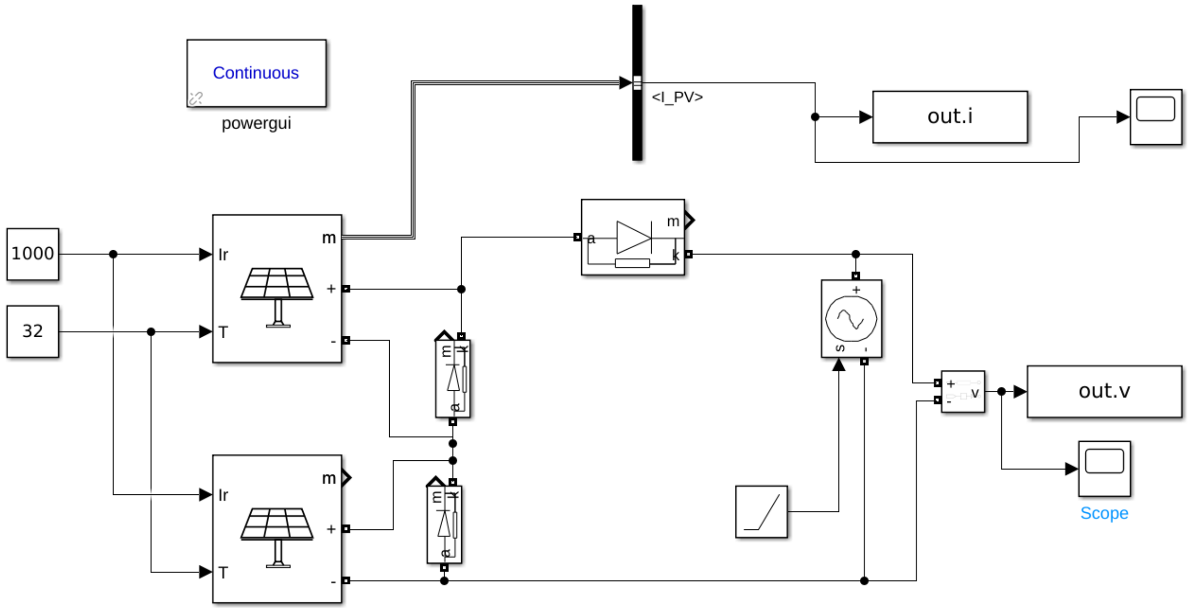


Figure 9: The required simulink model

```
%Ques 9

% Create a new figure
figure;
Irr = 1000;
t=32;
% Ensure the Simulink model and variables are set correctly
sim('Exp_1.slx');
% Plot data
subplot(2,1,1);
plot(ans.v.Data,ans.i.Data, 'r','LineWidth',1.5);
disp(max(ans.v.Data.*ans.i.Data));
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Current␣(A)');
title('I-V␣characteristics');
subplot(2,1,2);
plot(ans.v.Data, ans.v.Data.*ans.i.Data, 'r','LineWidth',1.5);
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Power␣(W)');
title('P-V␣characteristics');
```

The I-V and P-V plots for this model is shown below:

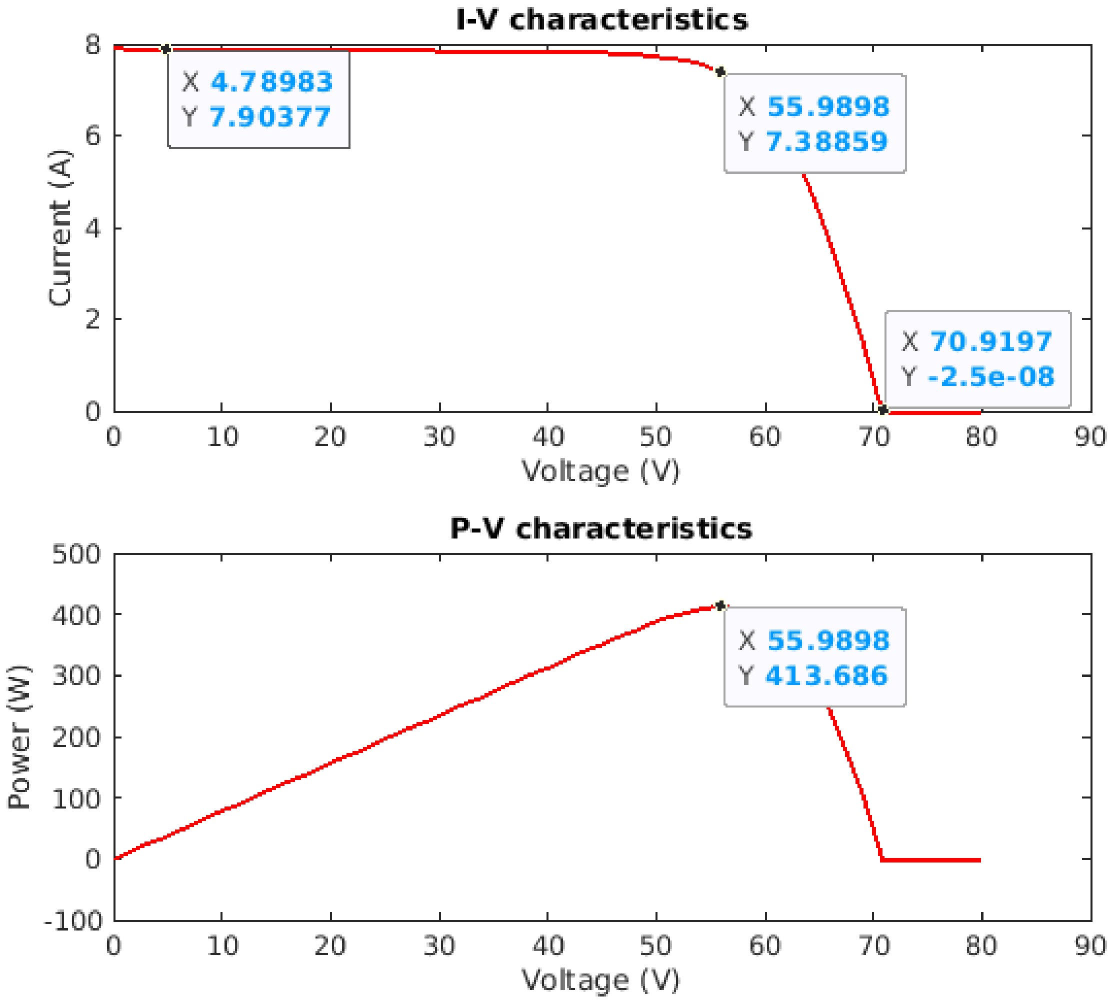


Figure 10: The required I-V and P-V characteristic plots for series PV Modules

From Figure 10, we can see that now the Short-circuit current, $Isc$ remains the same as in Question 5 which is equal to 7.903 A but now the Open-circuit voltage, $V_{oc}$ has become close to 71 V which is double the value of the Open-circuit voltage that we obtained in Question 5. The output power has now increased to 413.686 W which is nearly double the value obtained in Question 5 under standard conditions.

# Question 10

In this section, we have demonstrated what happens when partial shading happens to one of the panels. The irradiation on one of the panels is 1000 W/m 2 whereas the irradiation on the other panel is 500 W/m 2 .
The Required Simulink model is shown below:

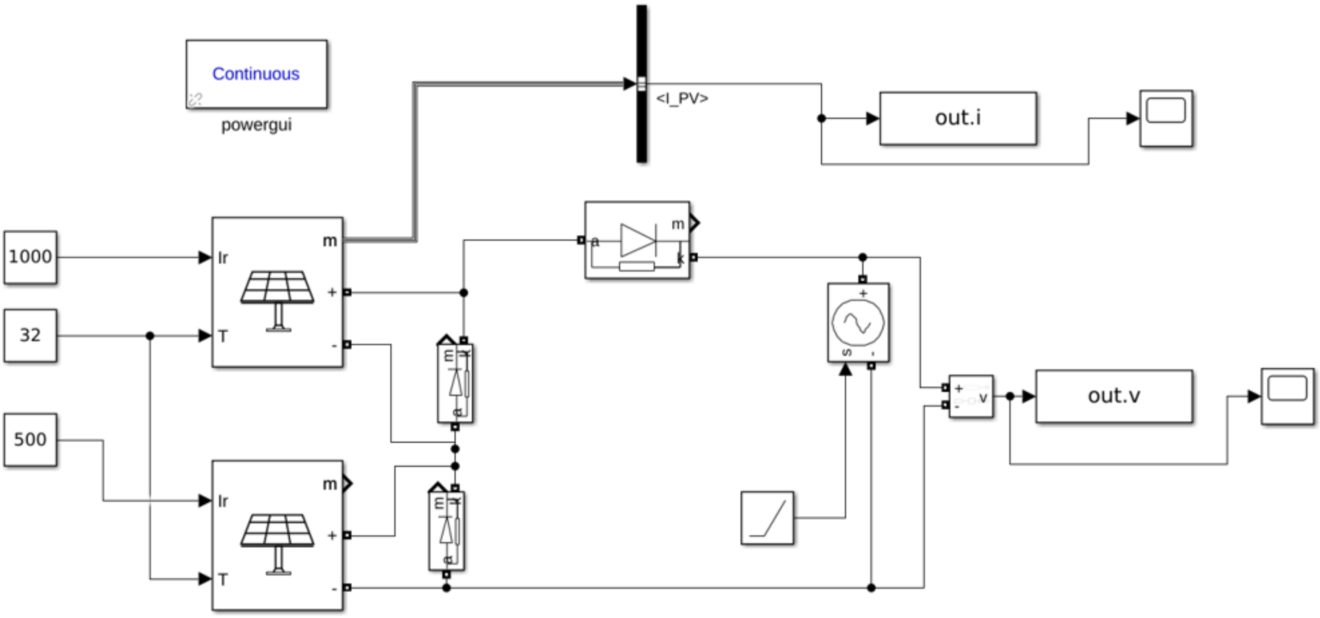


Figure 11: The required simulink model

```
%Ques 10

% Create a new figure
figure;

% Ensure the Simulink model and variables are set correctly
sim('Exp_1.slx');

% Plot data
subplot(2,1,1);
plot(ans.v.Data,ans.i.Data, 'r','LineWidth',1.5);
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Current␣(A)');
title('I-V␣characteristics');

subplot(2,1,2);
plot(ans.v.Data, ans.v.Data.*ans.i.Data, 'r','LineWidth',1.5);
% Add labels and title
xlabel('Voltage␣(V)');
ylabel('Power␣(W)');
title('P-V␣characteristics');
```

The obtained I-V and P-V curves are shown below:

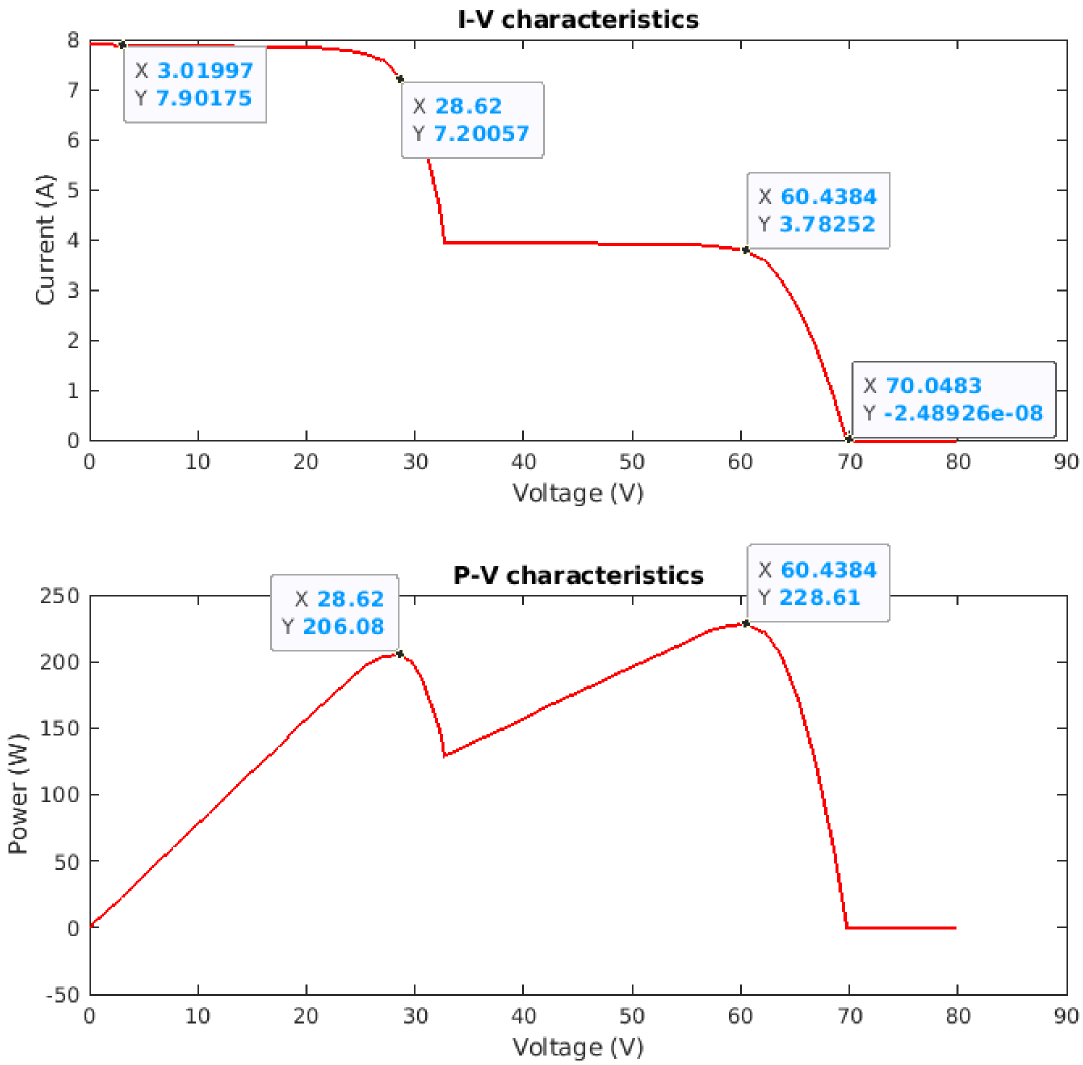


Figure 12: The required I-V and P-V characteristic plots

There are two peaks in the P-V characteristic plot as seen in Figure 12. This can cause problems if there is an MPP Tracking algorithm like the "Perturb and Observe method" because our tracker can settle at the local maxima as seen in Figure 2. Thus, maximum power cannot be extracted if shading effect is involved.

# Inferences

- **Characterizing PV Panels:** The I-V (current-voltage) and P-V (power-voltage) characteristic plots are essential tools for understanding the performance and behavior of a photovoltaic (PV) panel. These plots allow for the detailed characterization of the panel's electrical properties under varying conditions, such as different levels of irradiance and temperature.
- **Parallel Connection of PV Modules:** When PV modules are connected in parallel, the open-circuit voltage of the system remains unchanged and is equal to the open-circuit voltage of an individual module. However, the short-circuit currents from each module combine, resulting in a total short-circuit current that is the sum of the individual module currents. This configuration is particularly useful when higher current output is needed.
- **Series Connection of PV Modules:** In contrast, when PV modules are connected in series, the open-circuit voltages of the individual modules add together, creating a higher total open-circuit voltage for the system. The short-circuit current, however, remains consistent with the short-circuit current of a single module. This series configuration is typically used to achieve higher voltage output.
- **Impact of Shading on PV Performance:** Shading can significantly impair the performance of PV panels by distorting the I-V and P-V characteristic curves. Even partial shading can lead to a reduction in overall power output and may cause hot spots on the panels, potentially leading to permanent damage if bypass diodes are not utilized. Additionally, the presence of shading can introduce multiple local maxima on the P-V curve, which may confuse Maximum Power Point Tracking (MPPT) algorithms, leading to suboptimal power harvesting.
- **Solver Selection for Accurate Plotting:** A variable-step solver was employed in this analysis to ensure the accurate capture of the I-V and P-V characteristic plots. The use of a variable-step solver allows for finer resolution during periods of rapid change in the system, ensuring that the nuances of the PV panel's response to varying conditions are accurately represented in the plots.