

PV sizing and effect of temperature and irradiance

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More exercises – Problem sheet 3

Exercise 1 - Comparing Temperature and Irradiance Effects

A PV module has the following STC characteristics:

- $P_{max,STC} = 400W$
- $V_{oc,STC} = 48.5V$
- $I_{sc,STC} = 10.4A$
- Power temperature coefficient = $-0.38 \text{ \%/}^{\circ}C$
- NOCT = $44^{\circ}C$

Determine:

a) The cell temperature and module power for:

- Case A: $G = 1000W/m^2$, $T_a = 15^{\circ}C$
- Case B: $G = 1000W/m^2$, $T_a = 40^{\circ}C$

b) Repeat for:

- Case C: $G = 600W/m^2$, $T_a = 15^{\circ}C$
- Case D: $G = 600W/m^2$, $T_a = 40^{\circ}C$

c) Rank the four cases according to expected power output.

Learning objective: show that high irradiance does not necessarily imply maximum efficiency because module temperature may become limiting.

Exercise 2 - Estimating Energy Yield During a Heat Wave

A 20 kWp PV array operates during a summer day with the following average conditions:

Period	Irradiance (W/m ²)	Ambient Temperature (°C)
08:00-11:00	700	25
11:00-14:00	950	38
14:00-17:00	800	41

Assume:

- NOCT = 45°C
- Power temperature coefficient = -0.45 %/°C

Determine:

- a) Cell temperature during each period.
- b) Effective output power during each period.
- c) Total energy generated.
- d) Percentage energy loss due to temperature compared with operation at 25°C.

Learning objective: quantify thermal losses over a full day rather than at a single operating point.

Exercise 3 - String Voltage Under Winter and Summer Conditions

A PV module has:

- $V_{oc} = 41.5\text{V}$
- $V_m = 34.2\text{V}$
- Voltage coefficient = $-0.12\text{ V/}^\circ\text{C}$

An inverter has:

- Maximum DC voltage = 1000 V
- MPPT range = $550\text{--}850\text{ V}$

The site experiences ambient temperatures from -15°C to 45°C .

Assume:

- $\text{NOCT} = 46^\circ\text{C}$
- Irradiance = 1000 W/m^2 at maximum operating temperature.

Determine:

- a) Maximum possible module voltage.
- b) Minimum possible MPP voltage.
- c) Maximum allowable modules per string.
- d) Minimum allowable modules per string.
- e) Safe range of string lengths.

Learning objective: understand how temperature simultaneously constrains both inverter startup and maximum-voltage limits.

Exercise 4 - Energy Yield Sensitivity to Climate

Two identical 500 W modules are installed in different climates:

Site A

- Annual average irradiance: 1800 kWh/m²/year
- Average cell temperature: 28°C

Site B

- Annual average irradiance: 2100 kWh/m²/year
- Average cell temperature: 48°C

Module specifications:

- Temperature coefficient: -0.40 %/°C
- Performance ratio excluding temperature losses: 0.80

Determine:

- a) Annual temperature loss for each site.
- b) Annual specific yield (kWh/kWp).
- c) Annual energy production.
- d) Which site provides greater annual energy and why.

Learning objective: illustrate the trade-off between abundant solar resource and high operating temperature.

Exercise 5 - Non-uniform Irradiance and String Performance

A series string contains 10 identical modules.

Under a passing cloud:

- 7 modules receive 1000 W/m^2
- 3 modules receive 400 W/m^2

Assume:

- Current varies linearly with irradiance.
- Voltage remains approximately constant.
- No bypass diodes initially.

Determine:

- a) Current produced by the string.
- b) Relative power reduction compared with uniform irradiance.
- c) Repeat assuming each module is fitted with a bypass diode and the shaded modules are bypassed.
- d) Discuss the advantages and disadvantages of bypass diodes under partial shading.

Learning objective: bridge the concepts of irradiance dependence and array-level performance, preparing students for mismatch-loss analysis.

Solutions

Exercise 1 - Comparing Temperature and Irradiance Effects

Given

- $P_{STC} = 400W$
- $\gamma_P = -0.38\%/^{\circ}C = -0.0038/^{\circ}C$
- $NOCT = 44^{\circ}C$

Cell temperature approximation:

$$T_c = T_a + \frac{NOCT - 20}{800} G$$

Case A

$$G = 1000W/m^2, T_a = 15^{\circ}C$$

$$T_c = 15 + \frac{44 - 20}{800} \times 1000 = 45^{\circ}C$$

Temperature loss:

$$\begin{aligned}\Delta P &= (45 - 25) \times 0.0038 = 7.6\% \\ P &= 400 \times (1 - 0.076) = 370 \text{ W}\end{aligned}$$

Case B

$$G = 1000W/m^2, T_a = 40^{\circ}C$$

$$T_c = 70^{\circ}C$$

Loss:

$$\begin{aligned}(70 - 25) \times 0.0038 &= 17.1\% \\ P &= 400(1 - 0.171) = 332 \text{ W}\end{aligned}$$

Case C

$$G = 600W/m^2, T_a = 15^{\circ}C$$

$$T_c = 15 + \frac{24}{800} \times 600 = 33^{\circ}C$$

Power:

$$P = 400 \times 0.6 \times (1 - 0.0038 \times 8)$$

$$P \approx 233 \text{ W}$$

Case D

$$G = 600 \text{ W/m}^2, T_a = 40^\circ \text{C}$$

$$T_c = 58^\circ \text{C}$$

Power:

$$P = 400 \times 0.6(1 - 0.0038 \times 33)$$

$$P \approx 210 \text{ W}$$

Ranking

$$A > B > C > D$$

Case	Power (W)
A	370
B	332
C	233
D	210

Exercise 2 - Heat-Wave Energy Yield

Period 1

$$G = 700 \text{ W/m}^2$$

$$T_c = 25 + \frac{25}{800} \times 700 = 46.9^\circ \text{C}$$

Temperature loss:

$$0.45\%(46.9 - 25) = 9.86\%$$

$$P = 20 \times 0.7 \times 0.901 = 12.6 \text{ kW}$$

$$E_1 = 12.6 \times 3 = 37.8 \text{ kWh}$$

Period 2

$$G = 950 \text{ W/m}^2$$

$$T_c = 67.7^\circ \text{C}$$

Loss:

$$19.2\%$$

$$P = 15.35 \text{ kW}$$

$$E_2 = 46.1 \text{ kWh}$$

Period 3

$$G = 800 \text{ W/m}^2$$

$$T_c = 66^\circ \text{C}$$

Loss:

$$18.45\%$$

$$P = 13.05 \text{ kW}$$

$$E_3 = 39.2 \text{ kWh}$$

Total Energy

$$E_{tot} = 37.8 + 46.1 + 39.2$$

$$E_{tot} = 123.1 \text{ kWh}$$

Reference Energy Without Thermal Losses

$$E_{ideal} = (14 + 19 + 16) \times 3 = 147 \text{ kWh}$$

Thermal Loss

$$L_T = \frac{147 - 123.1}{147} \times 100$$

$$L_T \approx 16.3\%$$

Exercise 3 - String Voltage Limits

Maximum Voltage

Lowest temperature:

$$T = -15^{\circ}\text{C}$$

Difference from STC:

$$\Delta T = -40^{\circ}\text{C}$$

$$V_{oc} = 41.5 + 0.12 \times 40$$

$$V_{oc} = 46.3\text{V}$$

Maximum modules:

$$N_{max} = \frac{1000}{46.3}$$

$$N_{max} = 21$$

Minimum MPP Voltage

At 45°C ambient:

$$T_c = 45 + \frac{26}{800} \times 1000 = 77.5^{\circ}\text{C}$$

Voltage reduction:

$$52.5 \times 0.12 = 6.3\text{V}$$

$$V_m = 34.2 - 6.3 = 27.9\text{V}$$

MPPT Lower Limit

$$N_{min} = \frac{550}{27.9} = 19.7$$

$$N_{min} = 20$$

Safe Design Range

$$20 \leq N \leq 21$$

The designer may adopt:

- 20 modules/string
- 21 modules/string

depending on inverter operating strategy.

Exercise 4 - Climate Comparison

Site A

Temperature loss:

$$L_A = 0.4\%(28 - 25) = 1.2\%$$

Effective PR:

$$PR_A = 0.80(1 - 0.012) = 0.790$$

Annual yield:

$$Y_A = 1800 \times 0.790 = 1422$$

1422 kWh/kWp

Site B

Temperature loss:

$$L_B = 0.4\%(48 - 25) = 9.2\%$$

Effective PR:

$$PR_B = 0.80(1 - 0.092) = 0.726$$

Annual yield:

$$Y_B = 2100 \times 0.726 = 1525$$

1525 kWh/kWp

Comparison

Site	Yield (kWh/kWp)
A	1422
B	1525

Although Site B operates significantly hotter, the larger solar resource compensates for the increased temperature losses.

Exercise 5 - Partial Shading

Assume module current at STC:

$$I_{mp} = 10A$$

Without Bypass Diodes

For shaded modules:

$$I_{sh} = 10 \times \frac{400}{1000} = 4A$$

Series string current:

$$I_{string} = 4A$$

Voltage approximately unchanged:

$$V_{string} = 10V_m$$

Power:

$$P = 10V_m(4)$$

Relative power:

$$\frac{4}{10} = 40\%$$

Power loss:

$$60\%$$

With Bypass Diodes

Three shaded modules bypassed.

Remaining modules:

$$N = 7$$

Current:

$$10A$$

Power:

$$P = 7V_m(10)$$

Relative power:

70%

Power loss:

30%

Discussion

Benefits:

- Reduced mismatch loss
- Avoids severe power limitation
- Reduces hotspot risk

Drawbacks:

- Loss of voltage
- Reduced energy production
- Additional component reliability considerations