

PHOTOVOLTAICS

You have 60 minutes to solve this test. You may answer in English or Portuguese. Assume reasonable data for any relevant parameters that are not presented.

1. Consider a solar car with 4m² of solar panels set on the horizontal plane.
 - 1.1. Estimate its range both in winter and summer considering the average insolation in Lisbon (assume 0.10 kWh/km and 25% PV efficiency). [3]
 - 1.2. If the solar battery is Li-ion (150Wh/kg) determine the weight of the battery for 3 days autonomy. [3]
 - 1.3. How these results impact on the feasibility of solar mobility? Discuss its main benefits and challenges. [2]

Table 1. Solar irradiation for Lisbon, (Wh/m²/day) for the horizontal and optimally inclined plane.

Month	Horizontal plane	Optimally inclined plane
Jan	2180	3510
Feb	3210	4670
Mar	4680	5750
Apr	5640	6040
May	6680	6450
Jun	7450	6790
Jul	7620	7100
Aug	6880	7110
Sep	5400	6460
Oct	3800	5230
Nov	2510	4000
Dec	1950	3350
Year	4840	5540

2. A 2.7kWp PV roof system in Lisbon is assembled with PV modules as described in table 2, at optimum inclination, connected to the inverter presented in Table 3.

Table 2. Module specifications for STC.

P _{max}	150 W
V _{oc}	42.8 V
I _{sc}	4.75 A
V _m	34 V
I _m	4.45 A
Efficiency	15%
NOCT	48 °C
Voltage T coef.	-0.33 %/°C
Cells in series	72

Table 3. Inverter specifications.

P _{nom}	2.8 KW
P _{max}	3 KW for 30 mins
V _{in}	0 - 260 V

1.
 - 2.1. Determine the expected annual electricity generation. [2]
 - 2.2. Estimate the total area of the modules. [2]
 - 2.3. Considering the inverter of Table 3, discuss the required configuration of the modules' array. [4] 34
 - 2.4. If the modules were to be mounted on a 2-axis tracker would this inverter be adequate? Why? [3] 2
 - 2.5. If the modules were used on a tracker with a set of mirrors that increase the concentration by a factor of 3, what would be their I_{sc}, V_{oc} output power and efficiency (assume R_s=2Ω)? [1] 2

$$K = 1.38 \times 10^{-23} \text{ kg/s}^2/\text{K}$$

$$q = 1.6 \times 10^{-19} \text{ C}$$

$$I = I_L - I_0 \left[\exp \left(\frac{qV}{nkT} \right) - 1 \right]$$

Resolução teste ENERGIA SOLAR

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1. solar car $4m^2$

- 1.1. Summer (July) 7620 Wh/m²/day
 Winter (Dec) 1950 Wh/m²/day

$$4 \times \frac{7.620 \times 0.25}{0.1} \frac{\text{kWh}}{\text{m}^2 \text{day}} \frac{\text{km}}{\text{kWh}} \text{m}^2 = 76.2 \text{ km/day}$$

$$4 \times \frac{1.950 \times 0.25}{0.1} = 19.5 \text{ km/day}$$

The range is therefore 20 to 76 km/day, in winter and summer, respectively.

1.2. 3 days autonomy.
 daily range 20 km

$$\left\{ \begin{array}{l} \rightarrow 60 \text{ km} \times 0.1 \frac{\text{kWh}}{\text{km}} \\ = 6 \text{ kWh} \times \frac{1}{\text{DoD}} \end{array} \right.$$

this is the required capacity of the battery to guarantee 3 days autonomy.

Assuming DoD = 80% $\rightarrow C = 7.5 \text{ kWh}$

$$W = \frac{7.5 \text{ kWh}}{0.15 \text{ kWh/kg}} = \underline{\underline{50 \text{ kg}}}$$

1.3. These results show that solar panels onboard EVehicles in a city like Lisbon can only guarantee limited ranges, particularly in winter. ($< 20\text{km/day}$) and therefore PEV should be combined with pluggin charging. (2)

For applications where these limited ranges are ok, the weight of the battery (50kg) is not a serious technical challenge.

2. 2.7 kWp

(3)

2.1 $E_d = 5540 \text{ Wh/m}^2/\text{day}$

(table 1, optimally inclined surface)

$$\frac{E_d}{1000 \text{ W/m}^2} = 5.54 \frac{\text{h}}{\text{day}}$$

therefore, on average one has $E_{PV} = 2.7 \times 5.54 \frac{\text{kWh}}{\text{day}}$

and for the year:

$$E_{PV} = 2.7 \times 5.54 \times 365 = \underline{5460 \text{ kWh}}$$

2.2 $\eta = 15\% \rightarrow P = 150 \frac{\text{Wp}}{\text{m}^2}$ (each module is 1 m^2 !!)

$$P_{inc} = 1000 \text{ W/m}^2$$

$$A = \frac{2.7}{0.15} = \underline{18 \text{ m}^2} \quad (18 \text{ modules})$$

2.3 $P_{nom} = 2.8 \text{ kW}$ (or 3.0 kW for 30 mins)

$V_{in} = 0 - 260 \text{ V}$

we need to check how many modules in series we can accommodate with this inverter

$\text{max } V = V_{oc} |_{T = -10^{\circ}\text{C}}$

$V_{oc}(NOCT) = 42.8 \text{ V}$

$\Delta T = 25 - (-10) = 35^{\circ}\text{C}$

$\Delta V = 0.33\% \times 42.8 \times \Delta T = 4.9 \text{ V}$

$\text{max } V = 42.8 + 4.9 = 47.7 \text{ V}$

$\frac{260}{47.7} = 5.4$ and therefore we cannot have more than 5 modules per string

we want the same number of modules in all strings and therefore the optimal solution is 6 strings with 3 modules each

2.4. If modules on 2-axis tracking we get higher PV power more often and therefore the nominal power of the inverter should be slightly higher (+5%) than the PV power.

$$\frac{2.8 \text{ kW}}{2.7 \text{ kW}} \sim 1.04 \text{ is } 4\% \text{ higher \& it is ok.}$$

2.5 $x = 3$

$$I_{sc}^x = x \cdot I_{sc}^1 = 3 \times 4.75 = \underline{14.25 \text{ A}}$$

$$V_{oc}^x = V_{oc}^1 \cdot \ln x = 42.8 \times 1.098 = \underline{47 \text{ V}}$$

$$P_{PV}^x = x \cdot P_{PV}^1 \ln x - \underbrace{(P_{loss}^x)}_{\rightarrow R_s (I_{sc}^x)^2}$$

$$= 3 \cdot 150 \cdot \ln 3 - 2 \times 14.25^2 = \underline{88 \text{ W}}$$

$$\eta = \frac{88}{1000 \times 3} = 3\% \ll 15\%$$

These modules are not suitable for concentration because they have large R_s ! (R_s should be below 0.2Ω for higher efficiency)