SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

Renewable Energy: Exercise 8

In this exercise you will use characteristics of PV to calculate their efficiency and estimate their electricity production.

Figure 1: Solar impulse airplane flying over EPFL campus

Data Solar Impulse 1
Wingspan/Length/Height 63.40 m / 21.85 m / 6.40 m
Weight 1'600 Kg
PV 11'628 monocrystalline Si cells; total area: 200 m^2
45 kWp (on PV panels)
Batteries Li-polymer 450 kg (weight); 4 x 21 kWh
Engines 4 x 10 HP electric engines (1 HP = 745.7 W) max
Optimal consumption: 6 kW
Speed 70 km/h cruise speed; average 50 km/h
Flight altitude 8'500 – 12'000 m
Scheduled endurance up to 36h ; record flight : 1'541 km in 18h20

Data Solar Impulse 2
Weight 2 300 Kg
Motor power 4 x 17.4 HP electric engines max
PV 17 248 monocrystalline Si cells; total area: 270 m^2
66 kWp
Batteries Li-ion 633 kg (weight); 4 x 41 kWh
Speed cruise speed 90 km/h @day / 60 km/h @night

average 70 km/h
Flight altitude 8’500 – 12’000 m
Planned stops for world trip 12

1. First estimations
   (a) Estimate the maximal daily electrical energy that can be harvested on March the 29^{th} at latitude 30 °N in the best conditions. Use the website: sunearthtools.com and a location at 30 °N (like Agadir in Marocco)
   Assumptions:
      - The solar irradiance as a function of air mass and altitude can be experimentally determined (adapted from PVeducation and is given by: $I = 1.1 \cdot I_0 \cdot \left((1 - h/15)\, 0.7^{AM^{0.678}} + h/15 \right)$ where $I_0 = 1.353$ kW/m^2, h is the altitude in km (assumed as 10km) and the factor 1.1 is derived assuming that the diffuse component is 10% of the direct component.
      - The air mass (AM) is given by Kasten and Young (1989): $AM = \frac{1}{cos(z) + 0.50572 \cdot (96.07995 - z)^{-1.6364}}$ where z is the zenith angle that varies with time (use a zenith angle for each 10min using the website sunearthtools.com)

   (b) For both Solar Impulse 1 and 2:
      i. Estimate the maximum PV efficiency. Consider a zenith angle of 0°, an altitude of 12 km and an albedo of only 10% (12 km altitude!).
      ii. Estimate the propulsion efficiency (PV to engine).

   (c) Evaluate SI1’s record flight and endurance. Assume PV to battery storage efficiency 85%

   (d) Evaluate SI2’s feasibility of a world trip in 12 stops (notably the Pacific or Atlantic crossing with 5’000 km non-stop trips). Assume same optimal engine consumption than SI-1.

   (e) Estimate the specific consumption (kWh/km).

2. Calculate the theoretical efficiency of a solar cell based on its band gap. Plot the efficiency as a function of bandgap. Use matlab or a similar tool.
   Hint: Use the black body emissive power, $e_{\lambda b}(\lambda, T)$, given in the lecture slides. The solar cell efficiency depending on the bandgap is given by: $\eta = \frac{\int_0^{\lambda_{gap}} \frac{E_{gap}}{E_\lambda} e_{\lambda b} d\lambda}{\int_0^{\infty} e_{\lambda b} d\lambda}$

3. A given type of solar cell delivers 0.2 W/cm^2 at an efficiency of 20% and an irradiance at that moment of 950 W/m^2. How is this possible?

4. A solar cell has a short circuit current density of 33 mA/cm^2 and a open circuit voltage of 0.55. Its fill factor is 0.7.

   (a) Estimate the maximum power delivered by the cell

   (b) Using the idealized diode equation with a shunt resistance of infinity and an unknown series resistance, what is the series resistance? Plot the IV-curve and the power curve. To simplify the problem assume a dark current density of $i_0 = 10^{-8}$ mA/cm^2 and a light generation current of $i_L = i_{sc} + i_0$.
   Hint: Solve the diode equation iteratively using Matlab.

5. Consider average annual solar irradiance in Switzerland, 1'250 kWh/yr/m^2, on a horizontal surface.

   (a) We have photovoltaic cells on the roof (10 m^2, total chain efficiency 12%). The roof tilt improves the captured irradiation on an annual basis by 10%. How does the generated electricity compare to annual needs of 5'000 kWh$_{el}$ (for a family)?

   (b) We have thermal absorbers as well (6 m^2, annual efficiency 30%). How does the collected heat compare to total annual heat needs of 20'000 kWh (for a family) which split up as ca. 5/6 for space heating and 1/6 hot water heating?