Tutorial problems for "Solar Energy" lecture (23745), WS 2020/2021

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Tutorial Questions #4: Tandem cells, PV modules

1. **Tandem cell J_{sc} in solar simulator (adapted from: exercise 13.6 of textbook 'Solar Energy')**
In this exercise we study thin-film silicon tandem solar cells and a simple solar simulator. The spectral irradiance $I_{e\lambda}$ of the solar simulator is shown in Figure 1a. It is given as

$$I_{e\lambda} = +\,7.5 \times 10^{15}\ \mathrm{Wm^{-2}m^{-2}} \times \lambda \; - \; 2.25 \times 10^{9}\ \mathrm{Wm^{-2}m^{-1}}$$
for 300 nm < λ < 500 nm,
$$I_{e\lambda} = -\,1.5 \times 10^{15}\ \mathrm{Wm^{-2}m^{-2}} \times \lambda \; + \; 2.25 \times 10^{9}\ \mathrm{Wm^{-2}m^{-1}}$$
for 500 nm < λ < 1500 nm,

where the wavelength λ is expressed in metres. The EQE of the tandem cell with junction A and junction B under short circuited (V = 0V) conditions is shown in Figure 1b.

(a) Calculate the total irradiance of the solar simulator.
(b) What is the photon flux of the solar simulator?
(c) Which junction acts like a top cell in the tandem cell? A or B?
(d) What is the bandgap of the absorber layer of junction A?
(e) Calculate the short circuit current density J_{sc} of junction A if the solar cell is measured under the spectrum provided by the solar simulator.
(f) Junction B has a different absorber layer than junction A. Above its bandgap, the solar cell B has an EQE of 0.60 that remains constant. Calculate the short-circuit current density Jsc of junction B if the solar cell is measured under the solar simulator.

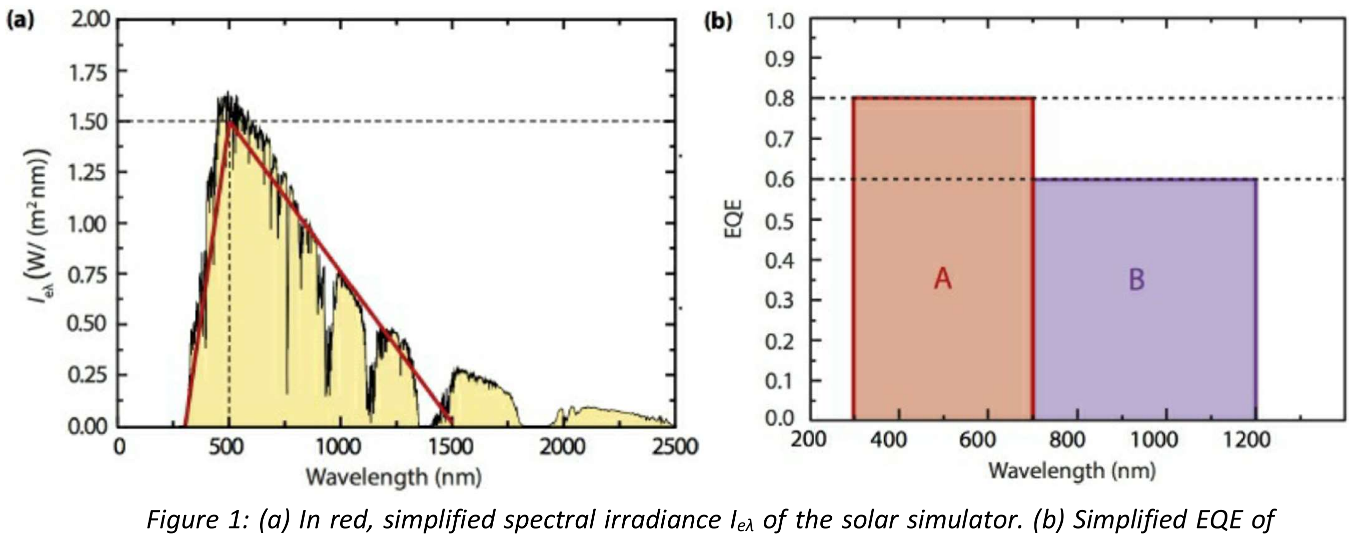

Figure 1: (a) In red, simplified spectral irradiance $I_{e\lambda}$ of the solar simulator. (b) Simplified EQE of the tandem solar cell.

2. **PV module (adapted from: exercise 15.1 of textbook 'Solar Energy')**
   We have identical crystalline silicon solar cells available, with a short circuit current of 4 A and an open circuit voltage of 0.6 V at STC.
   These cells are used to make a PV module with 54 cells connected in series.

   (a) What is the open circuit voltage of the module at STC? Assume that the interconnection losses are negligible.
   (b) What is the short circuit current of the module at STC?
   (c) Assume that the module does not have any bypass diodes. If the module is partially shaded and one of the cells is only able to produce 2 A, what will be the new short circuit current under these conditions?

3. **Shading in PV modules (adapted from: exercise 15.5 of textbook 'Solar Energy')**
   Consider a PV module made up of 40 cells in series, of which 20 solar cells are shaded 30% of their area and 10 solar cells are shaded 60% of their area. Each individual cell has a V_{oc} of 0.68 V and I_{sc} of 6 A. Assume that each solar cell in the module has its own bypass diode with a constant forward voltage of 10 mV. Also assume that there is no leakage current from the bypass diodes and the module temperature is 25 °C.

   (a) Draw I-V curves of this module. Indicate specific (x,y) intercepts and necessary numbers in the curves.
   (b) Calculate the total power loss from the bypass diodes.
   (c) For the same module and conditions as above, if the breakdown voltage of a shaded solar cell is 12 V, what will be the maximum number of solar cells that can be connected in series with one bypass diode?

4. **Maximum power point (MPP) tracking (adapted from: exercise 19.5 of textbook 'Solar Energy')**
   Consider that an MPPT based on the perturb and observe algorithm is connected to a PV module with the P-V curve shown in the Figure 2. The MPPT has two different modes of operation: coarse and fine. A coarse adjustment corresponds to a voltage change of ±5 V, while a fine adjustment corresponds to a voltage change of ±1 V.
   If the MPPT has taken a step such that a change in voltage has led to an increase in power, then the next step is a coarse adjustment in the same direction as the previous step.
   On the other hand, if the MPPT has taken a step such that a change in voltage has led to a decrease in power, then the next step is a fine adjustment in the opposite direction to the previous step.
   Consider that the module is currently operating at point A, corresponding to a voltage of 8V, and that the MPPT is just about to take a coarse step by increasing the voltage. If the irradiance and temperature conditions are maintained, i.e. the P-V curve remains the same, how many steps will the MPPT take before it reaches the MPP?

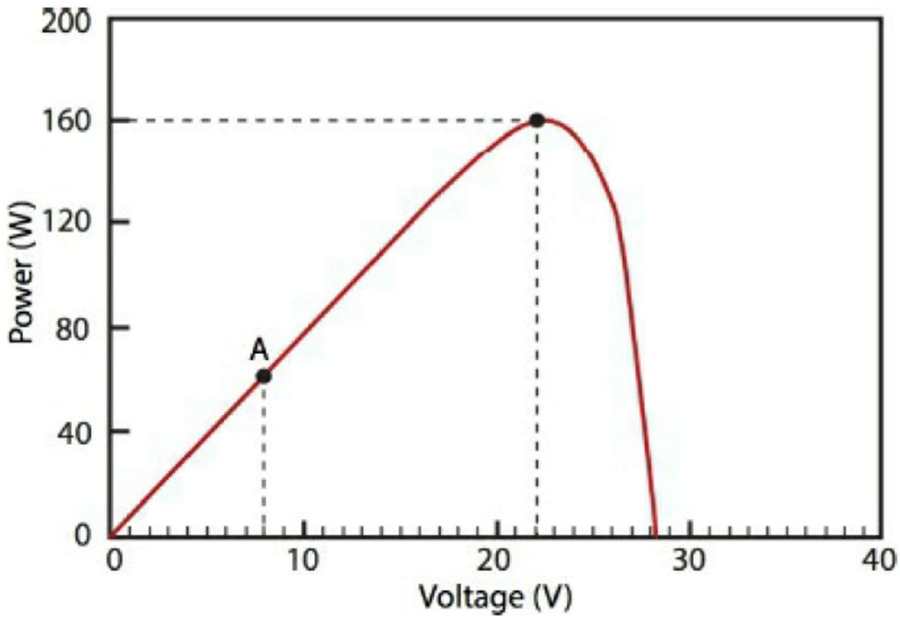

Figure 2: Power-Voltage curve of a PV module. In the exercise, MPPT starts from point 'A'.

5. Battery (adapted from: exercise 19.12 of textbook 'Solar Energy')

Consider a lead acid battery with 100 Ah capacity and a rated voltage of 12 V.

(a) What is the total capacity of energy in watt-hours that can be stored in the battery?
(b) Assume that the battery is at 40% of its rated capacity. The battery is now charging at a C-rate of 2C. What is the charging current that is going into the battery?
(c) How much time will it take for the battery to increase the SoC from 40% to 100%, assuming a constant C-rate of 2C? You may assume a linear rate of charging.
(d) If the voltaic efficiency of the battery is 90%, and the coulombic efficiency of the battery is 90%, how high is the round-trip efficiency of storage?