ECE 333 Green Electric Energy

Fall 2017
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Room 4052 ECEB

Homework 6

Quiz Date: Tuesday, November 28, 2017 during class

The quiz is based on the following material: Lecture 12, Lecture 13, Lecture 14, and the problems in Homework 6.

Problem 1: 6.1, 6.2 (skip part c), 6.3 (skip part c), 6.6, and 6.8 from the textbook.

6.1 A clean, 1 m^2, 15% efficient module (STC), has its own 90% efficient inverter. Its NOCT is 45°C and its rated power degrades by 0.5%/°C above the 25°C STC.

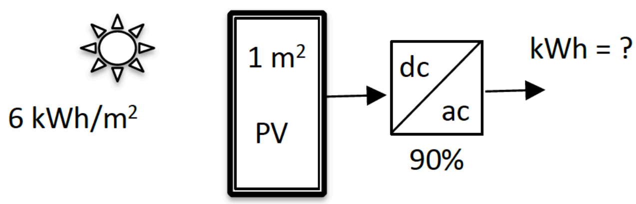


Figure P 6.1

a. What is its standard test condition (STC) rated power of the module?

b. For a day with 6 kWh/m^2 of insolation, find the kWh that it would deliver if it operates at its NOCT temperature. Assume the only deratings are due to temperature and inverter efficiency.

SOLN:

a. The STC output of this module $P_{dc,STC}$ = 0.15 x 1 m^2 x 1 kW/m^2 = 0.15 kW

b. Operating at its NOCT temperature,

Temp derating = [1 - 0.5%/°C x (45-25)°C] = 0.90

Inverter derating = 0.90

Total derating = 0.90 x 0.90 = 0.81

Energy = 0.15 kW x 0.81 x 6 h/d = 0.729 kWh/day

6.2 NREL's PVWATTS website predicts that 5.56 kWh/m^2-day of insolation on a south-facing, 40^o tilt array in Boulder, CO, will deliver 1459 kWh/yr of ac energy per $kW_{dc,STC}$ of PV modules.

a. Using the "peak-hours" approach to performance estimation, what overall derate factor (including temperature effects) would yield the same annual energy delivered?

SOLN:

$$\text{kWh/yr} = P_{dc,STC} \text{ x Overall Derate x (h/daypeaksun) x 365d/yr}$$

$$\text{Overall Derate} = \frac{1459 \text{ kWh/yr}}{1 \text{ kW x } 5.56 \text{ h/day x } 365\text{d/yr}} = 0.7189$$

b. Since PVWATTS' derate value of 0.77 includes everything but temperature impacts, what temperature induced derating needs to be included to make the peak-hours approach predict the same annual energy?

(Overall Derate = PVWATTS Derate x Temperature Derate).

SOLN:

$$\text{kWh/yr} = P_{dc,STC} \text{ x Overall Derate x (h/daypeaksun) x 365d/yr}$$

$$\text{Boulder Overall Derate} = \frac{1459 \text{ kWh/yr}}{1 \text{ kW x } 5.56 \text{ h/day x } 365\text{d/yr}} = 0.7189$$

$$\text{Temperature Derate} = \frac{\text{Overall Derate}}{\text{Default } 0.77} = \frac{0.7189}{0.77} = 0.9337$$

which is a 1 - 0.9337 = 0.066 = 6.6% loss due to temperature.

6.3 You are to size a grid-connected PV system to deliver 4000 kWh/yr in a location characterized by 5.5 kWh/m^2-day of insolation on the array.

a. Find the dc, STC rated power of the modules assuming a 0.72 derate factor.

SOLN:

$$\text{kWh/yr} = P_R(\text{kW}) \text{ x } (\text{h/day full sun}) \text{x } 365 \text{ day/yr x Derate}$$

$$P_R(\text{kW}) = \frac{4000 \text{ kWh/yr}}{5.5 \text{ h/day x } 365 \text{ day/yr x } 0.72} = 2.77 \text{ kW}$$

b. Find the PV collector area required if, under standard test conditions, these are 18%-efficient modules.

SOLN:

$$P_{dc,STC} = A\left(m^2\right)\cdot\frac{1\text{ kW}}{m^2}\cdot\eta$$

$$A = \frac{2.77\text{ kW}}{1\text{ kW/m}^2\text{ x }0.18} = 15.39\text{ m}^2$$

6.6 A grid-connected PV array consisting of sixteen 150-W modules can be arranged in a number of series and parallel combinations: (16S, 1P), (8S, 2P), (4S, 4P), (2S, 8P), (1S, 16P). The array delivers power to a 2500-W inverter. The key characteristics of modules and inverter are given below.

INVERTER			MODULE	
Maximum AC power	2500 W		Rated power Pdc,STC	150 W
Input voltage range for MPP	250 V - 550 V		Voltage at MPP	34 V
Maximum input voltage	600 V		Open-circuit voltage	43.4 V
Maximum input current	11 Amp		Current at MPP	4.40 A
			Short-circuit current	4.8 A

Table P 6.6

Using the input voltage range of the inverter maximum power point tracker and the maximum input voltage of the inverter as design constraints, what

series/parallel combination of modules would best match the PVs to the inverter? Check the result to see whether the inverter maximum input current is satisfied. For this simple check, you don't need to worry about temperatures.

SOLN: The PV modules have V_{OC} = 43.4V and V_R = 34V. The SB2500 has an MPPT range of 250-550V and a maximum input voltage of 600V.

(16S, 1P) has V_{OC} = 16 x 43.4 = 694 V which is too high X

(8S, 2P) has V_{OC} = 347 V, which is OK. V_R = 8 x 34 = 272 V which is OK

(4S, 4P) has V_R = 4 x 34 = 136 V which is too low X

(2S, 8P) and (1S, 16P) also are below the MPPT range X

Therefore (8S, 2P) is the best arrangement for the array. Checking its current 2P means 9.6A max, which fits under the 11A max. So it is fine with current.

6.8 You have four PV modules with identical *I-V* curves (I_{SC} = 1 A, V_{OC} = 20 V) as shown. There are three ways you could wire them up to deliver power to a dc-motor (which acts like a 10-Ω load):

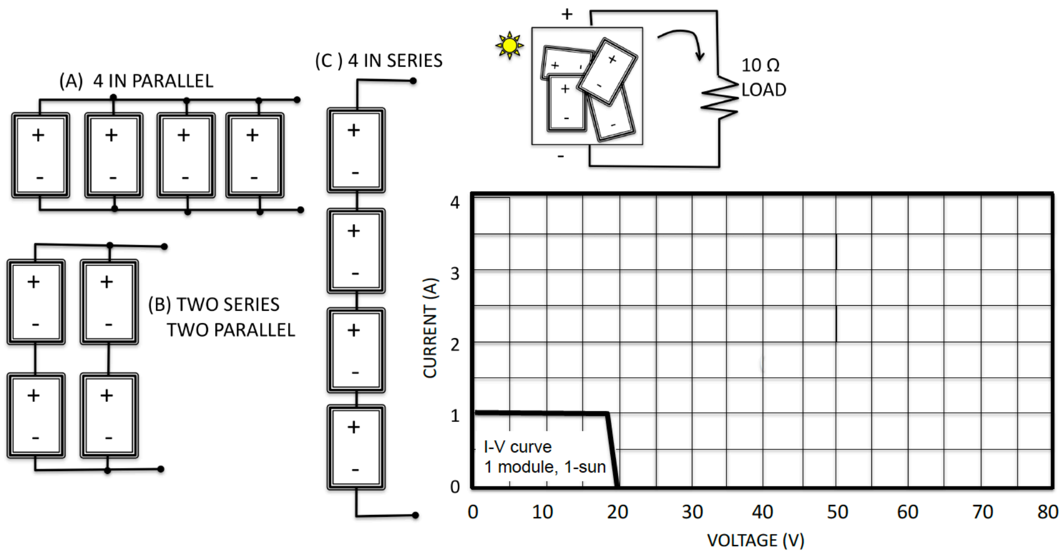


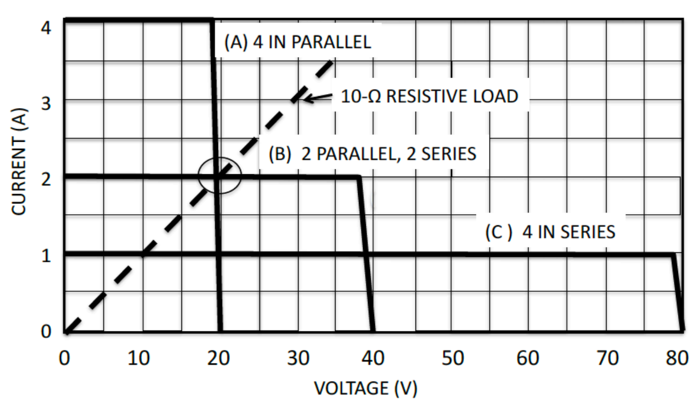
Figure P 6.8

Draw the I-V curves for all three combinations on the same graph. Which wiring system would be best? Briefly explain your answer.

SOLN: (A) 4 IN PARALLEL IS BEST

Why: At 1 sun A and B look to be about equal… each delivering 2A at about 20V, with perhaps a slight edge for B since at higher temperatures it will be less affected by the drop in Voc. B also looks slightly better at 1-sun given the tiny bit of curvature around the knee.

However: Over the course of a day, A is far better since at less than 1-sun A is not affected until you get less than 0.5 Sun (500W/m2) of insolation, and by then B is really terrible.



Problem 2:

a. Calculate the extraterrestrial solar irradiation on January 15 and July 31 by using the approximation on Slide 21 of Lecture 12. State all the units.

b. State the reason of why, in the Northern hemisphere, the extraterrestrial solar irradiance is higher on a winter day than it is on a summer day.

c. State three factors that causes the variation of solar position in the sky.

Solution:

a. $i_0|_d = 1{,}367\ [1 + 0.034\cos(2\pi\frac{d}{365})]$

For January 15, d=15. $i_0|_{15} = 1{,}367\ \left[1 + 0.034\cos\left(2\pi\frac{15}{365}\right)\right] = 1{,}412\ W/m^2$

For July 31, d=212. $i_0|_{212} = 1{,}367\ \left[1 + 0.034\cos\left(2\pi\frac{212}{365}\right)\right] = 1{,}326\ W/m^2$

b. We observe that in the Northern hemisphere, the extraterrestrial solar irradiation is higher on a cold winter day than on a hot summer day. This phenomenon results from the fact that the sunlight enters into the atmosphere with different incident angles; these angles impact greatly the fraction of extraterrestrial solar irradiation received on the earth's surface at different times of the year.

c.

- the specific geographic location of interest;
- the time of day due to the earth's rotation around its tilted axis;
- the day of the year that the earth is on its orbital revolution around the sun

Problem 3: Approximate the total direct beam radiation at solar noon on a clear November 15 in Chicago at latitude l=0.731 *radians*.

Solution:

$d = 319$ for November 15.

The apparent solar irradiation is given by the formula:

$a|_d = 1{,}160 \ + 75\, x \sin\,(2\pi \frac{(d-275)}{365})]$. For $d = 319$:

$a|_{319} = 1{,}160 \ + 75\, x \sin\,(2\pi \frac{(319-275)}{365})] = 1{,}211.53\, W/m^2$.

The solar declination angle is computed by the formula:

$\delta|_d = 0.41\, x \sin\,(2\pi \frac{(d-81)}{365})]$. For $d = 319$

$$\delta|_{319} = 0.41\, x \sin\,(2\pi \frac{(319-81)}{365})] = \ -0.335\, radians$$

The altitude angle at solar noon is given by the formula:

$\beta(0)|_d = \frac{\pi}{2} - l + \ \delta|_d$. For $d = 319$

$$\beta(0)|_{319} = \frac{\pi}{2} - 0.731 + \ (-0.335\,) = \ 0.505\, radians.$$

The air mass ratio is given by the formula:

$r(h)|_d = \sqrt{[708 \sin\,(\beta(0)|_d)]^2 + 1{,}417} \ - \ 708 \sin\,(\beta(0)|_d)$. For $d = 319$

$$r(h)|_{319} = \sqrt{[708\, x \sin\,(0.505)]^2 + 1{,}417} - \ 708\, x \sin(0.505) = 2.062$$

The optical depth is given by the formula:

$k|_d = 0.174 + 0.035 \sin\,(2\pi \frac{(d-100)}{365})]$. For $d = 319$.

$$k|_{319} = 0.174 + 0.035 \sin\,(2\pi \frac{(319-100)}{365})] = 0.149$$

The clear-sky direct beam radiation is given by the formula:

$i_b(h)|_d = \ a|_d\, e^{-k|_d r(h)|_d}$. For $d = 319$

$$i_b(h)|_{319} = (1{,}211.53)e^{-(0.149)(2.062)} = 891.05\, W/m^2.$$