Photovoltaic Systems II

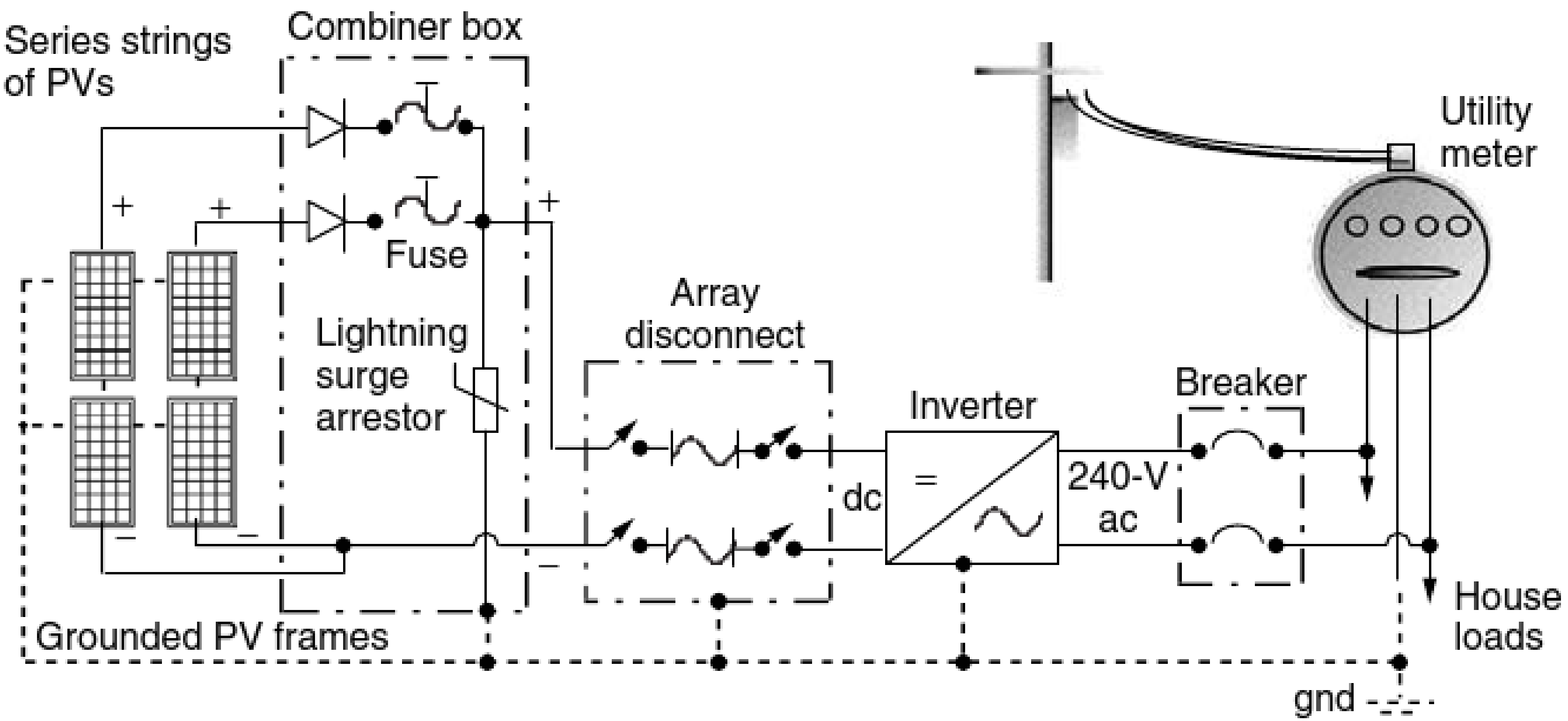
EE 446/646

Fall 2013

Components of a grid-connected residential PV system (net meter)

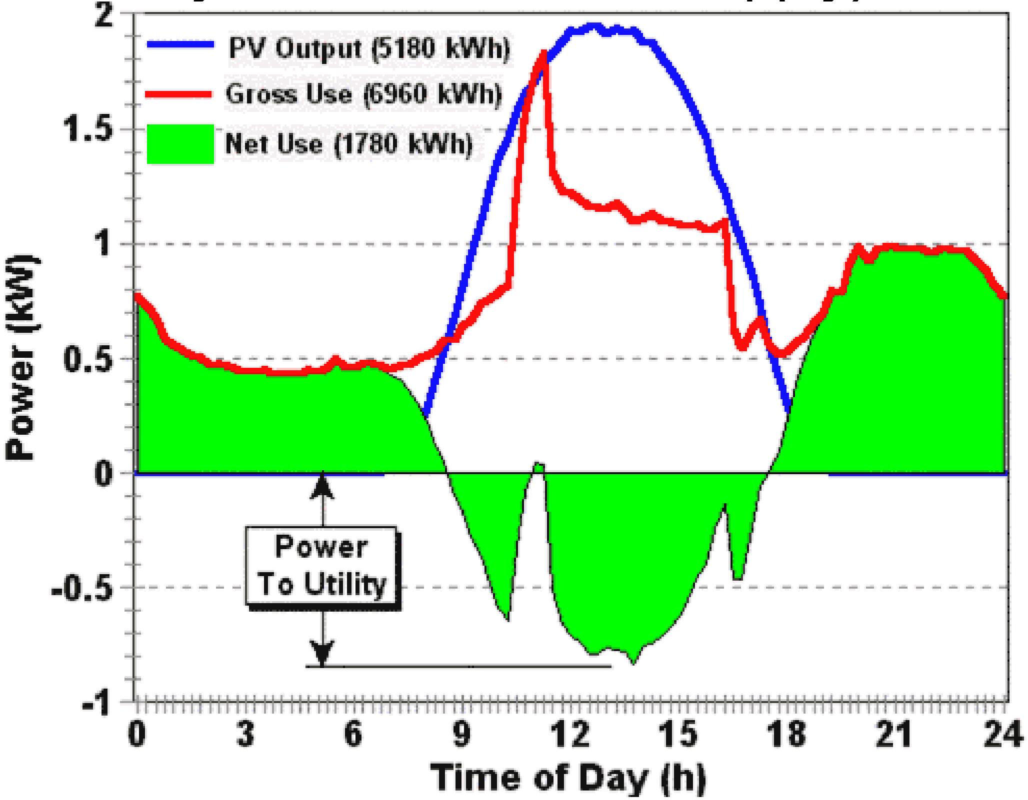
The inverter contains:

- Ground Fault Circuit Interrupter (GFCI)
- MPPT and Circuitry to disconnect the PV from the grid in case of power loss (built within the inverter).



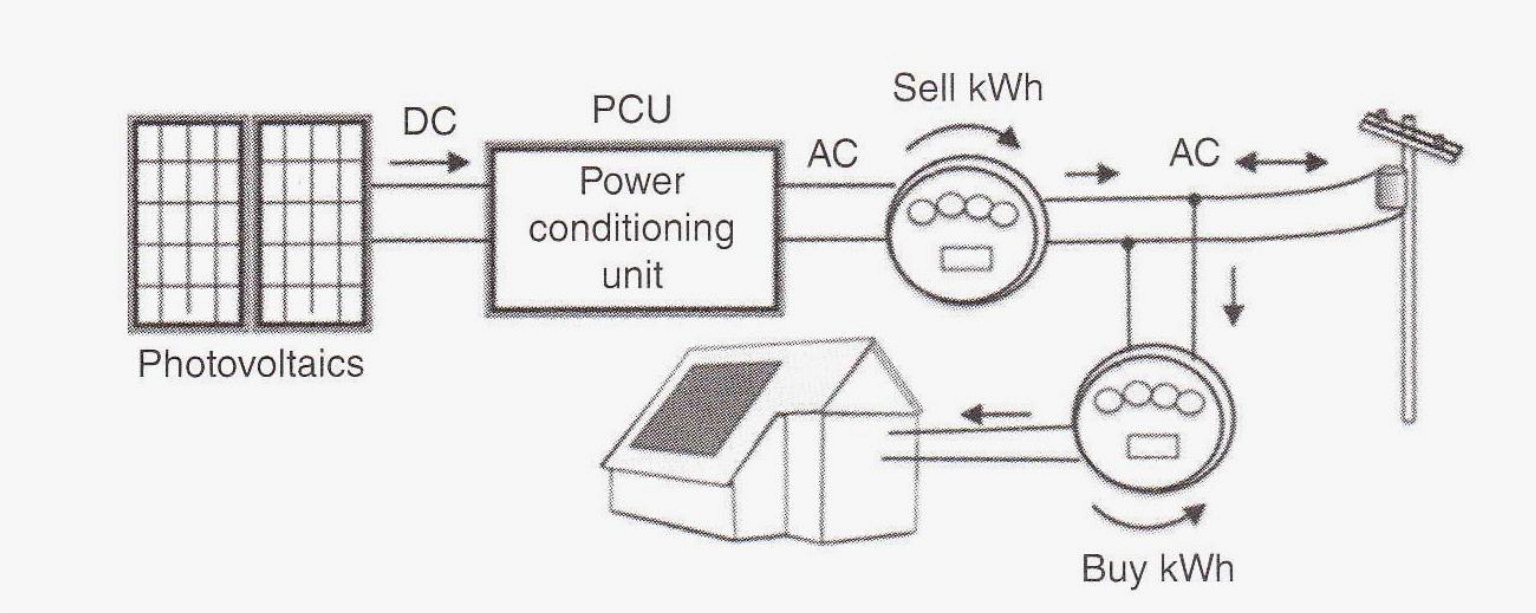
Interfacing with the utility

- Whenever the PV system delivers more power than the local demand, the electric meter runs backwards, building up a credit.
- When demand exceeds that supplied by the PV, the grid provides supplementary power. This arrangement is called *net metering* (the customer's monthly electric bill is only for that net amount of energy that the PV system is unable to supply).



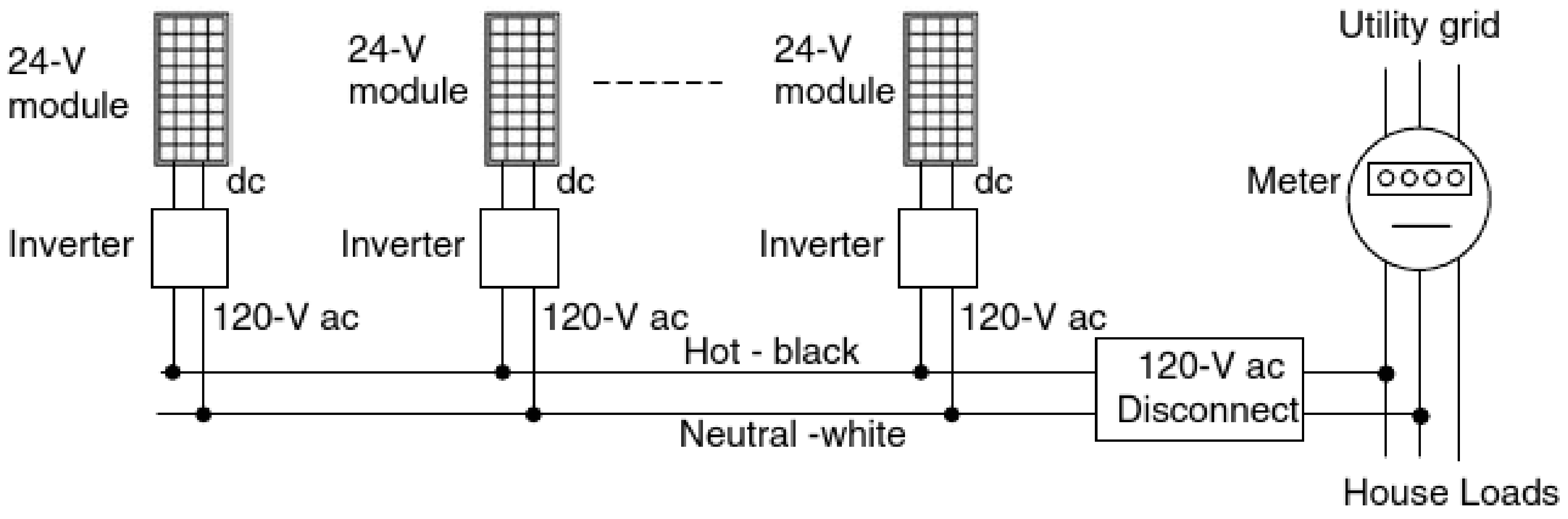
Components of a grid-connected Residential PV system (with two meters)

- A two-meter system allows a feed-in tariff to provide separate rates for power generated by the PV system and power used by the customer.



Option of using micro-inverters

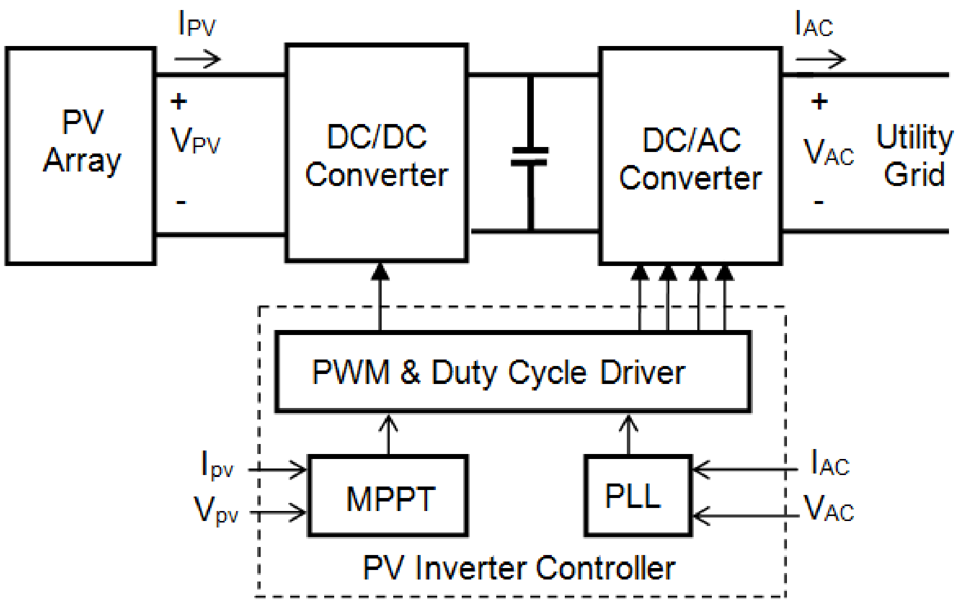
- An alternative approach is based on each PV module having its own small inverter (i.e., micro-inverter) mounted directly onto the backside of the panel.
- Now some panels come with built-in micro-inverters.
- These ac modules allow simple expansion of the system, one module at a time, as the needs or budget dictate.



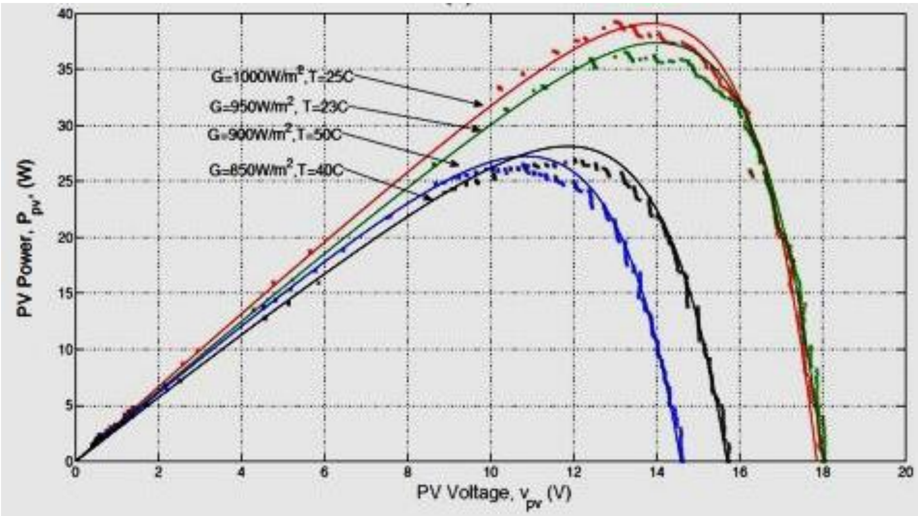
Today's Grid-Tied PV Inverters

Today's inverters are smart as they

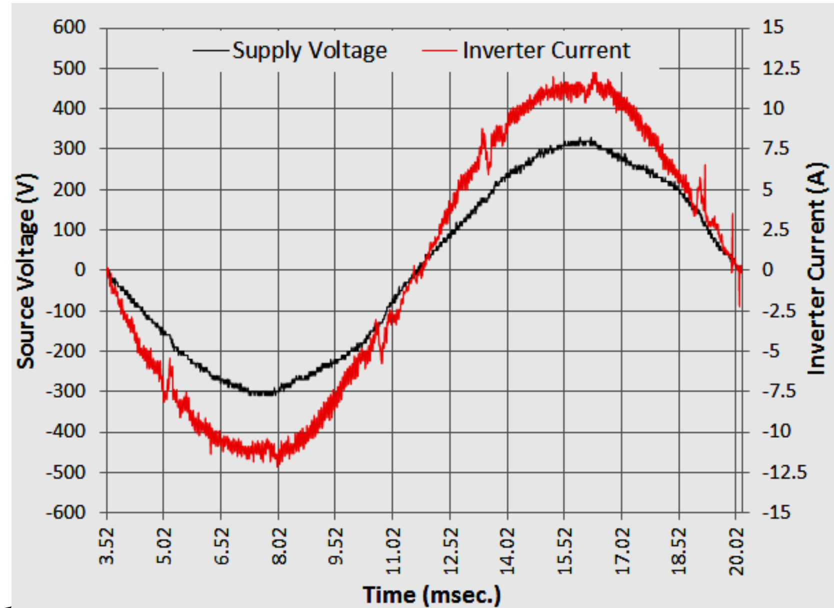
- monitor the PV array, track the maximum power and operate at that point,
- sense the presence of the grid, synchronize to and inject a current in phase with the voltage,
- monitor the grid and disconnect in case of trouble (e.g., swings in voltage or frequency).



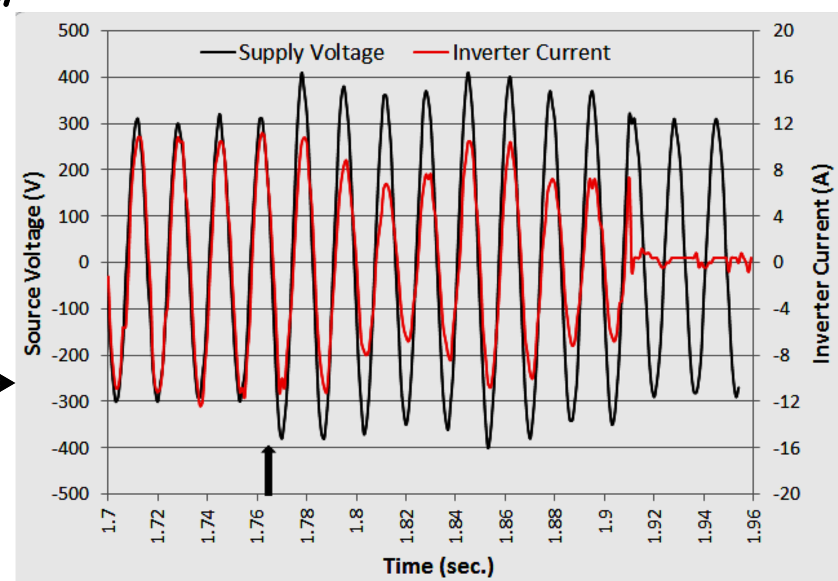
Today's Grid-Tied PV Inverters



Maximum Power Tracking



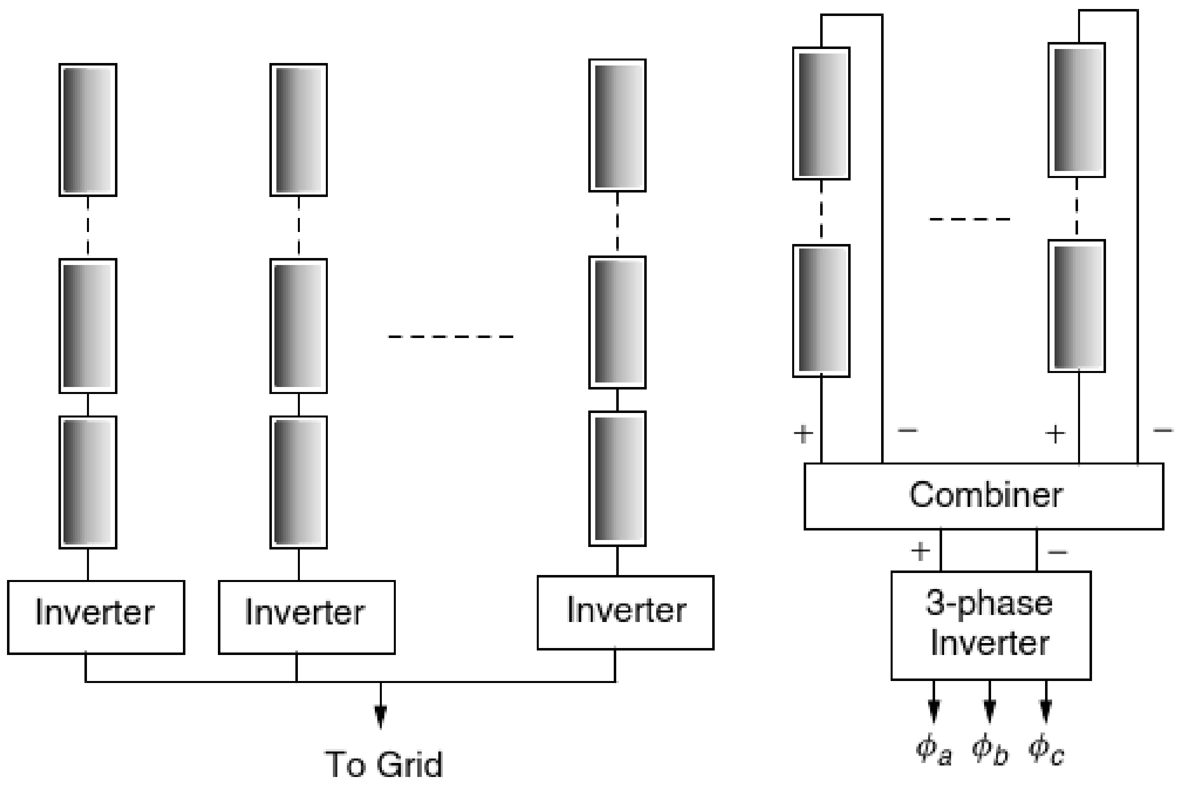
Grid synchronization



Grid Monitoring - Disconnect

Modular vs. centralized inverter

- For large grid-connected systems, strings of PV modules may be tied into inverters in a manner analogous to the individual inverter/module concept. By doing so, the system is modularized, making it easier to service portions of the system without taking the full array off line.
- Large, central inverter systems providing three-phase power to the grid are also an option.



AC Rated Power

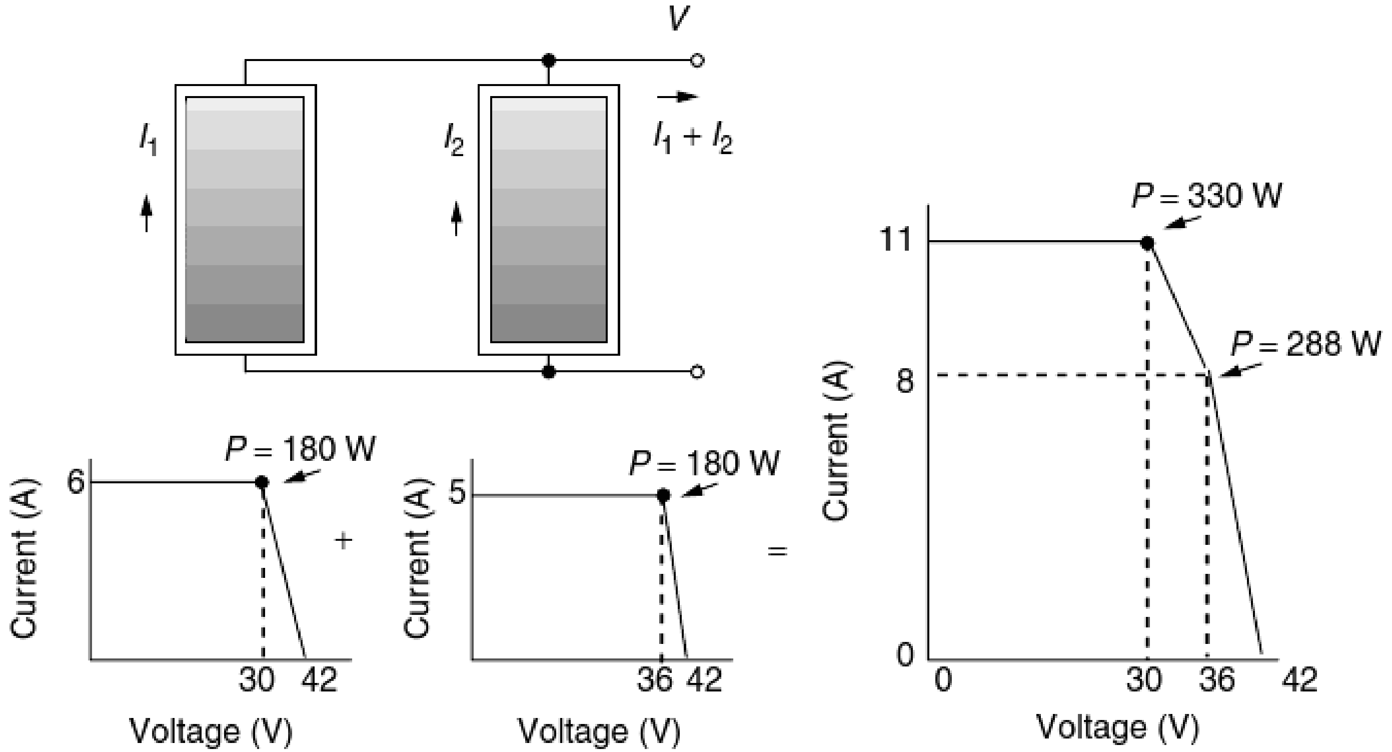
- The AC rated power of a grid-connected PV array is defined as

$$\mathbf{P_{ac} = P_{dc,STC} \times (Conversion\ Efficiency)}$$

  - where $P_{dc,STC}$ is the dc power of the array obtained by simply adding the individual module ratings under standard test conditions.
  - The conversion efficiency accounts for inverter efficiency, dirty collectors, mismatched modules, and differences in ambient conditions, losses in DC and AC wiring, impact of partial shading, etc.…
- Even in full sun, the impact of the above losses can easily de-rate the power output by 20% – 30%.

Mismatched modules

- Not all modules coming off the very same production line will have exactly the same rated output. For example, some 100-W modules may produce 103 W and others 97 W. → Production tolerances can reduce array output as well.



- What is the maximum power of the above modules if connected in series? *(Ans: 340 W)*

Impact of temperature

- An even more important factor that reduces module power below the rated value is cell temperature. In the field, the cells are likely to be much hotter than the 25^{o}C at which they are rated (STC) and we know that as temperature increases, power decreases.
- Other rating systems:
  - The PVUSA test condition (PTC) is defined as 1-sun irradiance in the plane of the array, ambient temperature of 20°C, and a wind-speed of 1 m/s. California, for example, has chosen to use the PTC rating for its PV rebate program.
    - What is the difference between PTC and NOTC?

      (Ans: different solar irradiances).
    - What is the difference between PTC and STC?

      (Ans: different cell temperatures).

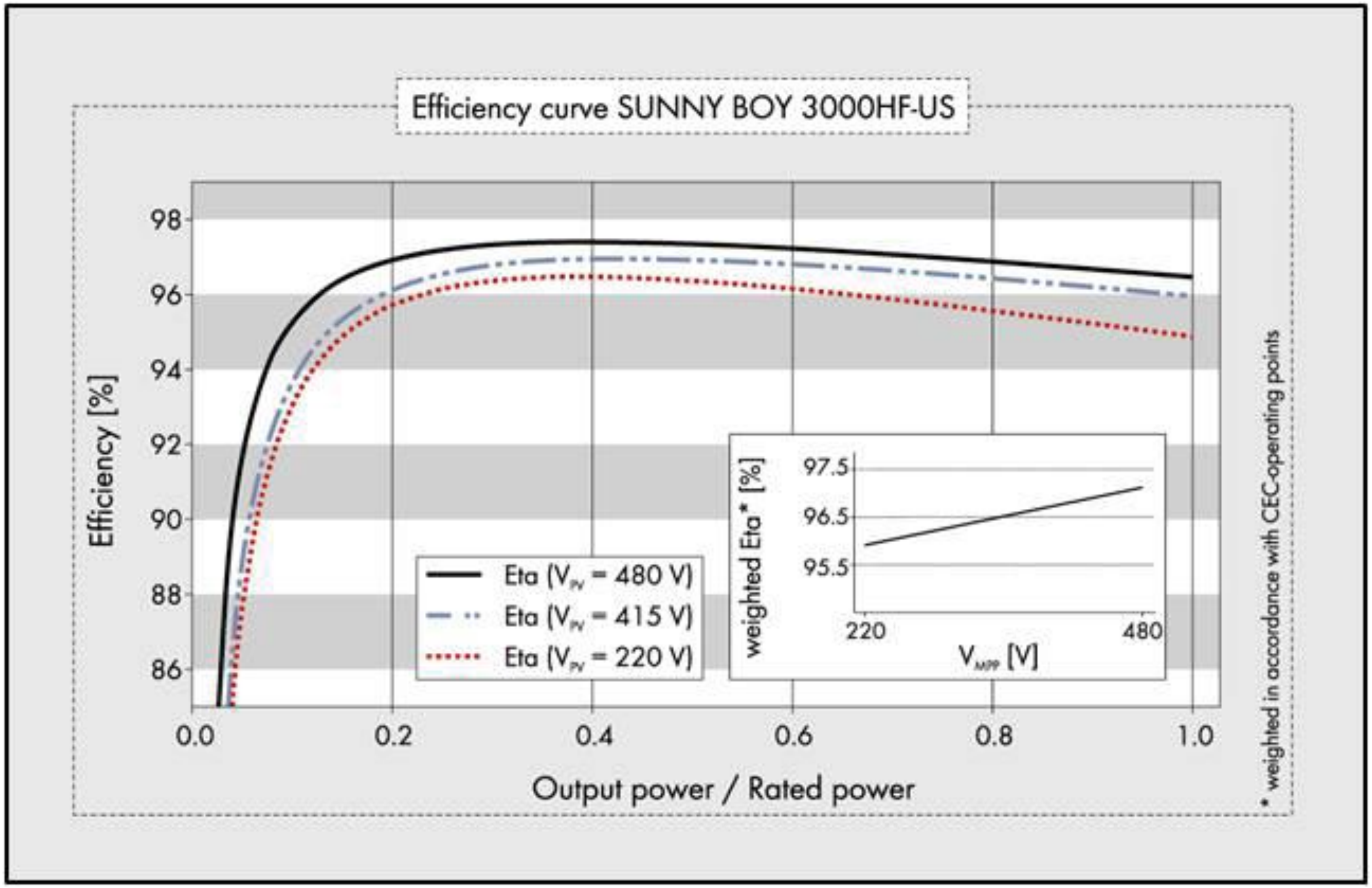
Accuracy using PTC

- The PTC rating assumes a nominal ambient of 20°C, which is a pretty good average estimate for many locations in the United States.
- For Las Vegas, NV, we expect PTC to
  - be accurate during for the months of March and November
  - over-predict performance during the months of April-October,
  - under-predict during December-February.

	LAS Vegas, NV						Latitude 36.08°N						
Tilt	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Year
Lat − 15	4.4	5.3	6.4	7.5	7.8	8.1	7.7	7.5	7.1	6.1	4.8	4.2	6.4
Lat	5.1	5.9	6.7	7.4	7.3	7.4	7.1	7.2	7.2	6.6	5.5	4.9	6.5
Lat + 15	5.6	6.1	6.6	6.8	6.5	6.3	6.2	6.5	7.0	6.8	5.9	5.4	6.3
90	5.0	5.1	4.7	3.9	3.0	2.6	2.6	3.4	4.5	5.3	5.2	5.0	4.2
1-Axis (Lat)	6.2	7.3	8.8	10.2	10.6	11.1	10.4	10.3	9.8	8.6	6.7	5.9	8.8
Temp. (°C)	14.1	17.4	20.4	25.3	31.0	37.9	41.1	39.6	34.8	27.8	19.7	14.2	26.9

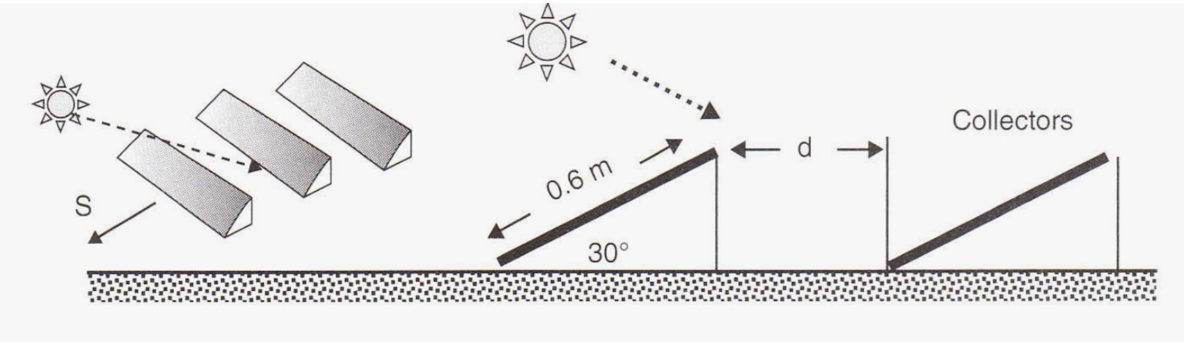
Inverter efficiency

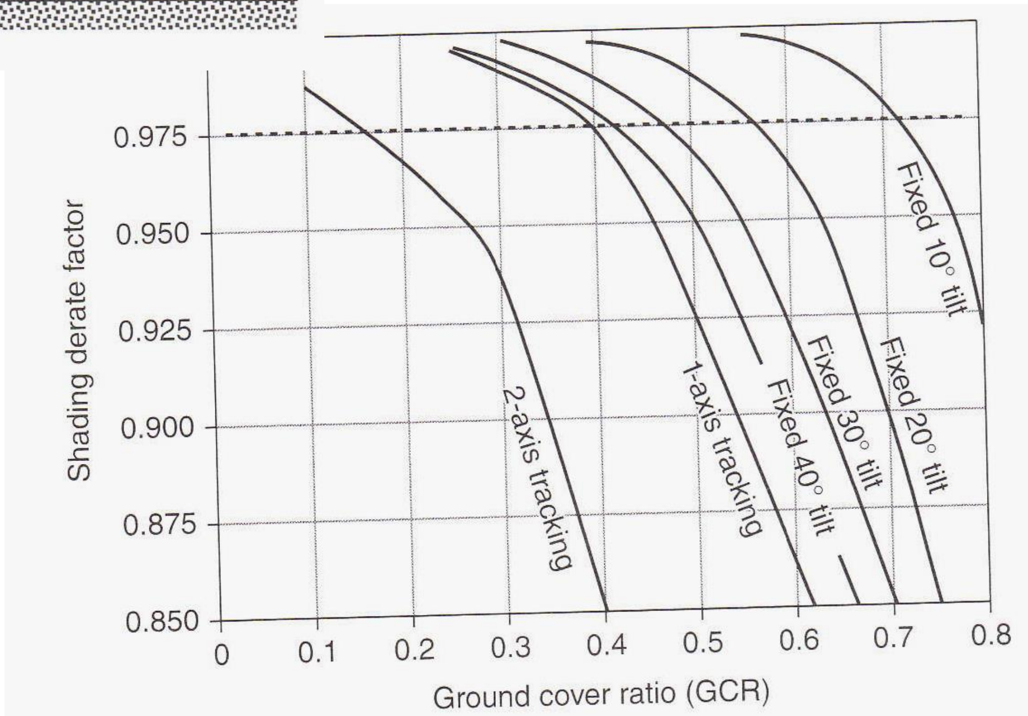
- There is power loss in the inverter itself, which varies depending on the power flow.



Derating due to Shading – ground cover ratio (GCR)

- GCR = ratio of area of PV to total ground area.
- Industry practice: optimize use of space for a 2.5% loss – this corresponds to a shading derate factor of 0.975.





Useful Tool: PV-Watts
http://www.nrel.gov/rredc/pvwatts/version1.html

A Performance Calculator
for
Grid-Connected PV Systems

PV-Watts performs an hour-by-hour calculation using TMY weather data, with corrections for things such as the PV module temperature's impact on PV efficiency and inverter efficiency as a function of power generation.

PV-WATTS – DC-to-AC Derate Factors

Station Identification:

WBAN Number: 23169
City: Las_Vegas
State: Nevada

PV System Specifications:

DC Rating (kW): 2
DC to AC Derate Factor: 0.77 DERATE FACTOR HELP

Array Type: Fixed Tilt

Fixed Tilt or 1-Axis Tracking System:
Array Tilt (degrees): 20 (Default = Lat
Array Azimuth (degrees): 180.0 (Default = So

Energy Data:

Cost of Electricity (cents/kWh): 13

Calculate HELP Reset For

Temp. derate
not included

Derate Factors for AC Power Rating at STC

Component Derate Factors	PVWATTS Default	Range
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availabilty	0.98	0.00 - 0.995
Shading	1.00	0.00 - 1.00
Sun-tracking	1.00	0.95 - 1.00
Age	1.00	0.70 - 1.00
Overall DC-to-AC derate factor	0.77	

PV-WATTS OUTPUT RESULTS

Station Identification	
City:	Las_Vegas
State:	Nevada
Latitude:	36.08° N
Longitude:	115.17° W
Elevation:	664 m
PV System Specifications	
DC Rating:	2.0 kW
DC to AC Derate Factor:	0.770
AC Rating:	1.5 kW
Array Type:	Fixed Tilt
Array Tilt:	20.0°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	13.0 ¢/kWh

Results			
Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.42	202	26.26
2	5.35	217	28.21
3	6.27	281	36.53
4	7.45	316	41.08
5	7.97	336	43.68
6	8.11	320	41.60
7	8.00	321	41.73
8	7.56	305	39.65
9	7.11	281	36.53
10	5.96	256	33.28
11	4.93	214	27.82
12	4.21	192	24.96
Year	6.45	3241	421.33

Output Hourly Performance Data

Output Results as Text

About the Hourly Performance Data

Saving Text from a Browser

‘‘Peak-Hours’’ Approach to Estimating PV Performance

- Predicting performance is a matter of combining the characteristics of the PV system (including the inverter) with local insolation and temperature data.
- Since 1-sun of insolation is defined as 1 kW/m^2 , we can think of an insolation of say 5.6 kWh/m^2/day as being the same as 5.6 h/day of 1-sun, or 5.6 “peak sun hours” (PSH). So, if we know the ac power delivered by an array under 1-sun insolation (P_{ac}), and assume that the system efficiency remains constant, then the daily energy collected would be equal to

$$\textbf{Energy (kWh/day)} = \mathbf{P_{ac}}\ \textbf{(kW)} \cdot \textbf{(PSH)}$$

Examples: Annual Energy Using the Peak-Sun-Hours

Example 1: Estimate the annual energy delivered by the 1-kW (dc, STC) array described in the previous example if it located in Las Vegas, NV, is south-facing, and has a tilt angle L - 15◦. Use an overall derating factor of 72%.

- *Answer: PSH = 6.4 (see Appendix E). De-rated ac power output 1kW x .72 = 0.72 kW. Annual Energy = 0.72 kW × 6.4h/day × 365 day/yr = 1,682 kWh*

Problem 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.

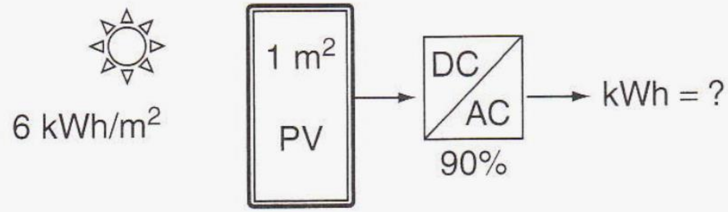


FIGURE P6.1

a. What is the 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.

Ans: a. ………

b. ………

Examples:

- **Problem 6.2:**

NREL's PVWATTS website predicts that 5.56 kWh/m^2/d of insolation on a south-facing, 40° 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?

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 × Temperature derate).

c. Use the PVWATTS website to find the overall annual temperature derate factors for a cold place (Bismarck, ND) and a hot place (Houston, TX). Use the same south-facing, 40° tilt array.

Ans: a) ………………..

b) ………………..

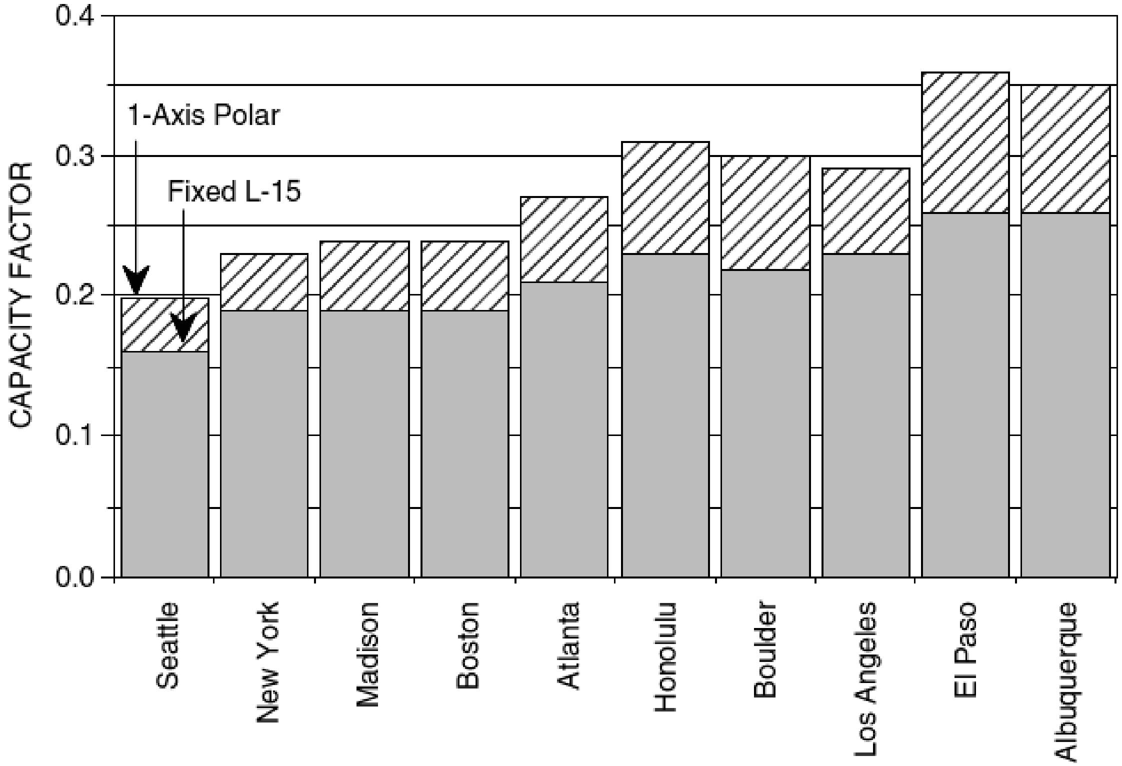
c) ………………..

Capacity Factor (CF)

- Capacity Factor for grid-connected PV systems:

$$\text{Capacity factor (CF)} = \frac{\text{(h/day of "peak sun")}}{\text{24 h/day}}$$

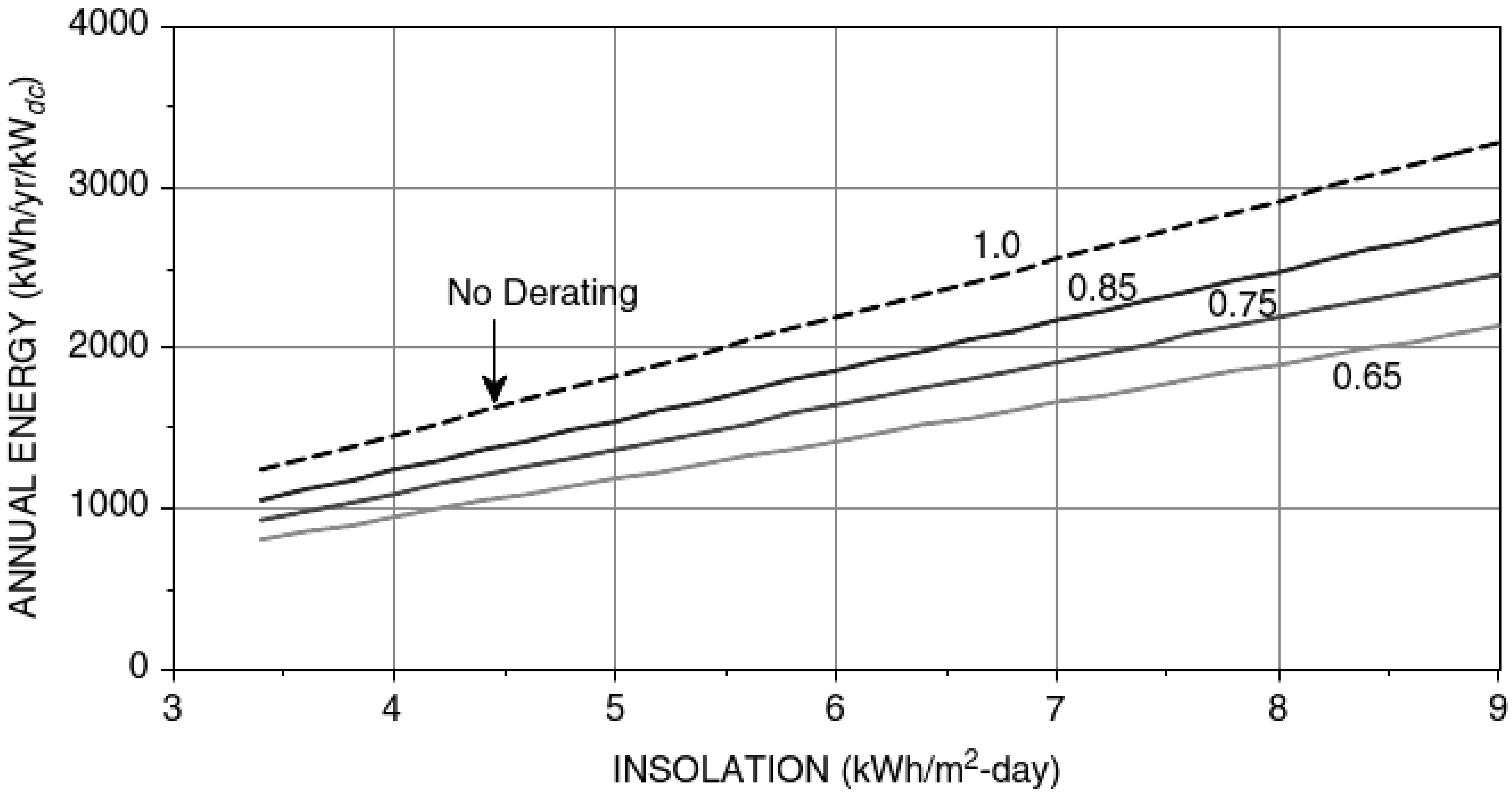
- Example: what is the capacity factor of a fixed PV array in Las Vegas, NV (south facing with tilt = latitude)? *(Ans: 6.4/24 = 0.27)*



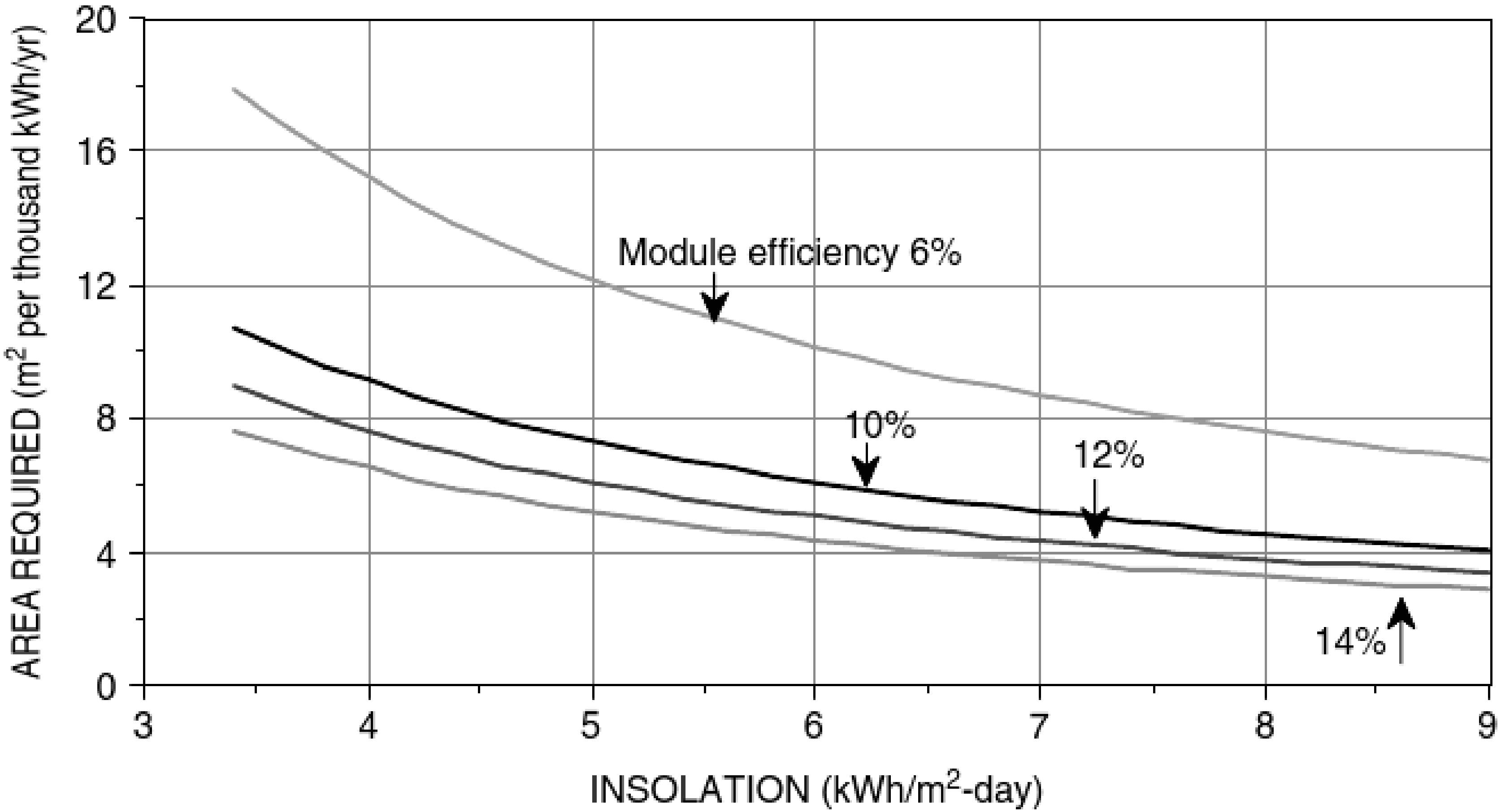
System Sizing – Practical Design Considerations

- **System sizing (First Cut):** How many kWh/year are required? How many peak watts of dc PV power are needed to provide that amount? How much area will that system require?
- **Case of house in Fresno, CA:** Desire a rooftop PV array that will annually displace all of the 3600 kWh/yr of electricity that the home uses. How many kW (dc, STC) of panels will be required and what area will be needed? Make assumptions as needed.
- *Answer:*
  - *For Fresno, CA (Appendix G): 5.7 kWh/m²/day of annual insolation for L-15,*
  - $P_{ac} = 3600/(5.7 \times 365) = 1.73$ *kW*
  - *Assume derating factor of 75%* $\rightarrow P_{dc,STC} = 1.73/.75 = 2.3$ *kW*
  - *Assume collector efficiency of 12.5%* $\rightarrow$ *Area* $= 2.3/0.125 = 18.4\ m^2$

Annual Energy delivered by 1 kW (dc, STC) PV array



Area required to deliver 1 MWh/year (with dc-to-ac derating of 75%)



Panel & Inverter Selection

TABLE 9.4 Important Characteristics of Several High-Power PV Modules

Module:	Sharp NE-K125U2	Kyocera KC158G	Shell SP150	Uni-Solar SSR256
Material:	Poly Crystal	Multicrystal	Monocrystal	Triple junction a-Si
Rated power $P_{dc,STC}$:	125 W	158 W	150 W	256 W
Voltage at max power:	26.0 V	23.2 V	34 V	66.0 V
Current at max power:	4.80 A	6.82 A	4.40 A	3.9
Open-circuit voltage V_{OC}:	32.3 V	28.9 V	43.4 V	95.2
Short-circuit current I_{SC}:	5.46 A	7.58 A	4.8 A	4.8
Length:	1.190 m	1.290 m	1.619 m	11.124 m
Width:	0.792 m	0.990 m	0.814 m	0.420 m
Efficiency:	13.3%	12.4%	11.4%	5.5%

TABLE 9.5 Example Inverter Characteristics for Grid-Connected Systems

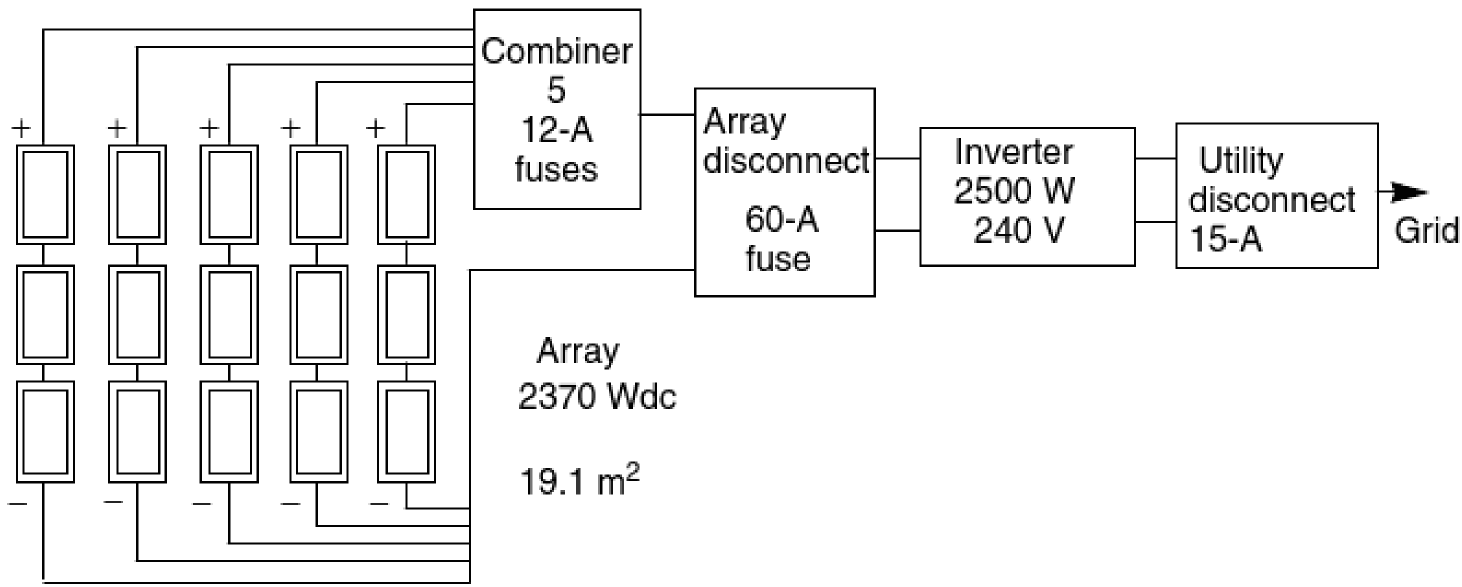
Manufacturer:	Xantrex	Xantrex	Xantrex	Sunny Boy	Sunny Boy
Model:	STXR1500	STXR2500	PV 10	SB2000	SB2500
AC power:	1500 W	2500 W	10,000 W	2000 W	2500 W
AC voltage:	211–264 V	211–264 V	208 V, 3Φ	198–251 V	198–251 V
PV voltage range MPPT:	44–85 V	44–85 V	330–600 V	125–500 V	250–550 V
Max input voltage:	120 V	120 V	600 V	500 V	600 V
Max input current:	—	—	31.9 A	10 A	11 A
Maximum efficiency:	92%	94%	95%	96%	94%

Panel & Inverter Selection

- Number of modules needed: 2300/158 = 14.6 (14 - 15 panels)
- Number of panels per string:
  - 2 panels result in a rated voltage of 46.4 V
  - 3 panels result in a rated voltage of 69.6 V
  - Which of these falls nicely in the MPPT range of the inverter? Ans: 3
- Therefore using 15 panels (5 parallel strings – each with 3 panels) is a nice fit.
- Check that the maximum Voc does not exceed the highest DC voltage of the inverter:
  - 86.7 V < 120 V
  - Check the case for the coldest temperature (recall that Voc increases a colder temperatures)
  - The National Electrical Code (NEC) restricts all voltages in family dwellings to not more than 600 V.

Roof area, energy production and fuses

- Roof area: 15 x 1.29 x 0.99 = 19.1 m^2
- Rated Power (dc, STC): 15 x 158 = 2,370 W
- Rated AC Power (assuming de-rating of 75%): 2.37x.75 = 1.777 kW
- Expected annual energy production: 1.777 x 5.7 x 365 = 3,698 kWh/year → goal is met.
- Combiner fuse > 1.56 (per NEC) x 7.58 = 11.8 A → 12 A
- DC Disconnect fuse > 11.8 x 5 = 59.2 A → 60 A
- AC Disconnect fuse > 1.25 (per NEC) x (2500/240) =13 A→ 15 A



Examples

- **Problem 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 $P_{DC,STC}$	150 W
Input voltage range for MPP	250–550 V	Voltage at MPP	34 V
Maximum input voltage	600 V	Open-circuit voltage	43.4 V
Maximum input current	11 A	Current at MPP	4.40 A
		Short-circuit current	4.8 A

Using the input voltage range of the inverter MPPT 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 do not need to worry about temperatures.

Ans: ………………..

Grid-connected PV System Economics: System Tradeoffs

- To illustrate the decision between system options, consider the trade-off between the benefits of higher irradiance with a tracking mount compared to a simple fixed, roof mount.
- **Example:** A PV system for a house in Boulder, CO, is to be designed to deliver about 4 MWh/yr. Given the following costs, decide whether to recommend a fixed array at tilt L-15 or a single-axis tracker. Assume 12% efficient PVs and a 0.75 dc-to-ac efficiency factor.

Component	Cost
PVs	\$4.20/Wdc
Inverter	\$1.20/ W
Tracker	\$400 + \$100/m^2
Installation, BOS	\$3800

Example (cont.)

- 1-axis tracker
  - Average insolation (see Appendix G): PSH = 7.2 kWh/m2/day
  - Pdc,STC = 4000/(.75x.72x365) = 2.03 kW
  - Area needed: 2.03/.12 = 16.9 m^2
- Fixed array
  - Average insolation (see Appendix G): PSH = 5.4 kWh/m2/day
  - Pdc,STC = 4000/(.75x7.2x365) = 2.71 kW

Component	Tracker	Fixed Tilt
PVs	$8,524	$11,365
Inverter	$2,435	$3,247
Tracker	$2,091	$0
Installation, BOS	$3,800	$3,800
Total	$16,850	$18,412

- → There might some advantage to using the tracker, but only a more careful analysis (including the reliability of the tracking system) could affirm the validity of this conclusion.

Dollar-per-peak-watt ambiguity

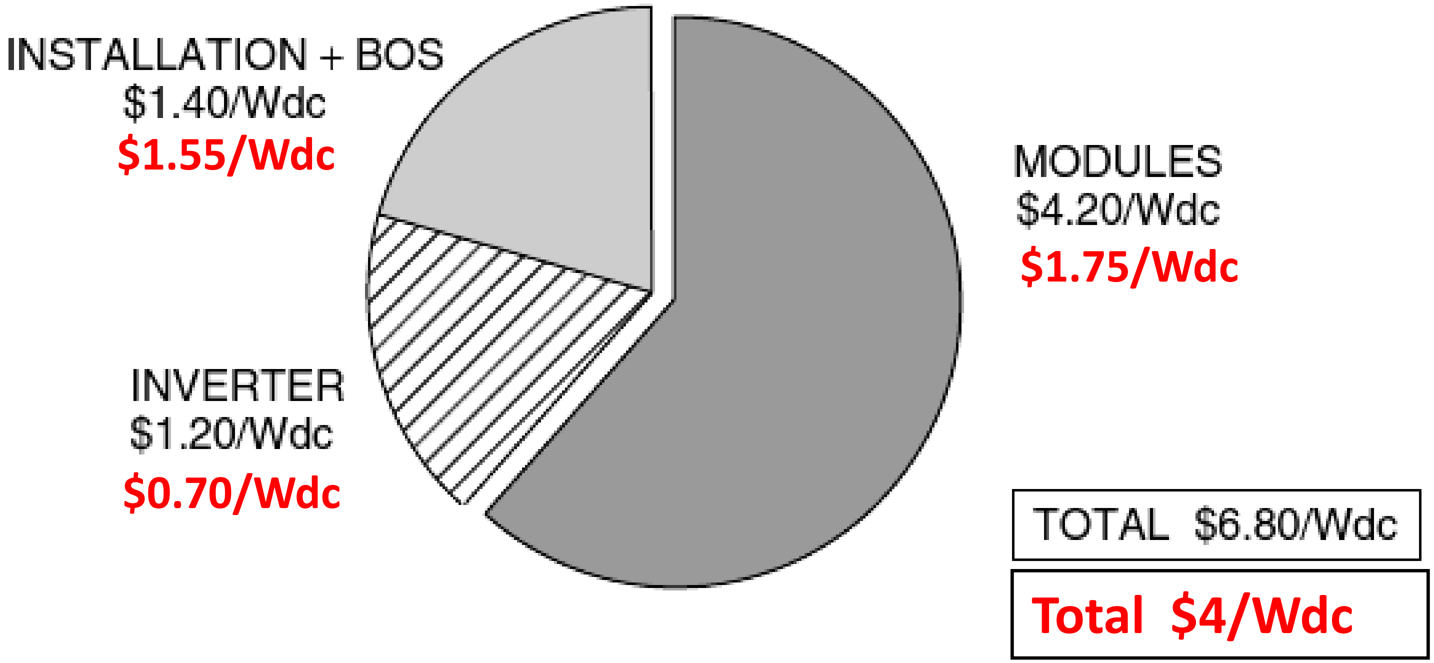
- It is common practice to describe installed costs in dollars per watt of peak power. There are two ambiguities with the \$/W indicator:
  - One is whether the watts are based on dc power from the PVs or ac power from the inverter.
  - The other is whether or not a tracker has been used.
- In the previous example, even though the tracker delivers the same kWh/yr and it is cheaper than the fixed-tilt array, it appears to have a higher cost when expressed as \$/Wdc or \$/Wac.
  - When a PV system uses tracking, an Energy Production Factor (EPF) must be included in order to make the \$/W descriptor comparable to that of a fixed array.

$$\text{Tracker}(\$/\text{W}) = \frac{\$/\text{W}}{\text{EPF}} = \frac{\$/\text{W}}{(\text{Tracking insolation/Fixed insolation})}$$

Grid-connected PV System Economics: Economic Viability

- Whether the system is economically viable or not depends on many factors:
  - the initial cost of the system,
  - the amount of energy it will deliver each year.
  - the price of the energy displaced by the system,
  - whether there are any tax credits or other economic incentives,
  - how the system is to be paid for.
- A detailed economic analysis will include:
  - estimates of operation and maintenance costs;
  - future costs of utility electricity;
  - loan terms and income tax implications if the money is to be borrowed, or personal discount rates if the owner purchases it outright;
  - system lifetime;
  - costs or residual value when the system is ultimately removed.

Average installed cost of residential PVs



– 2000 prices, *– 2012 prices*

Amortizing cost

- To estimate the cost of electricity generated by a PV system, consider a loan to pay for the system and then using annual payments divided by annual kWh delivered to give ¢/kWh.
- If an amount of money, or principal, P ($), is borrowed over a period of n (years) at an interest rate of i (decimal fraction/yr), then the annual loan payments, A($/yr), is expressed in terms of the Capital Recovery Factor (CRF) as

$$A = P \cdot \mathrm{CRF}(i, n)$$

- where

$$\mathrm{CRF}(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Example

- The tracking PV system of the previous example costs $16,850 to deliver 4,000 kWh/yr. If the system is paid for with a 6%, 30-year loan, what would be the cost of electricity?
- *Answer:*

$$\mathrm{CRF}(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1} = \frac{0.06(1.06)^{30}}{(1.06)^{30} - 1} = 0.07265/\mathrm{yr}$$

$$\mathrm{A} = \mathrm{P}\ \mathrm{CRF}(i, n) = \$16{,}850 \times 0.07265/\mathrm{yr} = \$1224/\mathrm{yr}$$

$$\text{Cost of electricity} = \frac{\$1224/\mathrm{yr}}{4000\ \mathrm{kWh/yr}} = \$0.306/\mathrm{kWh}$$

- But the interest on such loans are tax deductible. The tax benefit that results depends on the marginal tax bracket (MTB) of the homeowner. Furthermore, this means that the tax benefit of interest payments varies from year to year.

Example (cont.)

- For example, in the first year, interest is owed on the entire amount borrowed and the tax benefit is

$$\text{First-year tax benefit} = i \times P \times \text{MTB}$$

- Revisit the previous example: If the homeowner is in the 30.5% marginal tax bracket, what is the cost of PV energy in the first year?
- Answer:

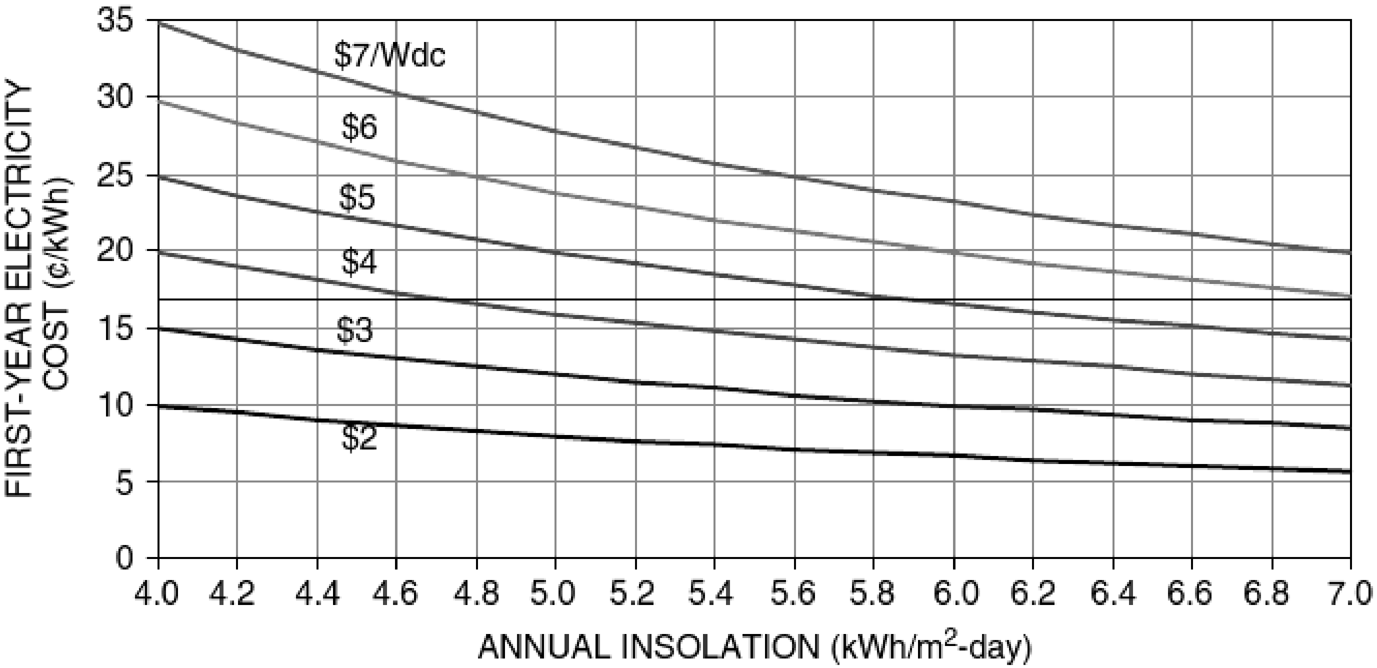
$$\text{First-year tax benefit} = 0.06 \times \$16{,}850 \times 0.305 = \$308$$

$$\text{First-year cost of PV} = \$1224 - \$308 = \$916$$

$$\text{Cost of electricity} = \frac{\$916/\text{yr}}{4000\ \text{kWh/yr}} = \$0.23/\text{kWh}$$

Example (cont.)

- First-year cost of electricity with \$/Wdc (STC) as the parameter. (Assumptions: 6%, 30-yr loan, MTB = 0.305, dc-ac conversion =75%)



- Some states have sizable rebates. Nevada, for example, has a rebate program funded by utility ratepayers that offers a \$2.50/Wac (as of 2012).

New Example: Financing a PV system

- A 3-kWac PV system is predicted to deliver 6000 kWh/yr to a house that currently pays $0.12/kWh for electricity. The system, which costs $27,000, is eligible for a rebate of $4.50/Wac. If the balance is paid for with a 6%, 30-year loan and the owner is in the 37% tax bracket (combined state and federal), what is the cost of PV electricity in the first year and what would be the net economic benefit in the first year?
- *Ans:*
  - Net cost after rebate: 27000-(4.5x3000) = $13,500
  - Annual loan: 0.07265x13500 = $980.78
  - Tax savings: 0.06x13500x0.37 = $299.70
  - Cost of electricity from the PV system: (980.78-299.7)/6000 = $0.1135/kWh
  - Net economic benefit: 6000x(.12-.1135)=$39/yr

Example (annual cash flow)

Year	Loan Balance	Loan Payment	Loan Interest	Delta P	Delta tax	Annual Cost	PV cost ¢/kWh	Utility ¢/kWh	Savings $/yr
0	13,500	981	810	171	300	681	11.4	12.0	39
1	13,329	981	800	181	296	685	11.4	12.2	50
2	13,148	981	789	192	292	689	11.5	12.5	60
3	12,956	981	777	203	288	693	11.6	12.7	71
4	12,753	981	765	216	283	698	11.6	13.0	82
5	12,537	981	752	229	278	702	11.7	13.2	93
6	12,309	981	739	242	273	708	11.8	13.5	103
7	12,067	981	724	257	268	713	11.9	13.8	114
8	11,810	981	709	272	262	719	12.0	14.1	125
9	11,538	981	692	288	256	725	12.1	14.3	136
10	11,249	981	675	306	250	731	12.2	14.6	147
11	10,943	981	657	324	243	738	12.3	14.9	157
12	10,619	981	637	344	236	745	12.4	15.2	168
13	10,276	981	617	364	228	753	12.5	15.5	179
14	9,911	981	595	386	220	761	12.7	15.8	189
15	9,525	981	572	409	211	769	12.8	16.2	200
16	9,116	981	547	434	202	778	13.0	16.5	210
17	8,682	981	521	460	193	788	13.1	16.8	220
18	8,223	981	493	487	183	798	13.3	17.1	230
19	7,735	981	464	517	172	809	13.5	17.5	240
20	7,218	981	433	548	160	821	13.7	17.8	249
21	6,671	981	400	581	148	833	13.9	18.2	259
22	6,090	981	365	615	135	846	14.1	18.6	268
23	5,475	981	328	652	122	859	14.3	18.9	276
24	4,823	981	289	691	107	874	14.6	19.3	284
25	4,131	981	248	733	92	889	14.8	19.7	292
26	3,398	981	204	777	75	905	15.1	20.1	300
27	2,622	981	157	823	58	923	15.4	20.5	306
28	1,798	981	108	873	40	941	15.7	20.9	313
29	925	981	56	925	21	960	16.0	21.3	318
30	0	0	0	0	0	0	0.0	21.7	1304

[a] Buyer is in the 37% tax bracket and utility electricity is projected to grow at 2%/yr.

Example

- **Problem 6.3:**

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

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

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

c. Find the first-year net cost of electricity ($/kWh) if the system costs $4 per peak watt ($\$4/W_{DC,STC}$), it is paid for with a 5%, 30-year loan, interest on the loan is tax deductible, and the owner is in a 29% marginal tax bracket.

Ans: a) ………………..
b) ………………..
c) ………………..