

# Sizing and Economics of Grid-Connected PV Systems



ECEN 2060

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# Grid-Connected PV System Sizing (1)

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- **Objective:** generate  $E_{ac}$  [kWh] of electrical energy over 1 year
  - **Find:** peak DC power system rating  $P_{DCpeak}$  [Wp] under standard test conditions (STC)
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- **Parameter 1:** average yearly insolation  $S$  [kWh/m<sup>2</sup>/day], based on:
  - Location
  - Fixed, 1-axis tracking, or 2-axis tracking installation
  - Tilt angle and Azimuth (ideally South facing)

$S$  can be obtained from textbook tables or at NREL PVWATTS site:  
[http://rredc.nrel.gov/solar/codes\\_algs/PVWATTS/version1/](http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/)

## Example:

Boulder, fixed, 25° tilt (roof), South-facing:  $S = 5.44$  kWh/m<sup>2</sup>/day

**Note:** since full sun insolation is 1 kW/m<sup>2</sup>,  $S$  is numerically equal to the average number of hours of full sun per day, e.g.  $S = 5.44$  hours of full sun in this example

# Grid-Connected PV System Sizing (2)

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**Parameter 2:** overall system efficiency  $\eta$ , from PV to AC grid,  $\eta = E_{ac}/E_{pvpeak}$ , also called “DC to AC derate factor”, including:

- Derating of PV nominal peak power (e.g. due to tolerances, temperature, or aging)
- Module mismatches
- Dirt
- Shading
- Losses due to wiring, blocking diodes, connectors
- Efficiency, and MPP tracking performance of the power electronics (“inverter”)

Typical  $\eta = 75\%$ . See discussion in Textbook Section 9.3

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**PV system sizing equation:**

$$365 \cdot S \cdot P_{DCpeak} \cdot \eta = E_{ac}$$

Example:  $S = 5.44$  hours,  $\eta = 75\%$

**$P_{DCpeak} = 1$  Wp installed produces  $E_{ac} = 1.49$  kWh per year for the example PV installation in Boulder**

# Grid-Connected PV System Sizing (3)

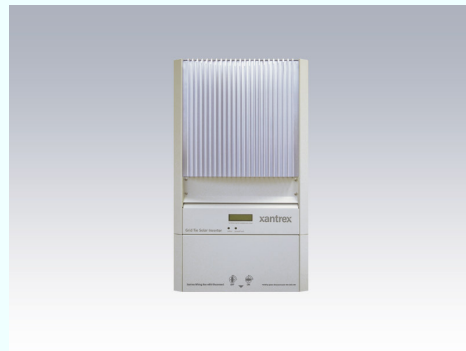
**Example:** size a residential PV system for a house in Boulder to generate  
 $E_{ac} = 7200$  kWh (600 kWh per month)

**Parameters:**  $S = 5.44$  hours,  $\eta = 75\%$

**Solution:**

- $P_{DCpeak} = 7200/1.49 = 4.8$  kWp is the required system rating
- Suppose we use 85 Wp,  $A_{pv} = 0.63$  m<sup>2</sup> modules (Shell SQ85-P)  
 $V_{oc} = 22.2$  V,  $I_{sc} = 5.45$  A  
 $V_R = 17.2$  V,  $I_R = 4.95$  A
- Need 57 modules, 36 m<sup>2</sup> (390 sq.ft.) of PV
- Choose a 5 kW (AC output) power electronics “inverter”

Example: Xantrex GT5.0 single-phase 240V RMS inverter



58.0 lb (25.8 kg)

28 1/2 x 16 x 5 3/4" (724 x 403 x 145 mm)

\$3950 list price, \$0.79/W

# “Inverter” example: Xantrex GT5.0

Models	GT5.0		GT4.0N		GT3.3N		GT2.8	
Output	240 V	208 V	240 V	208 V	240 V	208 V	240 V	208 V
Max. AC power output	5000 W	4500 W	4000 W	3800 W	3300 W	3100 W	2800 W	2700 W
AC output voltage (nominal)	240 V	208 V	240 V	208 V	240 V	208 V	240 V	208 V
AC output voltage range	211-264 Vac	183-229 Vac	211-264 Vac	183-229 Vac	211-264 Vac	183-229 Vac	211-264 Vac	183-229 Vac
AC frequency (nominal)	60 Hz							
AC frequency range	59.3 - 60.5 Hz							
Startup current	0 Aac							
Max. continuous output current	21 A	22 A	16.7 A	18.3 A	13.8 A	14.9 A	11.7 A	13.0 A
Max. output over-current protection	30 A		25 A		20 A		15 A	
Max. output over-current protection	30 Arms		25 Arms		20 Arms		20 Arms	
Max. utility backfeed current	0 A							
Total harmonic distortion (THD)	< 3 %		-		< 5 %		-	
Power factor	> 0.99 % (at rated power), > 0.95 % (full power range)							
Utility monitoring, islanding protection	UL1741-2005 / IEEE 1547							
Output characteristics	Current Source							
Output current waveform	True sine wave							

Max. array open-circuit voltage	600 Vdc							
MPPT voltage range (CEC & CSA)	240 - 550 Vdc		240 - 480 Vdc		200 - 400 Vdc		195 - 550 Vdc	
MPPT operating range	Low: 235 Vdc / High: 550 Vdc		Low: 235 Vdc / High: 550 Vdc		Low: 200 Vdc / High: 550 Vdc Vdc		Low: 193 Vdc / High: 550 Vdc	
Max. input current	22.0 Adc	20.0 Adc	18.0 Adc	17.0 Adc	17.5 Adc	16.5 Adc	15.4 Adc	14.9 Adc
Max. array short-circuit current	24.0 Adc							
Reverse-polarity protection	Short-circuit diode							
Ground-fault protection	GF detection, IDIF > 1 A							
Max. inverter efficiency	95.9%	95.5%	96.0%	95.7%	95.9%	95.6%	95.0%	94.6%
CEC efficiency	95.5%	95.0%	95.5%	95.0%	95.5%	95.0%	94.0%	93.5%
Night-time power consumption	1 W							

# PV array design and inverter check

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- Array design: arrange 57 modules
  - 3 parallel strings of 19 series modules each
- Check inverter input voltage rating:
  - $19 * V_{oc} = 19 * 22.2 \text{ V} = 422 \text{ V} (< 600 \text{ V inverter spec, ok})$
- Check inverter MPPT range:
  - Inverter spec: 240-550 V MPPT range
  - $(240-550 \text{ V})/19 = 12.6-28.9 \text{ V}$ , (module  $V_R = 17.2 \text{ V}$ , ok)
- Check inverter input current rating, 3 parallel strings
  - $3 * I_{sc} = 16.4 \text{ A} (< 24 \text{ A inverter spec, ok})$

# Simple cost analysis

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- Capital cost of PV systems is quoted in \$/Wp
  - **Typical: \$8/Wp**
    - PV modules: \$4.81/Wp
      - (this is as of Feb.22, 2009), see: <http://www.solarbuzz.com/>
    - BOS (balance of system)
      - Installation
      - Wiring
      - Power electronics “inverter”: < \$0.8/Wp (!)
- System example: 4.8 kWp => \$38,400 capital cost
- Nominal lifetime for PV systems: 20 years
- Simple cost per kWh calculation
$$\text{\$38,400} / (7200 \text{ kWh/y} * 20 \text{ y}) = 27 \text{ ¢/kWh}$$
- Alternatively, assuming 10 ¢/kWh cost of electricity, it would take 53.3 years for this system to pay off (simple calc)
- Textbook Section 9.4 gives more detailed cost analysis examples

# Incentives: Colorado and Federal

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- Net Metering: utility buys excess energy generated
- Colorado Amendment 37 (2004)
  - Major utilities are required to provide a percentage of their retail electricity sales from renewable sources (3% percent by 2007, 6% by 2011, 10% by 2015)
- Xcel Energy “Solar\*Rewards” in Colorado
  - \$2/Wp rebate
  - \$1.5/Wp renewable energy credit (REC)
- Federal Emergency Economic Stabilization Act of 2008 (Oct.3,2008)  
Investment Tax Credit (ITC) for residential PV installation: tax liability reduced by 30% of the system cost (after other incentives), no cap after January 1, 2009 through Dec. 31, 2016; allows unused credits to be forwarded to the next year
- Example system cost with incentives
  - 4.8 kWp @ (\$8–\$3.5)/Wp => \$21,600
  - $\$21,600 - 0.3 * (\$21,500) = \$15,120$
  - 10.5 ¢/kWh (simple calculation assuming 20 years lifetime)
  - The system would pay off in 21 years (simple calculation assuming 10 ¢/kWh cost of electricity)

Solar Energy Industry Association site: <http://www.seia.org/> includes summaries of various Federal and State incentives for residential and commercial PV installations