D-Lab: Energy

Week 4: Solar
Estimation

How big a solar panel do you need to power a 100W incandescent light bulb?
Solar Rules of Thumb

solar flux: 1 kW/m²

PV efficiency (best case): 10-20% ➞ 100 W/m²
Solar Options

**SODIS:** water disinfection

**Solar Thermal**
- cooking/drying
- water heating
- generating electricity

**PV:** generating electricity
Solar drying

Fruits of the Nile - Uganda

http://www.fullwellmill.co.uk/partners/fon.htm
Solar Thermal Panels

for water heating
Luz Project in Mojave Desert, CA
largest solar thermal-electric installation in the world
350MW peak output

generates high-temperature steam using arrays of concentrating mirrors. steam powers a turbine that drives a generator to produce electricity
Overview of Photovoltaics

Matthew Seitzler, M.S., E.I.T.
www.SRE-Engineering.com
How do photovoltaics work?

- Light is converted to electricity via photovoltaic effect in silicon.
- Materials have difference eff. and costs.
- 3–25% of light is converted directly into electricity.
- Dependent on the intensity of light normal to the surface of the module.
Many photovoltaic materials, all with pros and cons

- **crystalline silicon**
  - monocrystalline
  - polycrystalline
  - multicrystalline
  - ribbon silicon
- **amorphous silicon**
- **cadmium telluride**
- **copper indium selenide/sulfide**
- organic cells
How do photovoltaics work?

Solar cells (~0.5V) are wired together to obtain module (panel) voltage (5-31V).

Modules are wired together depending on solar electric system type to form array (15-1000V).

Module power values include efficiencies.

Sensitive to temperature.
Series vs. Parallel Wiring

**SERIES**

- 6 Volts @ 350 AH
- **12 Volts @ 350 Amp hours.**

**PARALLEL**

- 6 Volts @ 350 AH
- **6 Volts @ 700 Amp hours.**

**SERIES/PARALLEL**

- 6 Volts @ 350 AH
- **12 Volts @ 700 Amp hours.**

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Solar Electric System Components

Typical Components:

- Solar Panel or Module (3–20%)
- Solar Regulator or Charge Controller (90–95%)
- Battery (80%)
- Power Inverter (90–97%)
- DC Disconnect
- Fuses

Stand-alone PV system components

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Common PV system types

- Grid-tied PV systems
- Stand alone or autonomous systems
- Hybrid PV
Common PV system types

Stand alone systems

- Direct or stored PV energy possible
- System is completely autonomous i.e. not connected to an electric grid
- Like a mini-grid
- Lower system voltages
- Typically deployed in rural
Islanding (Hybrid) systems

- Connected to the utility grid
- Battery bank used to store energy
- Energy from battery bank fed to grid
- Uses lower array voltages

Courtesy of Matthew Seitzler. Used with permission.
PV System Examples

Bangladesh stand-alone PV system

Masdar 10 MW Solar array

Courtesy of Matthew Seitzler. Used with permission.
# Load and Energy Use Estimation

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent lights</td>
<td>60 - 150 W (per bulb)</td>
</tr>
<tr>
<td>Fluorescent lights</td>
<td>15 W (per tube)</td>
</tr>
<tr>
<td>Laptop computer</td>
<td>20 - 40 W</td>
</tr>
<tr>
<td>Desktop computer</td>
<td>150 - 200 W</td>
</tr>
<tr>
<td>Stereo system</td>
<td>20 - 50 W</td>
</tr>
<tr>
<td>Washing machine</td>
<td>600 - 1,000 W (includes heating the water)</td>
</tr>
<tr>
<td>Dryer</td>
<td>4,000 - 6,000 W</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>4,000 - 6,000 W</td>
</tr>
<tr>
<td>Oven</td>
<td>8,000 - 12,000 W</td>
</tr>
<tr>
<td>Microwave</td>
<td>750 - 1200 W</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>500 W</td>
</tr>
<tr>
<td>Telephone</td>
<td>2 - 5 W</td>
</tr>
<tr>
<td>Television</td>
<td>80 - 100 W</td>
</tr>
<tr>
<td>VCR</td>
<td>20 - 50 W</td>
</tr>
<tr>
<td>Hair dryer</td>
<td>1000 - 1500 W</td>
</tr>
</tbody>
</table>
Design Application

Problem:

- Can I power my small 110 volt AC 75 watt refrigerator for three hours during a day with 5 sun hours using a 12 volt, 100 amp hour battery and a 100 watt solar module?
- To prevent destroying the battery I do not want to go lower than 70% discharge.
- Assume system efficiencies of 80% for the battery conversion, 95% charge controller, 95% for the inverter.

What type of system is this?
Design Application

Tools:

- Ohm’s Law:
  - \[ \text{Voltage (V)} = \text{Current (I)} \times \text{Resistance (R)} \]
- Electrical Power Equation:
  - \[ \text{Power (P)} = \text{Current (I)} \times \text{Voltage (V)} \]
- Solar Energy International PV Design Manual
- Friends in PV.
Design Application

I. Resource Estimation

Known:

100 watt\footnote{1} module, 5 sun hours per day

Calculate Resource:

Energy = 100 \, W \times 5 \, \text{hrs/day} = 500 \, \text{Whrs/day}

Include Charge Controller Eff.:

Energy = 500 \, \text{Whrs/day} \times 0.95 = 475 \, \text{Whrs/day}

1. Nominal value ($P_{\text{nom}}$) from manufacturer for standard testing conditions.
II. Load Determination

Known:

75 W frig, 3 hours per day

Calculate Load:
Load = 75 W*3 hrs/day = 225 Whrs/day

Calculate Load with inverter eff.:
Load = 225 Whrs/day/0.95 \[^2\] = 236 Whrs/day

Note: Inverter size should be 1.25 times surge load for frig.

2. Eff. in divisor because of load or demand side computation.
III. Energy Storage

Known:

100 Amp*hr battery, 80% eff., with 70% allowable discharge

Calculate Storage Capacity:

1. Convert to kWhrs

\[100 \text{ Amp*hrs} \times 12 \text{ Volts} = 1200 \text{ Whrs}\]

2. Include eff. & allowable discharge

\[1200 \text{ Whrs} \times 0.70 \times 0.80 = 672 \text{ Whrs}^*\]

*Estimated value not including battery degradation overtime.
Design Application

IV. Energy Balance

Known:
Resource = 475 Whrs/day
Load = 236 Whrs/day

Resource side:
• Resource > Load? Yes, Load is only ~50% of Resource

Storage side:
• Storage > Load? Yes, Load is only ~35% of Resource
Design Application

IV. Limit Calculations

Days of Autonomy ($D_{auto}$):
- $D_{auto} = \text{Storage} / \text{Load}$
  - $D_{auto} = 672 \text{ Whr} / 236 \text{ Whr/day} = \sim 2.8 \text{ days}$

Days to charge battery ($D_{bat}$):
- $D_{bat} = \text{Storage} / \text{Resource}$
  - $D_{bat} = 672 \text{ Whr} / 472 \text{ Whr/day} = \sim 1.4 = 2 \text{ days}$

- Actual values depend on load and resource timing.
Conclusion

• Can provide energy to load based upon solar resource.
• Energy surplus per day predicted.
• System can run off battery for at least a day if needed.
• System needs at least two days (without load) to fully recharge.
Resources:

Hypothetical US grid PV: PVWATTS
http://www.nrel.gov/rredc/pvwatts/

~Natural Resources of Canada, RETSCREEN


Surface meteorology and Solar Energy
A renewable energy resource web site (release 6.0)
sponsored by NASA’s Earth Science Enterprise Program

http://eosweb.larc.nasa.gov/sse/
Developing World Applications
Grameen Shakti

Tea shop, woman technicians and mobile phone shop (www.gshakti.org)

Courtesy of Grameen Shakti. Used with permission.
IDEAAS - Brazil

- Fee for service
  - Company responsible for care of battery
- Flexible payment system
  - Customer determines timing/size of payment
- User education
  - Tools for teaching illiterate customers to care for own systems

Solar customer, installation, and lights for shrimp boats

Courtesy of Francisco Noguera. Used with permission.
SELCO - India

Lighting for a temple, silk cocoon sorting, and solar installation [www.selco-india.com](http://www.selco-india.com)

Courtesy of SELCO Solar Pvt. Ltd. Used with permission.
D.Light Design

www.dlightdesign.com

Courtesy of d.light design. Used with permission.
STG

Focused on Lesotho, MIT project, solar-thermal power technology solution: parabolic troughs, the organic Rankine cycle (ORC) engine, and the electrical control system.