

## Photo-voltaic system design and lab

Guest Speaker – Dr. Jim Bales, MIT; Assistant Director of the Edgerton Center.

Background:

- PhD at MIT in experimental solid state physics
- Experience with batteries in small robot submarines

Rule of thumb: “There are no good batteries.”

Lead-acid batteries are very reliable for the purposes of this class.

## Solar Panels

How do I collect solar energy, this electromagnetic energy that’s radiating down for free? Photovoltaic arrays.

How do I store it so that I can use it later? Batteries.

How much energy is available from the sun? At the surface of the earth, the sun’s energy is about 1 kW per square meter.

What’s in the way of getting and storing this energy? Things such as:

- Reflections
- Clouds, the atmosphere
- Losses due to heat (e.g. the efficiency of the array at different temperatures)
- Cosines (e.g. the directness of the angle at which the sun hits the array)

We can divide these factors into two categories: external (factors outside the photovoltaic system) and internal (factors within the system itself).

External factors (and how to address them):

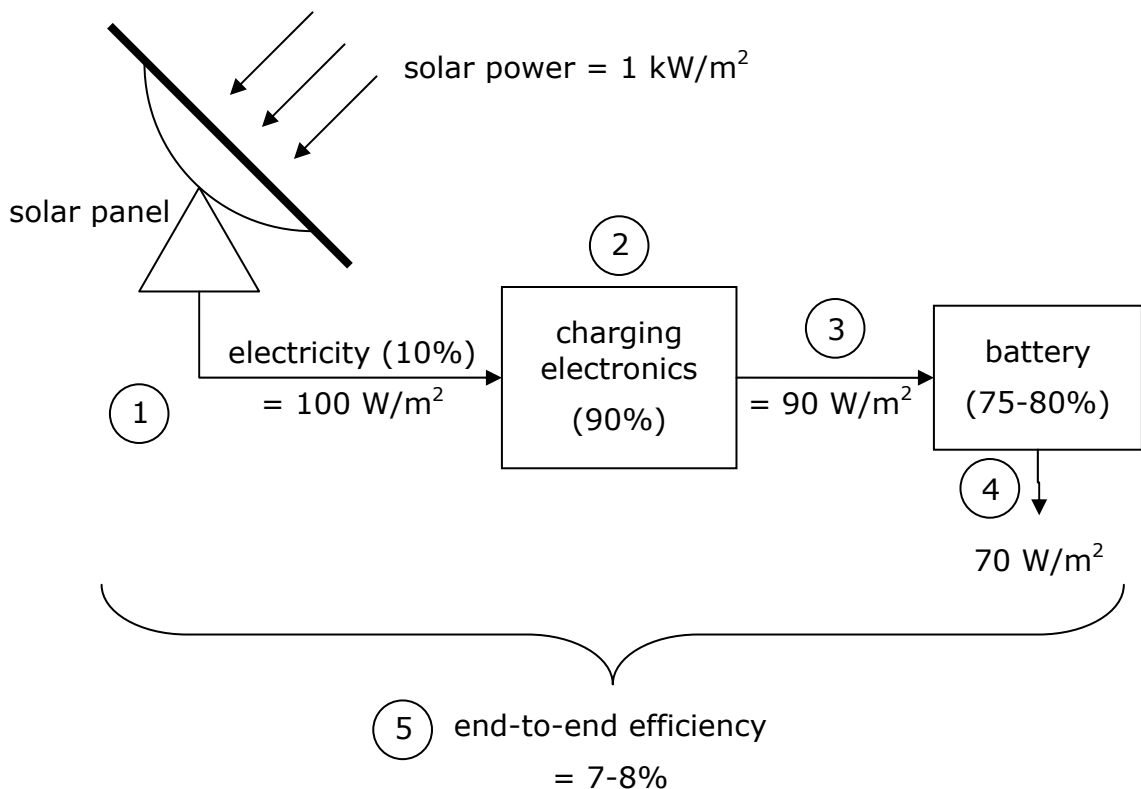
- Clouds, weather: Look at a solar map to determine the average irradiation over the course of the year.
- Cosine problem: The obvious solution is to have an array which can track the movement of the sun such that the sun’s rays will always hit the surface of the array at a right angle. However, in doing so, one must take into account the additional costs of building such a dynamic array:
  - It will be more expensive, have more moving parts and therefore may be less reliable or more likely to malfunction.
  - Some of the energy collected by the array will be lost in powering its movement.

- More land will be required (in the case of multiple arrays) so that the panels don't cast shadows on one another during the course of their movements.

To address this problem, determine the angle which will optimize the amount of radiation collected. This will depend upon latitude (and the consequent changes in the sun's angle over the daily and annual cycles). There are tables to look this stuff up.

Internal factors:

1. What's the typical efficiency of a photovoltaic array? ~10% efficiency; therefore, the electricity you get out will be 10% of the solar energy input.
2. Now we have to store the energy. Can we connect the array directly to the battery? Yes, but usually we want some sort of intermediary so that we can regulate how the battery charges. If the battery is always charged properly it will last longer.
3. How efficient are charging electronics? ~70-90%
4. We will also lose energy in putting the electricity into and extracting it out of the battery. How efficient is the battery? ~75-80%
5. The end-to-end efficiency of the system is therefore ~7-8%, neglecting the loss due to wiring and electrical connections.



How big of a battery do I need for my array?

Estimate the load:

ex: 4 lightbulbs @ 25 W per bulb (assuming 25 W is the load on the battery, conversion losses included)  
= need 100 W to power these bulbs

Remember:

- Power is the rate at which we use energy, i.e. energy divided by time.
- Energy has units of Power x Time, e.g. Watt-hours.

ex: A 10 amp-hour, 12 volt battery can give:

1 amp for 10 hours

0.1 amp for 100 hours

10 amps for 1 hour

BUT: Batteries don't work as well when discharging quickly!

So this battery has energy of 10 amp-hours x 12 volts

= 120 Watt-hours

This battery could run our 4 bulbs (from above) for how long?

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

$$\text{Time} = \frac{\text{Energy}}{\text{Power}} = \frac{120 \text{ W} \cdot \text{h}}{100 \text{ W}} = 1.2 \text{ h}$$

Assuming they are used for 3 hours per night, how big of a battery pack do I need to run these four 25 W bulbs for a night?

$$(4 \text{ lamps}) \left( \frac{25 \text{ W}}{\text{lamp}} \right) \left( \frac{3 \text{ hours}}{\text{night}} \right) = \frac{300 \text{ W} \cdot \text{h}}{\text{night}}$$

At 7% efficiency in the solar assembly, what size array do you need for this example?

1 day's worth of energy

= 7 % efficiency

× cosine  $\theta$  factor

× fudge factor for cloudcover

× fudge factor for rainy days

× fudge factor for air mass

×  $\frac{1 \text{ kW}}{\text{m}^2}$

× hours of daylight

This can all be combined into a single factor. A commonly used one is  $5 \frac{\text{kW} \cdot \text{h}}{\text{m}^2}$ .

$$= 5 \frac{\text{kW}}{\text{m}^2} \times 0.07 = 0.35 \frac{\text{kW}}{\text{m}^2}$$

So, does this mean we just need a one square meter array?

Nope: We need to account for rainy days, which, in succession, can pose another problem.

We need to ask ourselves:

2. In the event of successive rainy days (i.e. no charging of the battery), how long can I expect to have to run off my battery pack?
3. How long can I take to replenish my battery pack?

Current market costs for an array:

- Wholesale price (array only): ~\$3 per Watt
- Complete system: 20-30 Watts = ~\$300, or ~\$10 per Watt

Ed Kern:

About 800 megaWatts per year of solar panels are currently being produced in the industry.

- $\frac{1}{4}$  of these are going toward D-Lab type purposes.
- The rest are going toward subsidized applications in developed countries.

Ed just got back from the Philippines, assisting in building the largest photovoltaic array in the developing world = 1 hectare, 1 megaWatt A/C. The array feeds electric grid of a small private distribution utility supporting 80,000 customers in the surrounding area on Mindanao. It doesn't solve remote problems but will hopefully help solve the increasing appetite for electricity in the developing world. The World Bank is funding the project,

and for every dollar they spend on hardware, they spend two dollars on consulting.

In terms of the rainy day problem: having solar and hydropower on the same system can create a balance where you have solar on sunny days and water power on rainy days.

Also, you want to angle your solar array so that rain doesn't collect on it.

Sharp Corporation is the largest manufacturer of solar panels, making 20% of the panels in the world. They are starting to roll out standalone products: PV lights, PV water pumps, &c.

The battery is almost always the source of problems in the system, particularly mischarging.

PV as a "gateway drug" to electricity: When you introduce a developing area to electricity with a small PV system, the locals often become so greedy for power that they bring in other ways to generate power, such as diesel.

**Amy's Thoughts:**

There's a sense of three components to this trip:

	TEACHING	IMPLEMENTATION	LEARNING
Expectation:			
Reality:			

This is a common problem with people coming into developing countries from the West.

Listen. Ask. Keep these things in mind.

Be critical and objective about what you teach and implement. Do these things make sense for the location, the scope of the project, &c.?

Be cautious.

Ask yourself how you are implementing things. Are they sustainable? Does it make sense for community investment?

Don't mistake their fascination for interest.

Make friends, involve yourself in the cultural exchange.

Be able to defend your project to anyone who asks.