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Introduction to Solar Electricity

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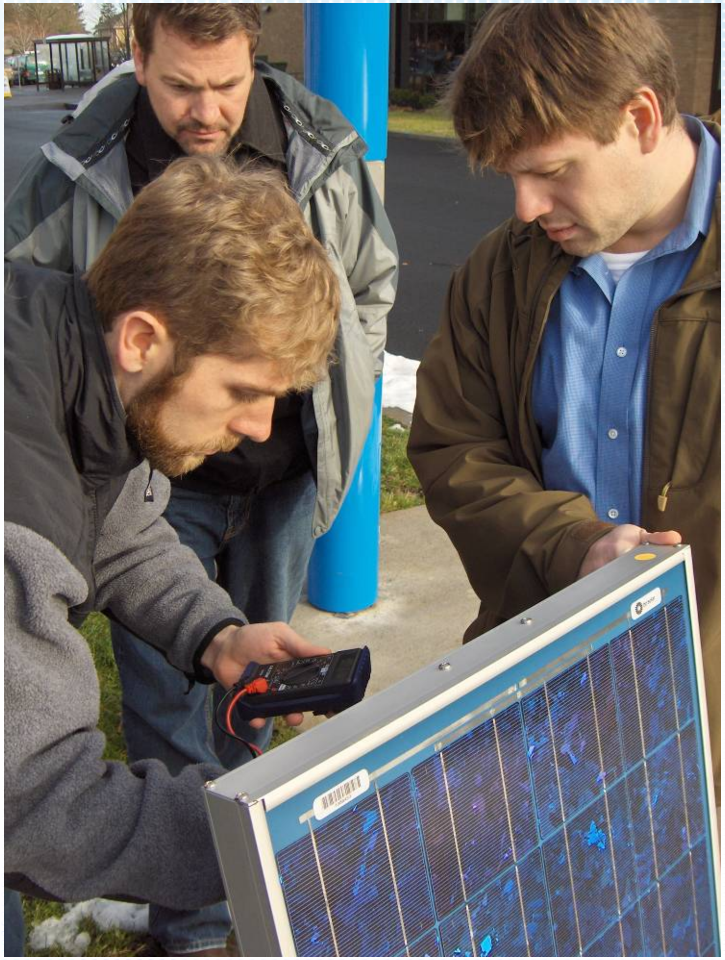
PV Hands-on 1



Take a PV panel and a Digital multimeter (DMM) out in the sun

1) Facing the sun, measure Voc and Isc (careful about how to use DMM for Voltage vs Current!)
2) At different angles vs the sun, repeat Voc and Isc measurements
3) Shade one or more cells, and repeat Voc & Isc measurements

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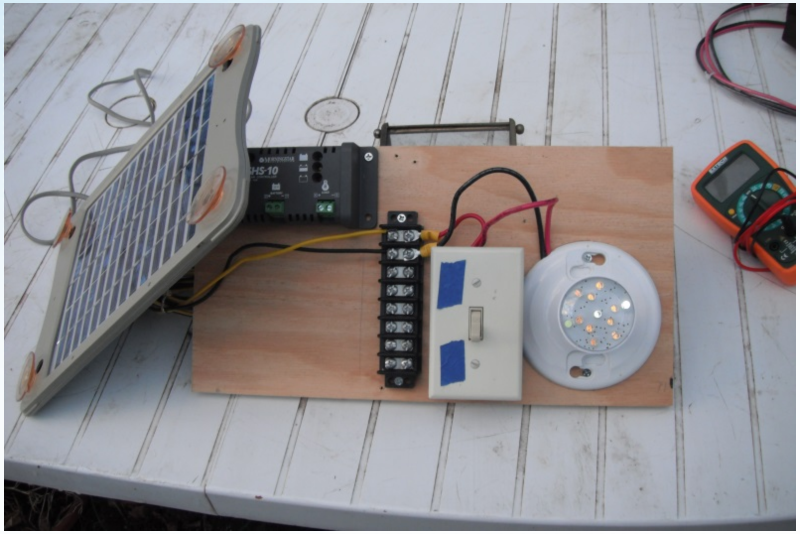
PV Hands-on 1, Part 2

4) Connect a PV panel directly to the circuit with a light bulb and observe

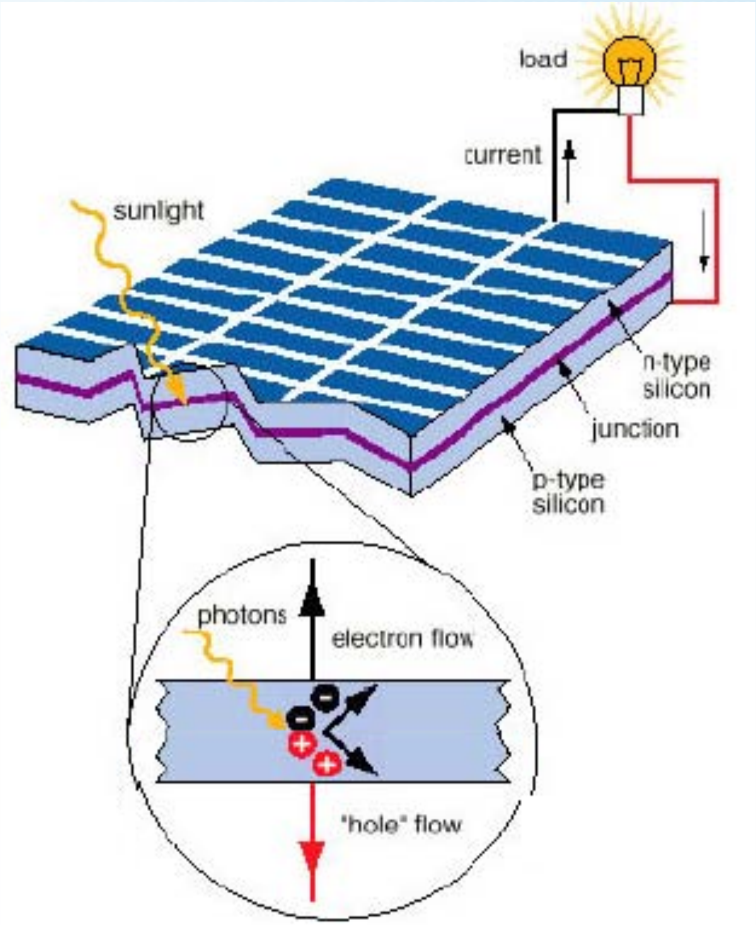
- what happens if orientation / exposure of the panel change
- what happens for various types of light bulbs: LED, CFL, incandescent.
- measure voltage & current to the bulb, compute power



5) If possible

- Connect 2 similar panels in series, then in parallel.
- Measure Voc and Isc and discuss.

Photovoltaic Effect

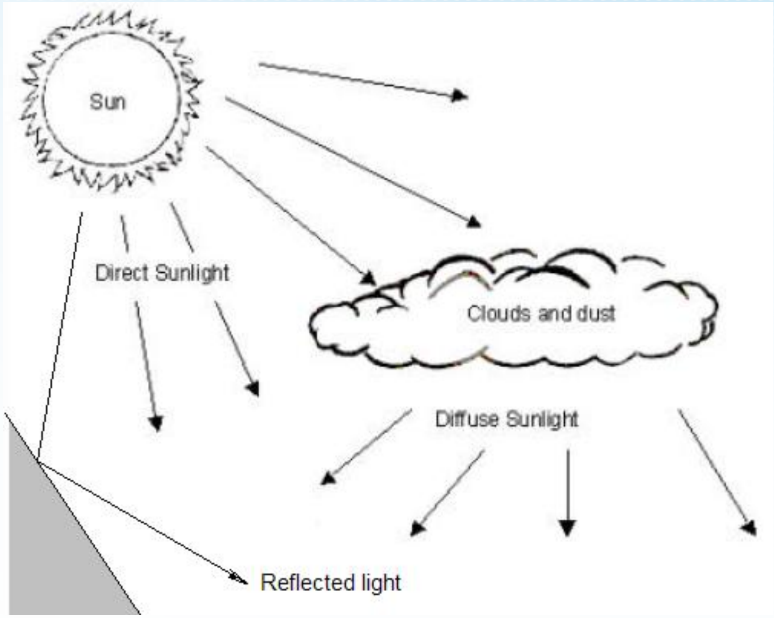


- PV cells produce electricity from sunlight (photons)
- To work properly each cell needs to receive sunlight
- Electrical energy needs to be stored for use if needed when there is not enough light

Cells, Modules, Panels

- Most common modules are composed of solar cells connected in series
- **Each cell generates the same voltage (~.5 V) regardless of size**
- **The current generated depends on the light intensity** and the cell size
- Many common solar panels are comprised of 2 modules in one frame
- 1 m^2 solar panel generates 60-120 Wp in 'standard conditions' , depending on the technology

Types of Solar Radiation



The total radiation (sunlight) is comprised of:

Direct light: Straight from the sun

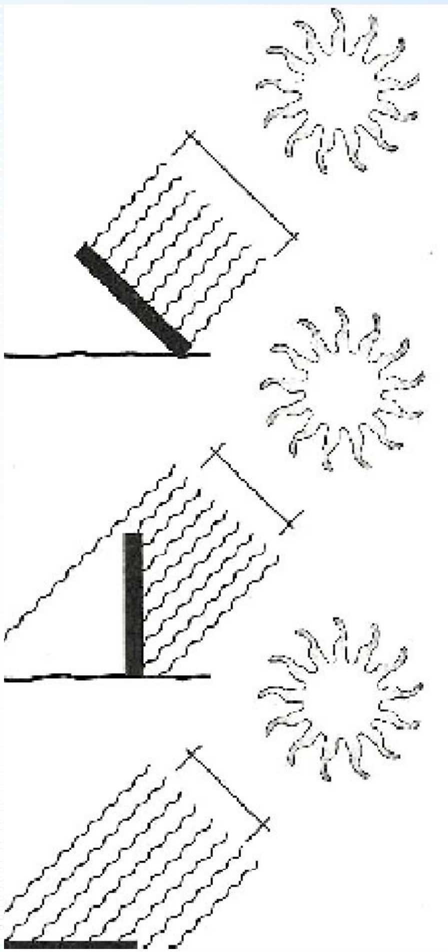
Diffuse light: Dispersed by clouds
Reflected light: From snow, water, etc.

On a completely cloudy day, all light may be diffuse.

Most PV panels produce the most power in direct radiation.
If one cell is shaded the panel electrical production (efficiency) drops drastically

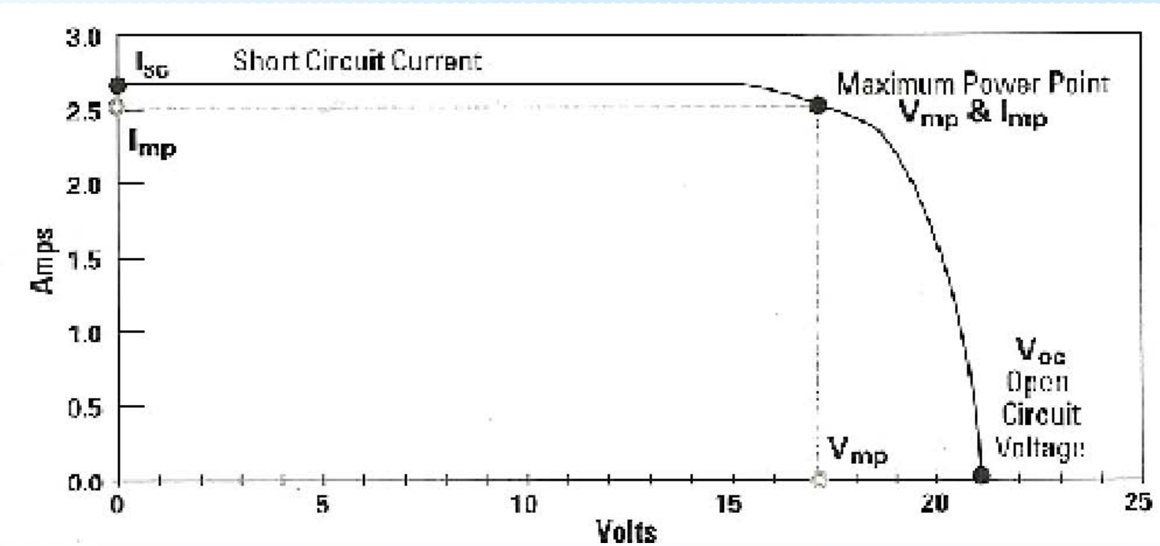
PV panels are much more sensitive to shade than thermal collectors

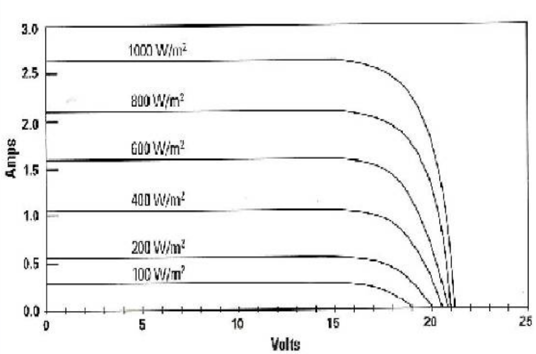
Panel Orientation



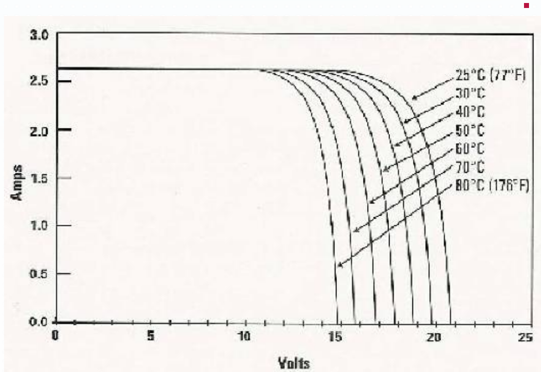
- Maximum power is received when the panel is facing the sun
- For a fixed panel, usually the **best yearly average power is received for an angle = latitude + 0° to 15°**
- The angle can be adapted according to seasonal needs
- In some cases, the angle can be adjusted every month, or even during the day
- **Close to the equator, 10° is the recommended minimum tilt angle** to allow rain to run off panels

PV Panels: Electrical Characteristics





Radiation effect (W/m²)



Temperature Effect

Shown on label:

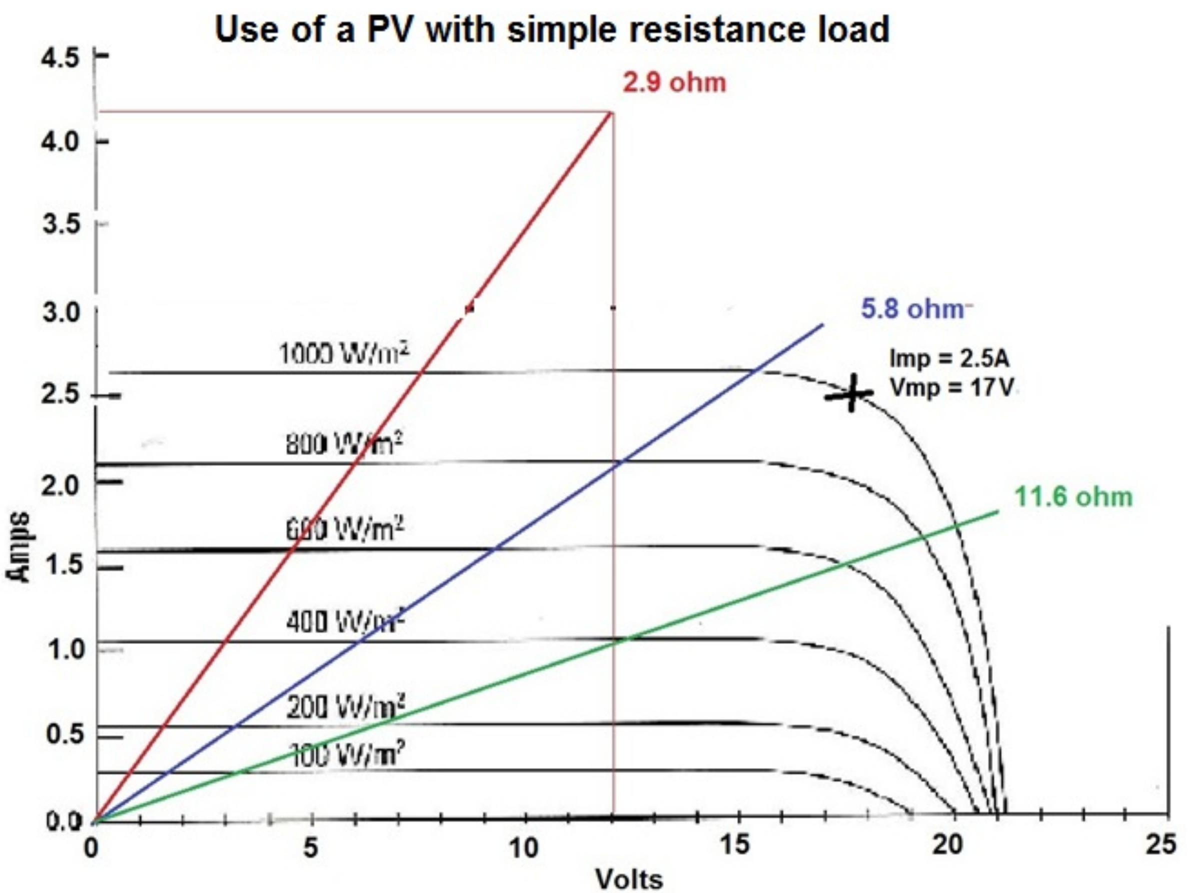
Isc = short circuit current depends on solar power received

Voc = open circuit current reduced for higher temperature

Maximum power: Vmp, Imp

All values are given for "standard conditions": 25°C and 1kW/m²

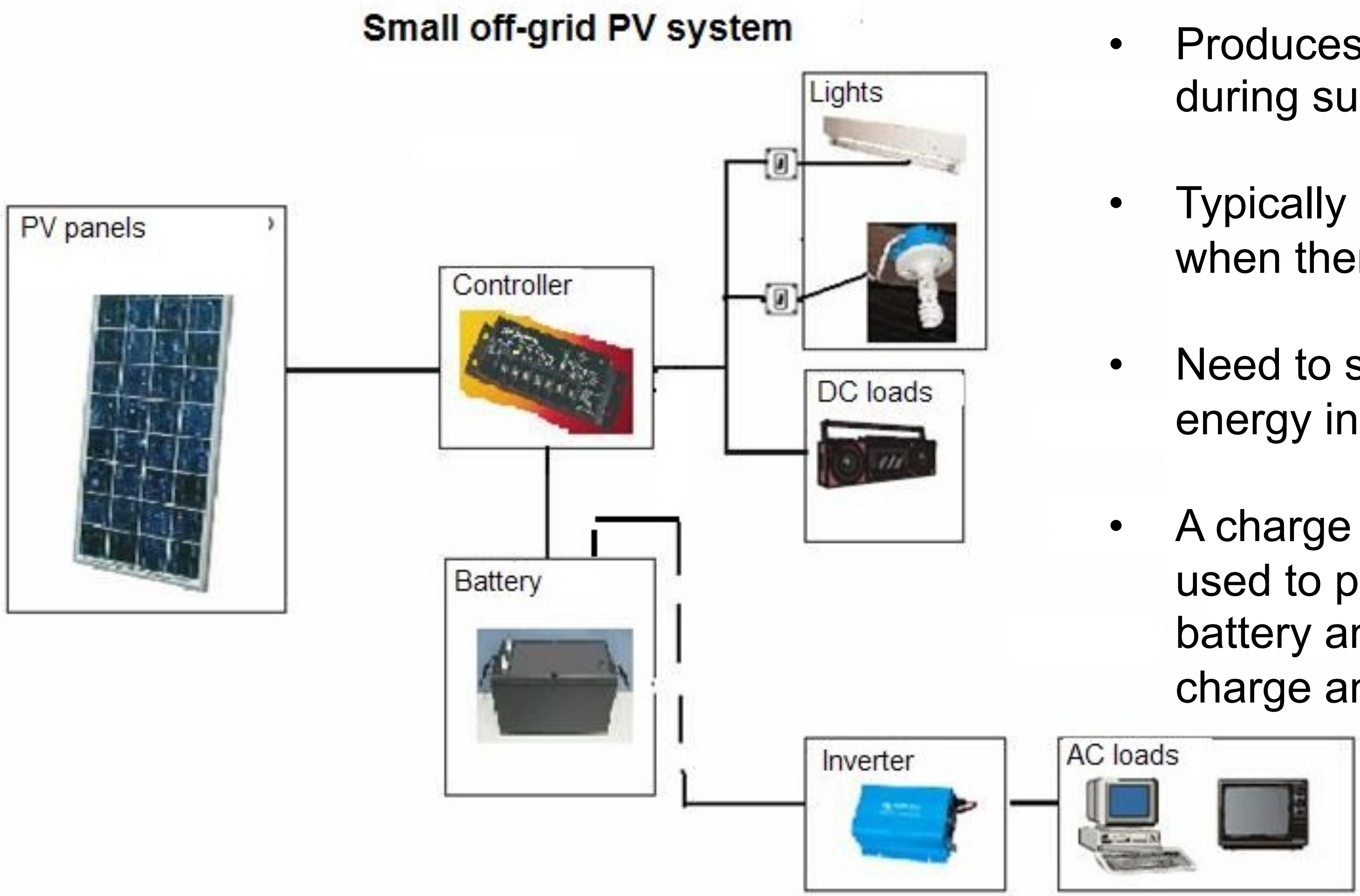
Interpreting the I-V curve



- A 50W bulb connected directly to a 50Wp panel may not consume 50W, even in bright sun.

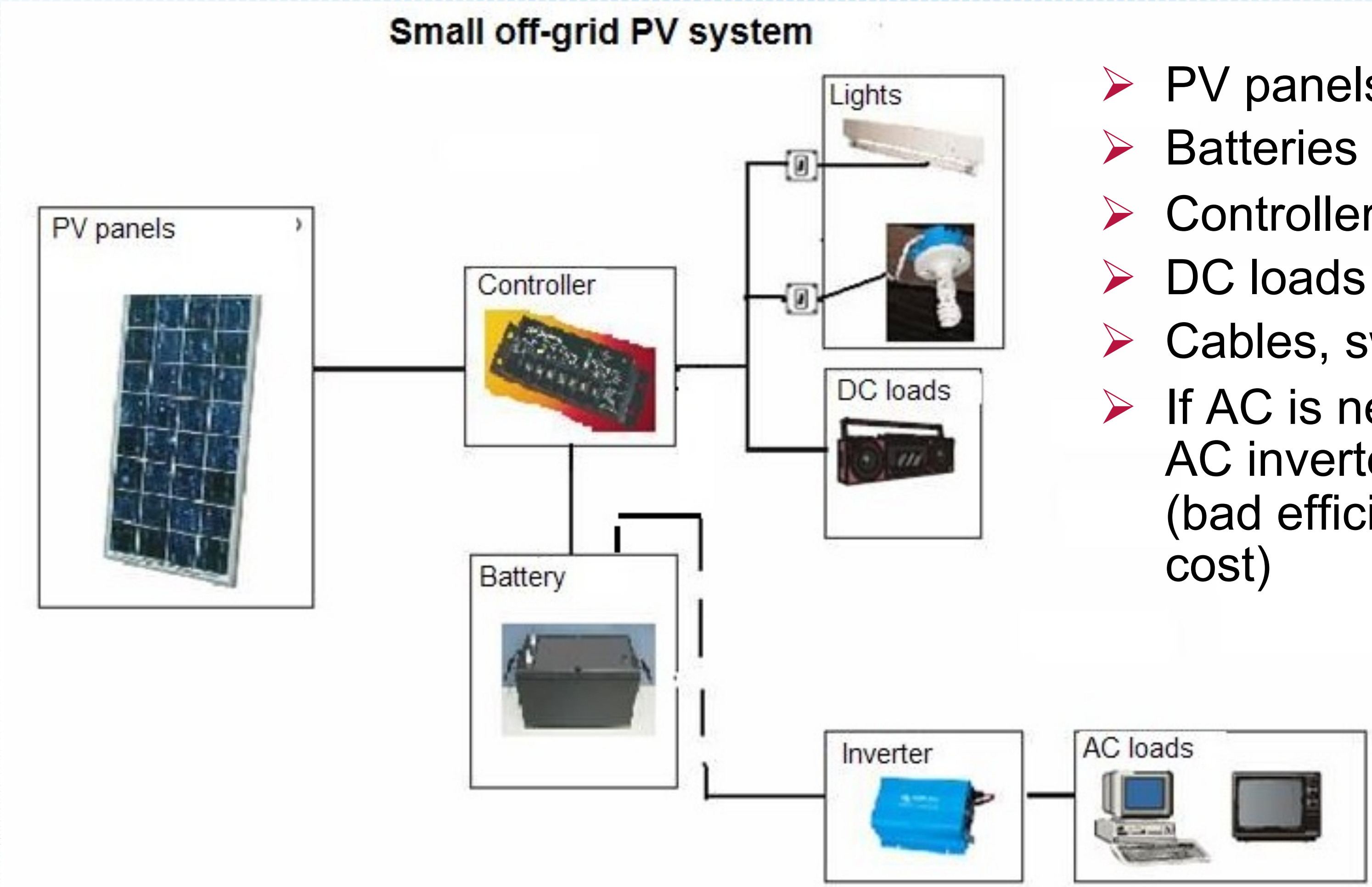
Small Photovoltaic Systems

Small PV System



- Produces electricity during sunlight hours
- Typically light is used when there is no sun
- Need to store electrical energy in batteries
- A charge controller is used to protect the battery and regulate its charge and discharge

Components of a PV System



- PV panels
- Batteries
- Controller
- DC loads
- Cables, switches, etc.
- If AC is needed a DC-AC inverter is required (bad efficiency, high cost)

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Battery

- Stores electrical energy to use when there is no sun
- 12 V is the most common for small systems
- Use “deep cycle” models designed for slow charge and discharge and longer life
- Car batteries are designed to supply quick bursts of energy and only partial discharge. They don’t last long in PV systems.
- Among Lead-Acid types, Deep cycle models have thicker plates, so they are heavier

Common Types of Lead-Acid Batteries

Lead Acid
- **Flooded**
  - Sealed (no maintenance)
  - **Not sealed**
    - **need regular addition of water**
    - **more risky in transportation**
- Gel (AGM)

Battery Capacity

Expressed in Amp-hours (Ah), is the product of discharge Amps x discharge time in hours, e.g. 100 Ah = 5Amps x 20hrs

If the battery is discharged quickly with a high discharge current, its usable capacity is lower.

Compare to a runner: a sprinter will use up his energy very quickly, vs a marathon runner may expand more energy over a longer time.

Specifications usually show C/100, C/20, or C/10, capacities, respectively for 100hrs, 20hrs, or 10 hrs discharge.

For example, a battery with a C/100 capacity of 100 Ah, may have a C/20 capacity of 88 Ah

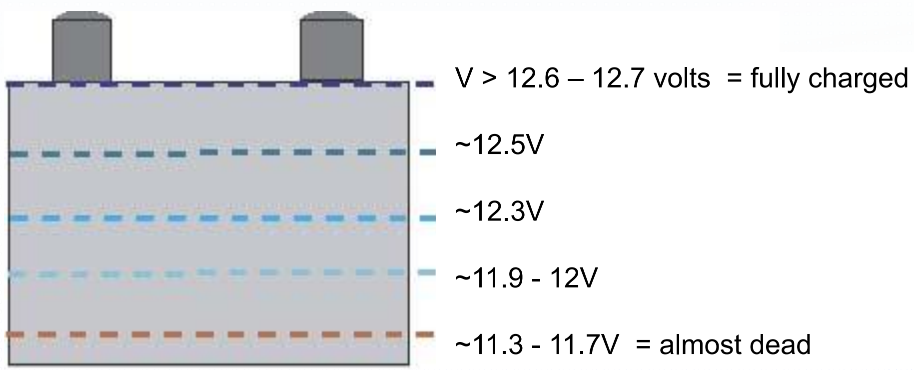
Note: battery capacity decreases when the temperature is low.

Battery capacity is not fixed

- A cold battery has less capacity than a warm one
- A battery stored in a warm place will self-discharge faster than a cold one – may be dead before using it

Depth of Discharge

- This term indicates how much of the battery capacity is depleted
- The battery life expectancy is reduced if the battery is discharged a lot on a regular basis
- A battery which is never more than 50% discharged can last twice as long as one that is regularly discharged 80%
- To keep the discharge around 50%, use a battery rated to store 2x the daily energy use



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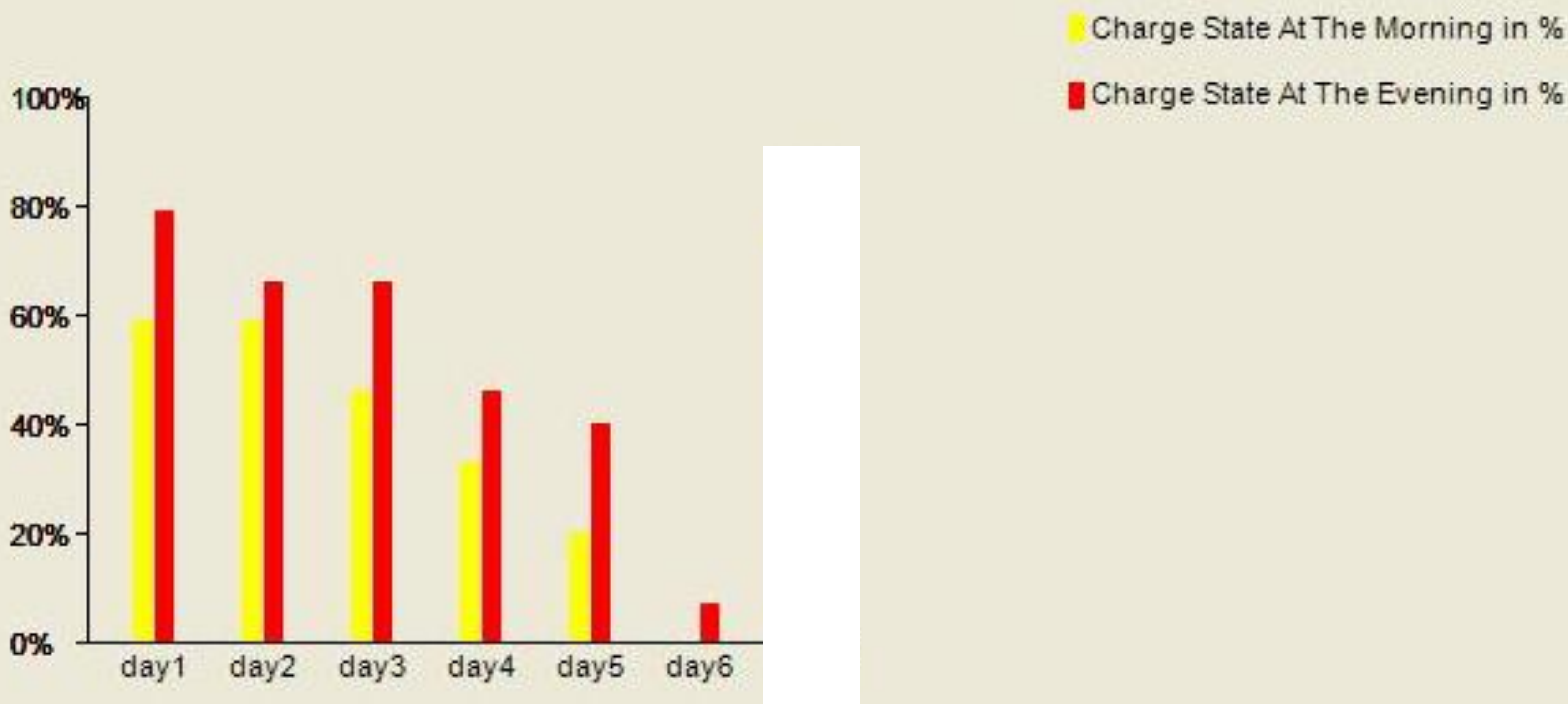
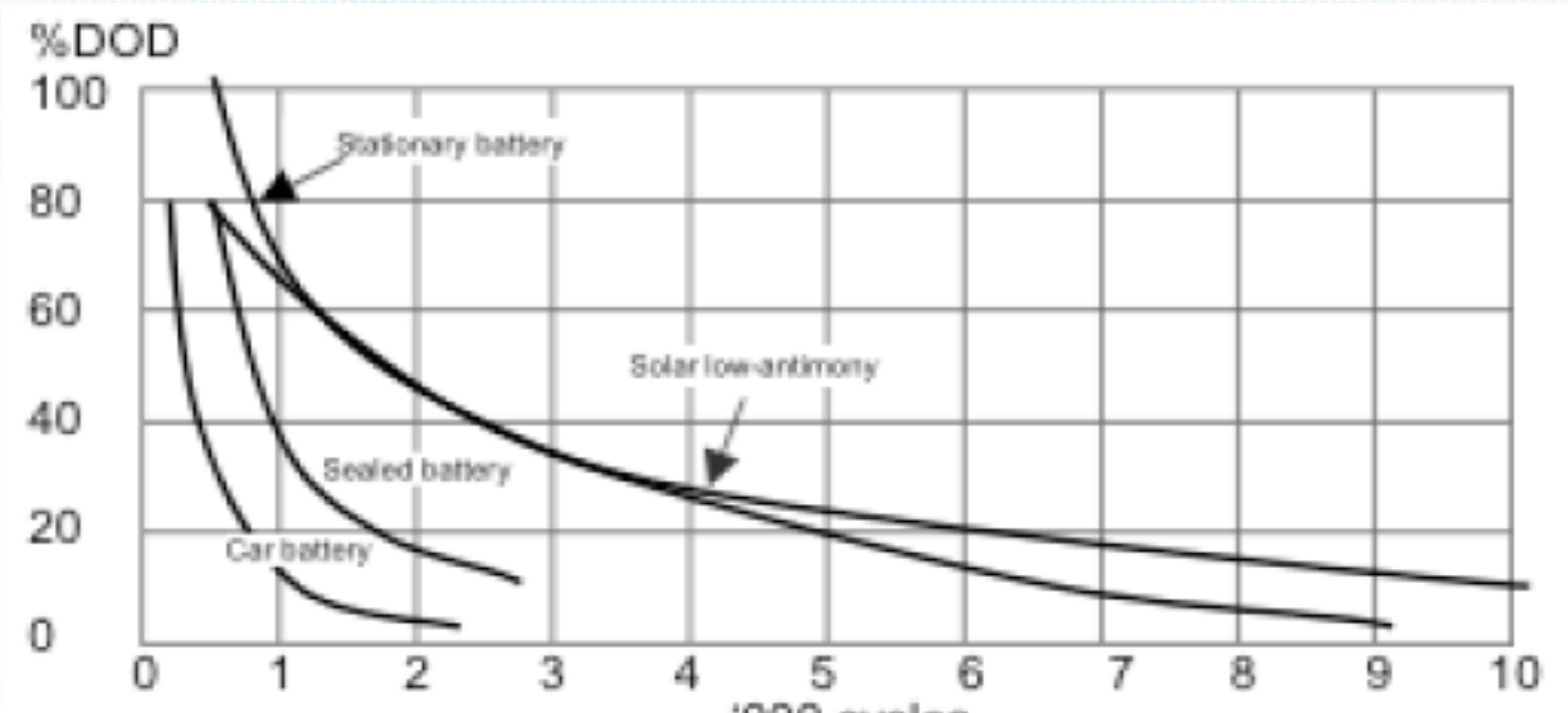
State of charge over time - example



Life expectancy in cycles vs. Depth of Discharge



Dangers and Precautions

Aggressive chemicals

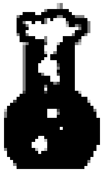
If the acid from a battery gets on a persons skin it can burn the skin. If the acid does touch someone's skin quickly apply baking soda to stop the burning

Throwing old batteries into the woods causes a lot of problems to the environment. It can pollute the water kill the plants and animals. Always bring your old battery back to the place where you purchase your new battery.

Wear goggles and gloves when working with batteries to protect yourself from the chemicals.

Use wood boxes and shelves to store the batteries metal conducts electricity

Flammable gas



Never store batteries in an enclosed area allow the gas from the batteries to escape never have fire or smoke a cigarette near a battery.

Electricity

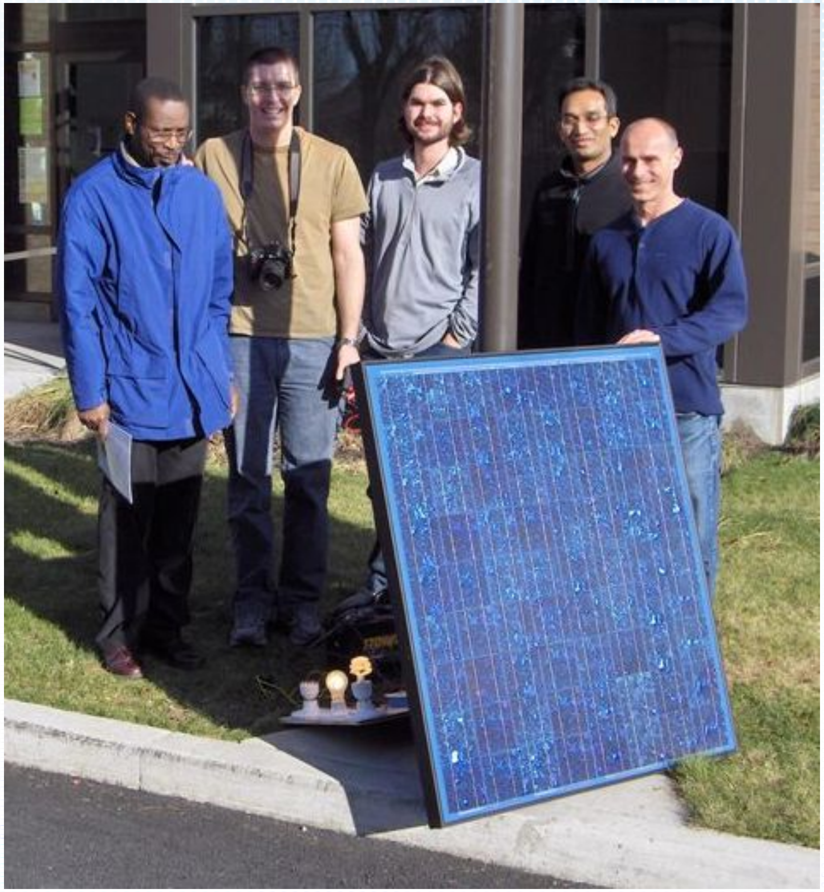
Always tape the end of your tools and leave only the working part of the tool exposed.

Charge Controller

- Controls proper charging of the battery when sun is shining
- Protects battery against overcharge
- Recommended protections
  - Low Voltage Disconnect (LVD)
  - Overcurrent
  - Reverse polarity
  - Short circuit
  - Blocking diode to avoid current flowing to panels at night
  - Equalization cycle to remove stratification in battery

- LEDs or display give information on the state of charge of the batteries

Hands-on Lab 2: using controller & battery



- Each group:

  1 PV panel, 1 12V battery, 1 circuit panel board, assortment of incandescent light bulb, and/or CFL, and/or LED,

  1 or 2 multimeter, 1 clamp meter (shared)

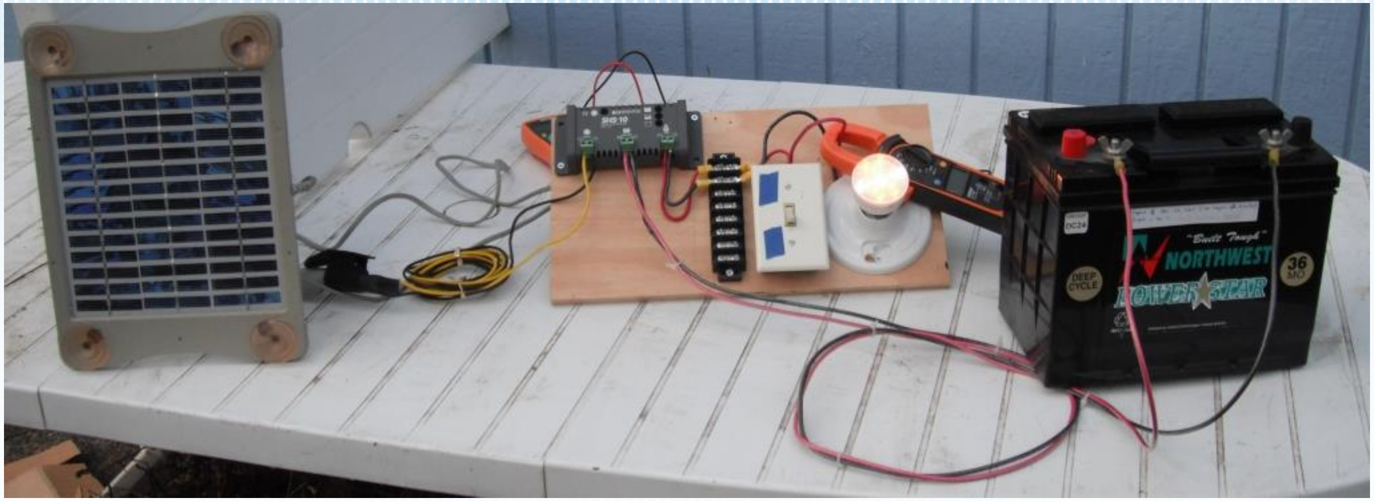
Connect circuit panel to battery and PV panels

- Respect instructions for connection order
- Observe controller lights or display

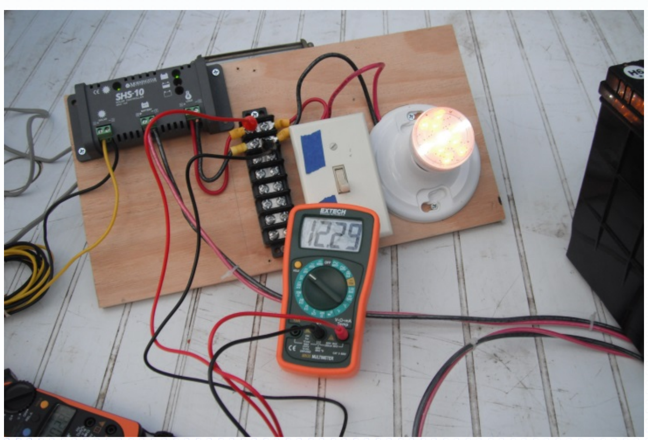
Check:

- Continuity of connections before turning on
- PV panels Voc vs. Voltage with light on
- Isc vs.current with light on
- Battery voltage

Hands-on Lab 2 - examples



Example of overall setup

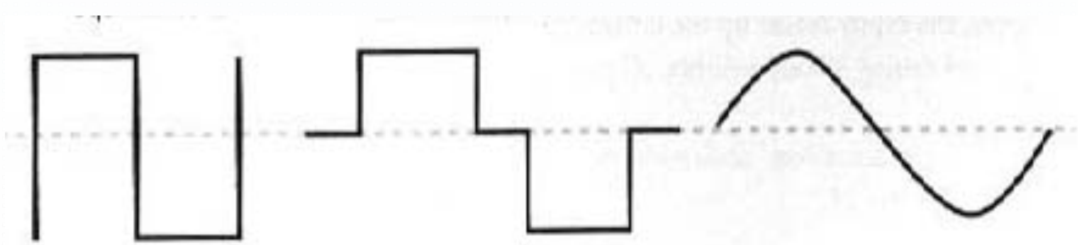


Measuring voltage to bulb

Measuring current to bulb

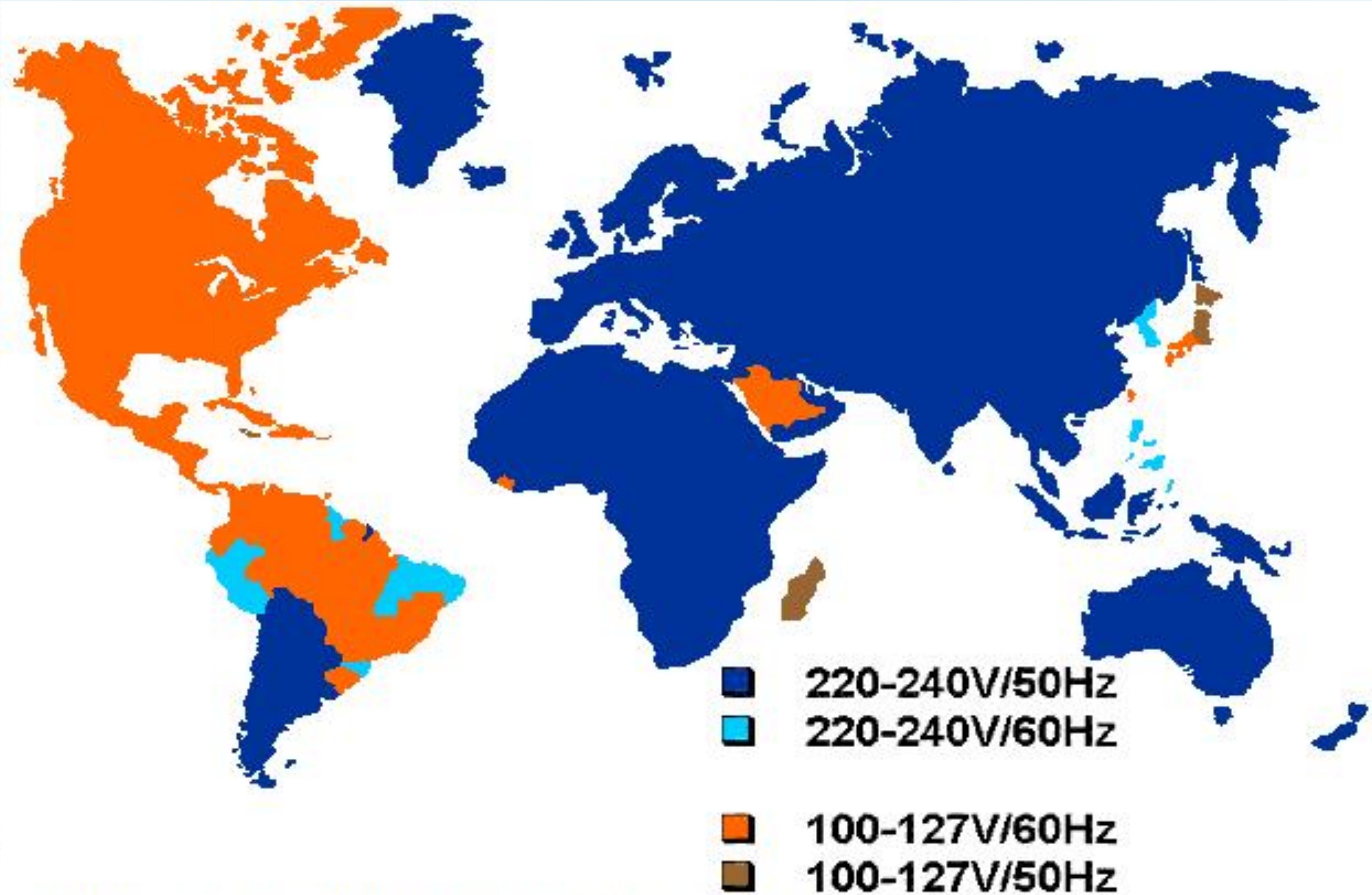
Inverter

- Transforms direct current (DC) into alternating current (AC)
- Must provide not only nominal power rating of the AC load, but also surge power (can be 2.5x the nominal rating for motors)
- Efficiency <90%, some power is lost
- Uses low but continuous power if left on when not in use
- Three types of waveforms
  - Square wave, modified sine wave, sine wave
  - True sine wave is most expensive but necessary for some sensitive electronics



•Always test the inverter with the load before field implementation

AC types



http://users.pandora.be/worldstandards/electricity.htm

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Demo: Using an inverter

- Allows to use AC light bulbs, which are easier to find than DC bulbs
- The inverter is connected directly to the battery (clips are temporary, a permanent connection is better)
- The battery consumes electricity even the light bulb is not ON
- Warning: this may discharge the battery too fully and reduce its life expectancy

PV System Sizing

Find out

1. How much energy is needed?
2. How much is available from the sun?
3. How much will be lost in the system?

Then calculate

1. What size panels are needed
2. How much battery capacity is needed

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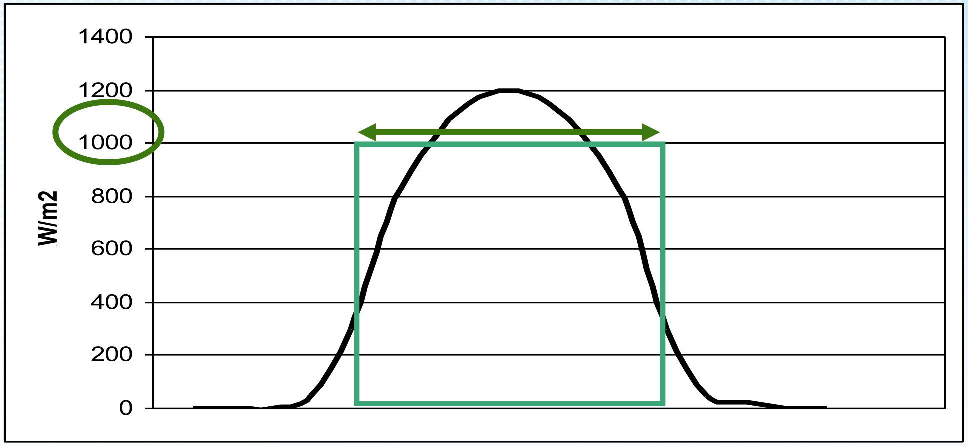
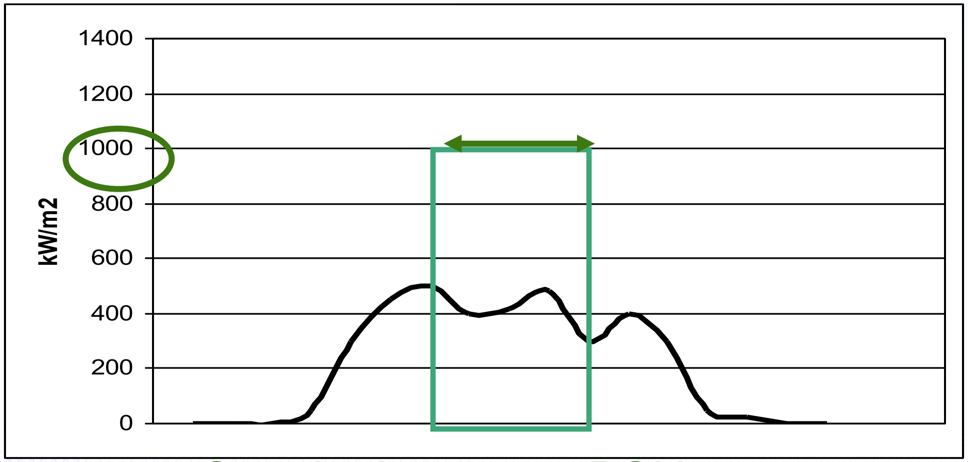
The Solar Resource



Perfect day: maximum PSH



Cloudy day: poor PSH

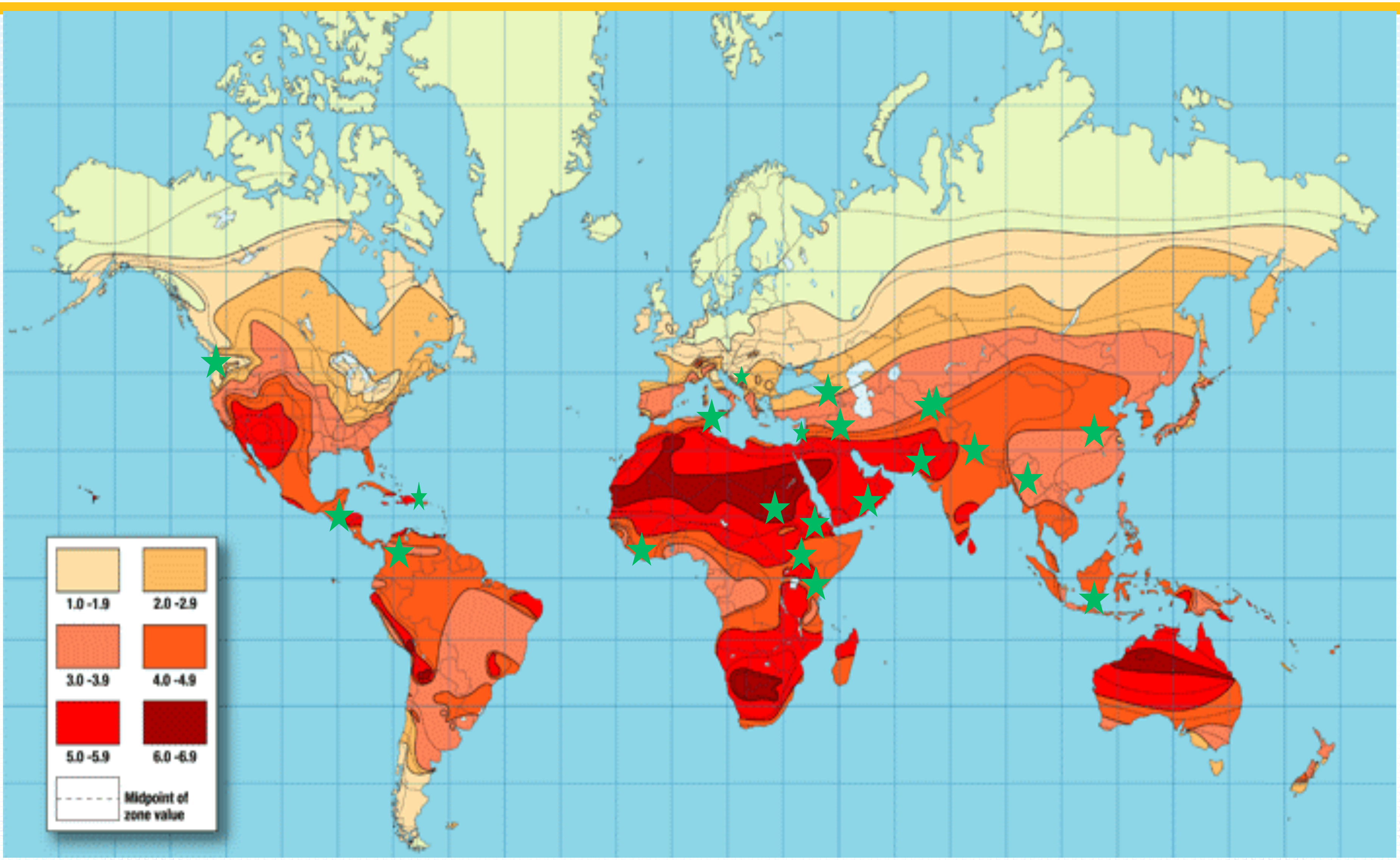
"Perfect Solar Hours" or "Peak Sun Hours" (PSH) are used to express the energy received in terms of equivalent hours at the "standard power" of 1000 W/m^2

Solar Maps / weather data can be expressed by the same number, either in PSH or kWh/m^2

1 PSH @ 1 kW/m^2 = 1 kWh/m^2

Common PSH values In tropical zones:

- Up to 7 on sunny days
- From 2-4 on cloudy days
- 4-6 as a monthly average



Yearly average kWh/m^2 on a **horizontal surface**

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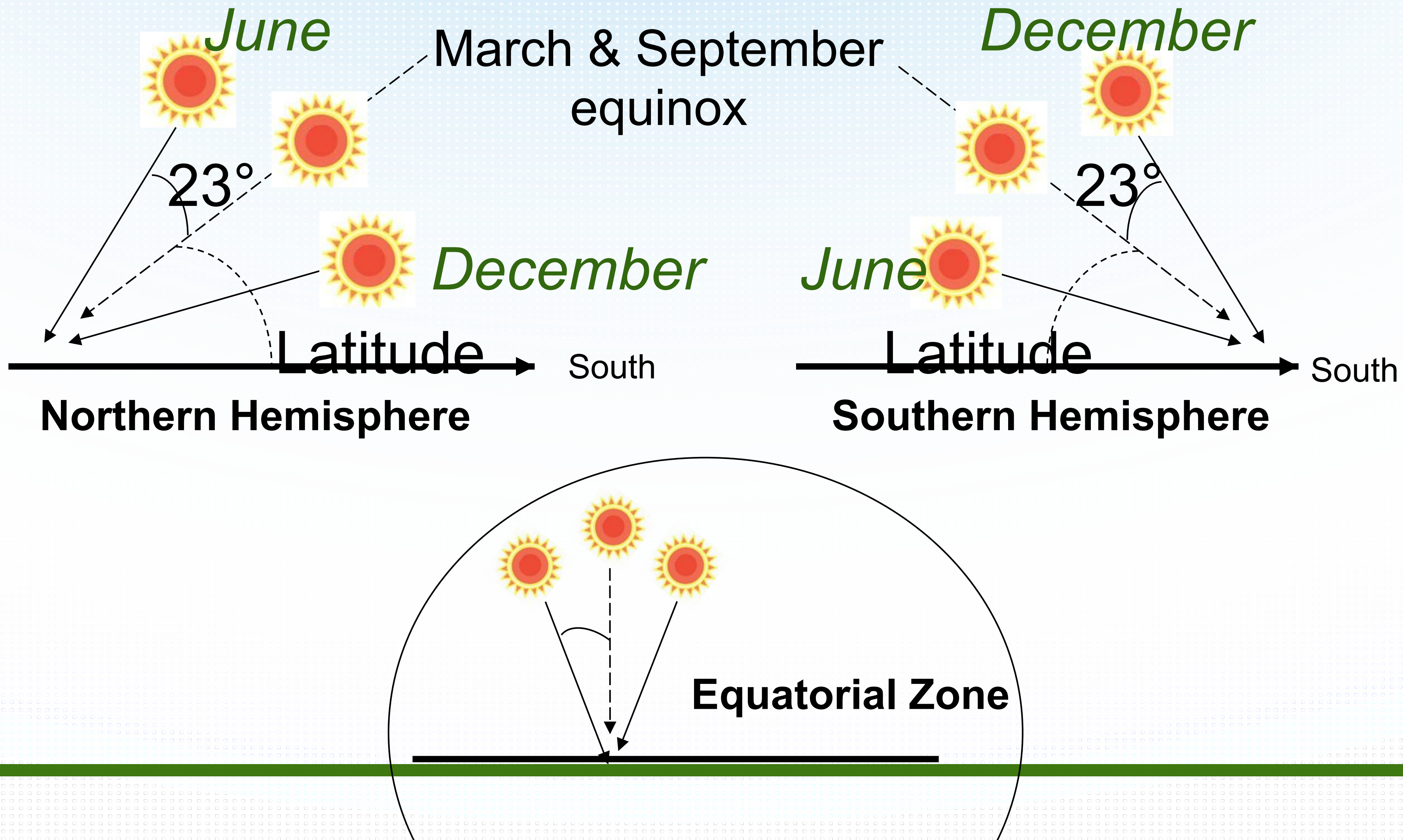
Seasonal Variation – incident angle



Step 1: Evaluation of the Load

	Quantity	W	Inverter Efficiency	Hours/day	Wh / day
CFL	4 4	11W 20W	n/a	4 3	176 Wh 240 Wh
LED	2	1.5W	n/a	11	33 Wh
Other DC loads (sound / tv)	1	35W	n/a	1	35 Wh
other					
AC load (TV + DVD)	1	110W	85%	1.2	157 Wh
TOTAL					641 Wh

Step 2: Weather Data (PSH)

Mindanao, Philippines

Latitude	6.5					
Longitude	125.5					
	NASA data		RETscreen 'Monthly average daily radiation in plane of PV array (kWh/m²/d)			
	Av temp	0deg horizontal	6 deg	10deg	15deg	20deg
Jan	25.2	4.58	4.75	4.84	4.93	4.99
Feb	25.3	4.94	5.05	5.11	5.15	5.17
Mar	26.1	5.29	5.32	5.33	5.30	5.25
Apr	26.8	5.56	5.50	5.43	5.32	5.19
May	27.2	5.27	5.14	5.03	4.87	4.68
Jun	26.7	4.87	4.72	4.60	4.43	4.24
Jul	25.9	4.96	4.82	4.71	4.55	4.36
Aug	25.9	5.19	5.10	5.02	4.90	4.75
Sept	26.1	5.22	5.22	5.20	5.14	5.06
Oct	26.1	5.03	5.12	5.16	5.18	5.17
Nov	25.9	5	5.18	5.27	5.36	5.43
Dec	25.3	4.78	4.99	5.10	5.22	5.31
annual	26	5.06	5.08	5.07	5.03	4.97
Mini		4.58	4.72	4.60	4.43	4.24
Maxi		5.56	5.50	5.43	5.36	5.43

http://www.retscreen.net/ and NASA database

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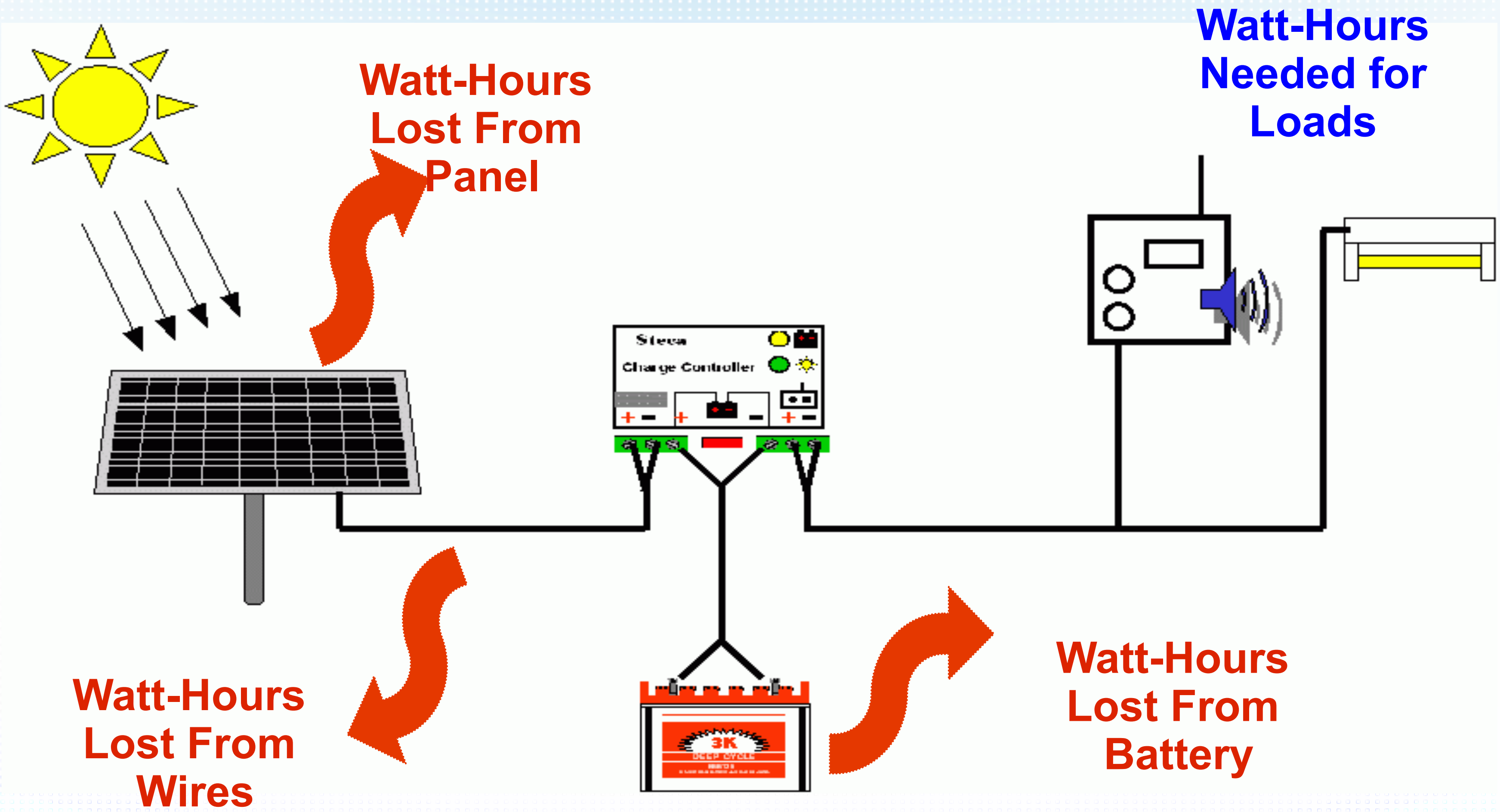
Losses & Efficiency



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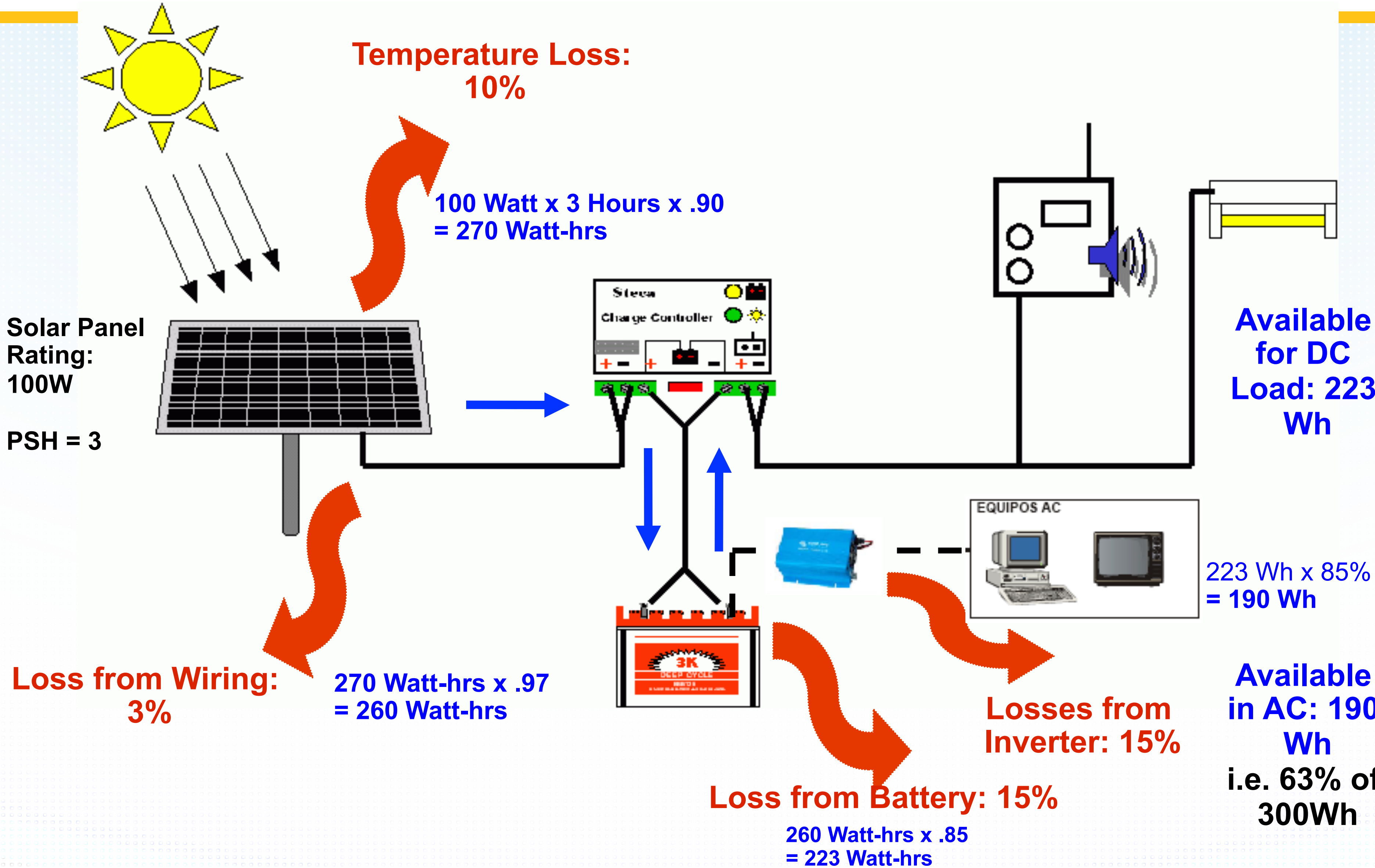
Example



Step 4: Simplified Panel Sizing

- The amount of energy available from the battery (in Wh) is:
  Peak panel power (Wp) x PSH (hrs) – losses, or
  Peak panel power (Wp) x PSH (hrs) x combined efficiencies

  Conservatively, you can use a 50% efficiency factor, i.e. 0.5

- To meet the average electricity load, we then need:

$$\text{Peak panel power (Wp)} = \frac{\text{Load (Wh)}}{\text{PSH (h)} \times 0.5}$$

- Use the PSH value for the worst month of the year, found through RETscreen / NASA, or regional maps

Panel Sizing - Example

Using the load from Step1 slide (641Wh)
and weather data from RETscreen for Chirinos, Peru (34.5ºC , 4.23PSH)

Power needed (Wp) =

$$\frac{641\ \text{Wh}}{4.23\text{h} \times 0.5} = 303\ \text{Wp}$$

This needs to be rounded to a number of commercially available solar panels,
e.g. 4 panels of 80 Wp each; or 3 panels of 100 Wp, etc.

Step 5: Battery Sizing

The main design parameters are:

- Number of days of autonomy (to use system during cloudy days, typically 2-5 days)
- Depth of Discharge (usually 50%)
- Battery and system voltage (for example a 12 V system could be supplied with 2 batteries of 6 V in series)
- In terms of energy supply:

$$\text{Battery Capacity (Wh)} = \frac{\text{daily load (Wh) x days of autonomy}}{\text{depth of discharge (\%)}}$$

Battery capacity is usually provided in amp hours (Ah)

Amps = Watts/Volts so:

$$\text{Capacity (Ah)} = \frac{\text{Capacity (Wh)}}{\text{System voltage (V)}}$$

Battery Capacity Sizing Example

For the same Chirinos load lets use:

- 3 days of autonomy
- 50% depth of discharge
- 12V system and battery
- To meet 641Wh daily load with 85% battery efficiency,

  The battery needs to store: 641Wh / 85%= 777Wh

$$\text{Needed Capacity (Wh)} = \frac{\text{777 (Wh) x 3 days of autonomy}}{50\%} = \text{4665 Wh}$$

In Amp hours this will be:

$$\text{Capacity (Ah)} = \frac{\text{4665 Wh}}{\text{12V}} = \text{389 Ah}$$

Rounding up to a multiple of what's available on the market;

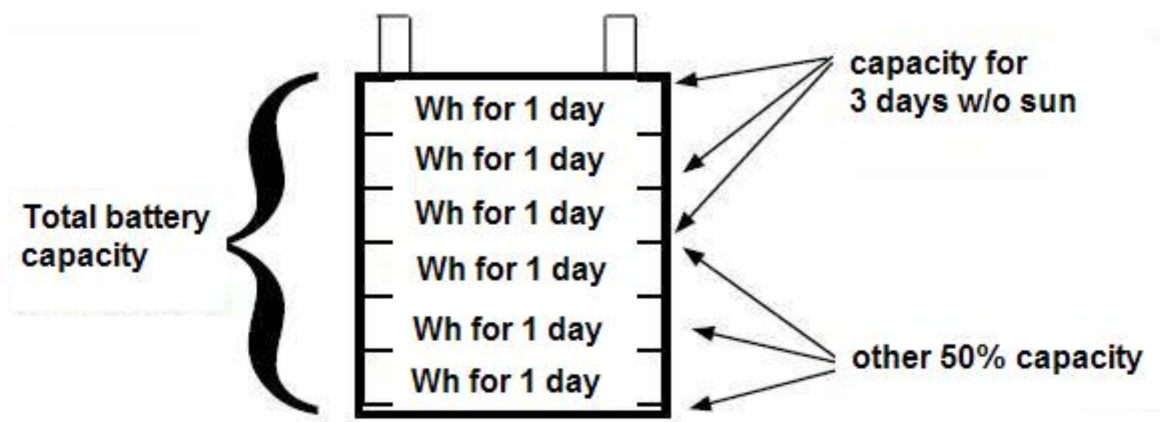
4 x 104Ah = 416 Ah,

2 x 200Ah = 400 Ah, etc.

Battery Charge Management

To maintain charge level and increase battery life:
1.) make sure design load values are not exceeded
2.) Every cloudy / rainy day try to reduce energy use
3.) if possible use a capacity 20-50% larger than calculations suggest (safety factor)

When the charge controller Low Voltage Disconnect switches the system off it means that the whole reserve, including days of autonomy, is exhausted. It will take the same number of days with full sunshine and no load use to fully recharge the batteries



Sizing Exercises

RETScreen® Solar Resource

Nearest location for weather data		Huancayo
Latitude of project location	°N	-12.1

Month	Monthly average daily radiation on horizontal surface (kWh/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/d)
January	7.38	12.5	6.93
February	6.71	12.5	6.50
March	6.54	12.0	6.58
April	6.54	12.0	6.91
May	6.18	11.0	6.86
June	6.28	9.5	7.22
July	6.30	9.5	7.14
August	6.74	11.0	7.30
September	7.18	12.5	7.37
October	7.47	13.0	7.31
November	7.75	13.0	7.31
December	7.21	12.5	6.72

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Sizing Exercises – Panels and Batteries

Groups A

- Size a home system for Huancayo, Peru, using previous demand analysis values

Groups B

- Size a similar system for a clinic in Huancayo replacing TV/DVD with a refrigerator, and eliminating the sound system

- Try 2 scenarios with different depth of discharge and days of autonomy

Homework: Reverse Sizing Exercise

In many countries, vendors sell pre-packaged domestic systems, e.g.

1. 50Wp
2. 75Wp
3. 100Wp

Select one of those and see how many hours of use it would give for three 11W CFLs and a 40W TV in various climates:

A. 4PSH (Amazon or Thailand)
B. 5PSH (Philippines)
C. 6 PSH (Cuzco, Peru)
D. 7 PSH (Mauritania)