

Small PV Systems for Developing Countries – Day 1



Green Empowerment



November 2010

Electricity basics

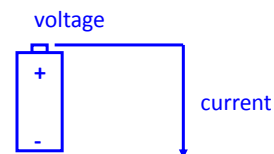
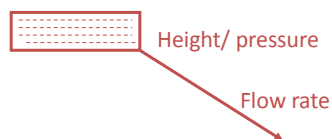
The flow of electrical current through a wire is a flow of electrons through.

It is comparable to the *flow of water through a pipe*

Voltage is similar to *water pressure*

Current is similar to *flow rate*

For a same wire (/pipe),
the higher the voltage (/pressure),
the higher the current (/flow rate)



Oct 2008 2



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Electrical Power

When an electrical voltage is applied to a “load” e.g. light, radio, etc. an electrical current flows through the load and the power used is calculated as:

$$\text{Power} = \text{Voltage} \times \text{Current}$$

Power is measured in Watts (W) and symbolized as P
Voltage is measured in Volts (V) and symbolized as V
Current is measured in Amps (A) and symbolized as I

a 60Watt light bulb designed for a 12V power source uses 5 Amps
 $12 \text{ Volts} \times 5 \text{ Amps} = 60 \text{ Watts}$

a 60Watt light bulb designed for a 120V power source uses 0.5 Amps
 $120 \text{ Volts} \times .5 \text{ Amps} = 60 \text{ Watts}$

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Electrical resistance

- Water flow analogy: the smaller the pipe, the more friction there is.
 - With electricity, the thinner the wire, the higher the resistance
 - Resistance R is measured in Ohms (Ω)
- Measuring with a Voltmeter/ Multimeter:
 - 0Ω = no resistance = there is continuity, the current flows
 - Overload/ maximum figure = open circuit (open switch)
- Key formula (Ohm’s law): $V = R \times I$
Voltage across the resistance (Volts) = Resistance (Ω) x Current (Amp)

A traditional incandescent light bulb is a high resistance wire:
the current is so high that the filament gets very hot and emits light
example: Resistance of an incandescent 60W bulb?

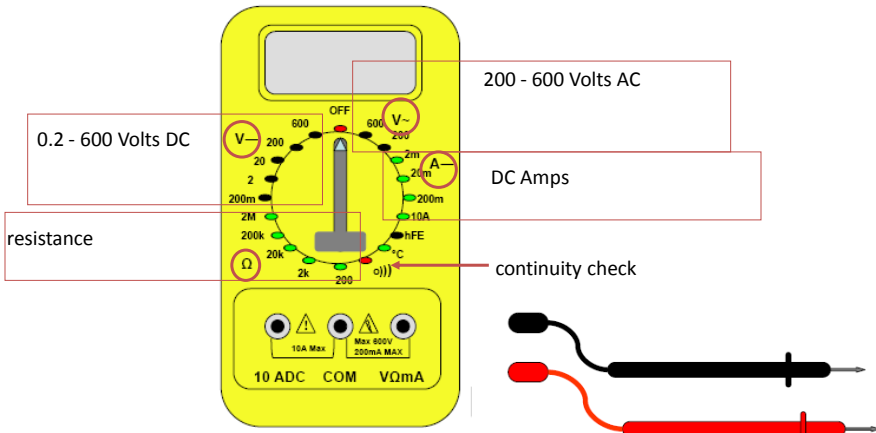
$$\begin{array}{ll} \text{Designed for 12V: } I = 60\text{W}/12\text{V} = 5\text{A} & R = 12\text{V}/5\text{A} = 2.4\Omega \\ \text{Designed for 120V: } I = 60\text{W}/120\text{V} = 0.5\text{A} & R = 120\text{V}/0.5\text{A} = 240\Omega \end{array}$$

For a given R value

- the higher the current, the higher the Voltage drop (e.g. losses in a wire)
- The higher the applied voltage, the higher the current
(E.G. light bulb: a bulb built for 12V or 110V will burn if plugged into 220V)
The 2.4Ω bulb, plugged into 120V will use $I = 120\text{V}/2.4\Omega = 50\text{A}$ VERY HIGH!

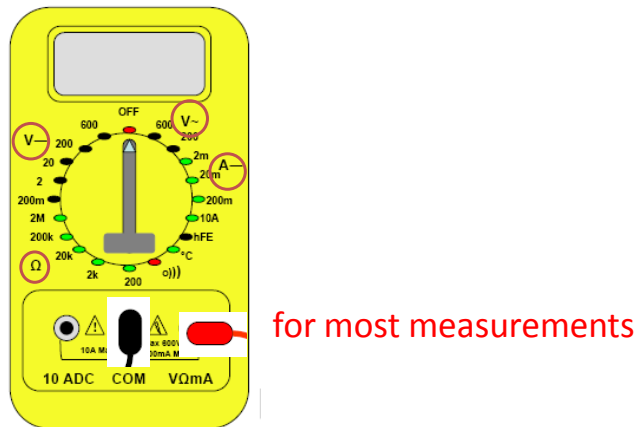
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Using a Voltmeter: select what will be measured



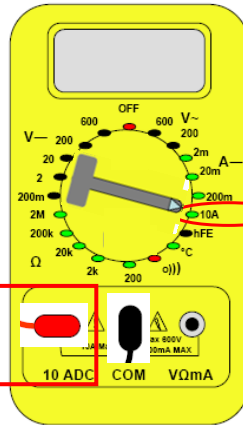
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Using a Voltmeter: connect probes



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Using a Voltmeter: connect probes



for DC current only

Do not leave
probe connected
like this!!!

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DC vs. AC



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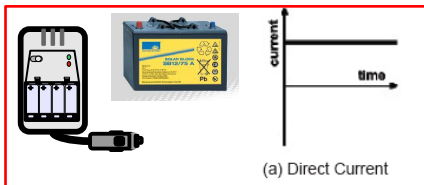
Electricity coming from a battery or solar panel is called Direct Current (DC)

There is a Positive contact/wire (+) and a Negative (-)

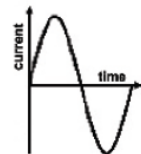
Most common DC voltages for small electronics are 1.5V (AAA, AA, C, D sizes)

Most common batteries for cars, marine, motorbikes etc. are 12V

Industrial application might use 6V, 12V, 24V, 48V



(a) Direct Current



(b) Alternating Current



The grid electricity provided to houses, industries, etc. is Alternative Current (AC)

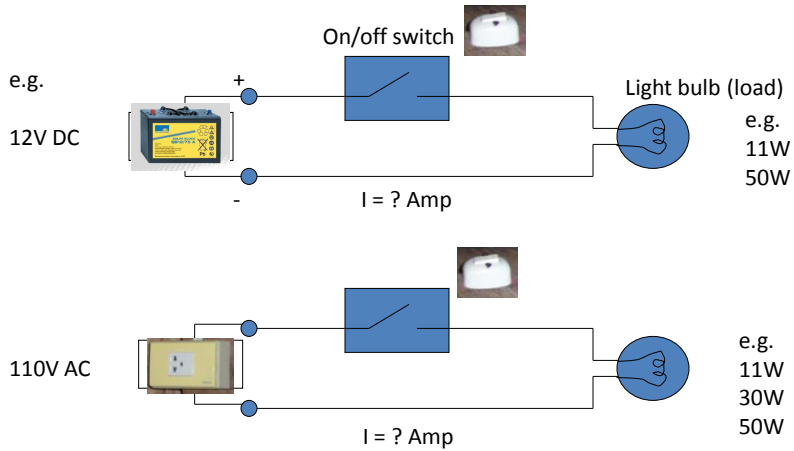
Each wire changes from + to - 50 (Europe) or 60 (US) times per second

Household voltage is usually 110V (US) or 220V (Europe)

**Devices made for one type of current CANNOT be used with the other
When measuring V or I, need to use different multimeter settings**

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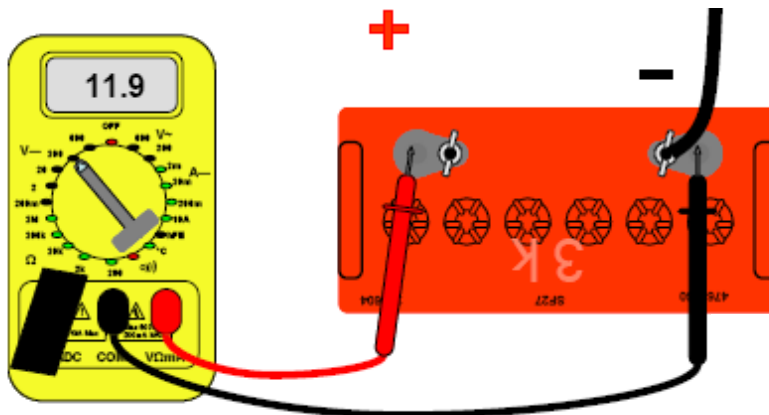
Simple electrical circuit



Remember: $P = V \times I$ i.e. $I = P / V$

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Measuring Battery Voltage



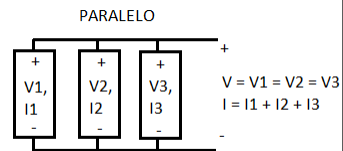
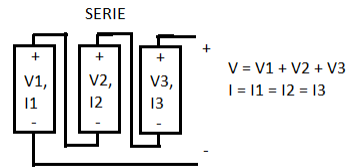
Warning!

If you try to measure a battery current without any load (like for a PV panel), you will fry the voltmeter!

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Series vs. parallel

- When components (generators or loads) are connected **in series**, The positive contact of one (+) is connected to the negative of the next one (-).
 - The same current passes through all components: $I = I_1 = I_2$ etc.
 - The voltage across the full circuit is the sum of the voltage across all components. $V = V_1 + V_2 + V_3$, etc.
- When components are connected in parallel, the contacts of same polarity (+) or (-) are connected together
 - The voltage is the same across all components: $V = V_1 = V_2 = V_3$,
 - The total current is the sum of currents in each branch: $I = I_1 + I_2 + I_3$.



Power vs. Energy



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- Power is an instantaneous measurement, in Watts (compare to flow rate of water)
- A constant power of 1 W received for 1 hour provides 1 Whr of energy (energy can be stored, analogous to the capacity of a bucket or a tank)



For electrical applications:

- Power (W) = Voltage (V) x Current (A) $1kW = 1000W$
- Energy consumed (Wh) = Power (W) x Time (hr)

One 60W light bulb ON for 1 hour uses 60Wh
 $60\text{ W} \times 1\text{h} = 60\text{Wh}$

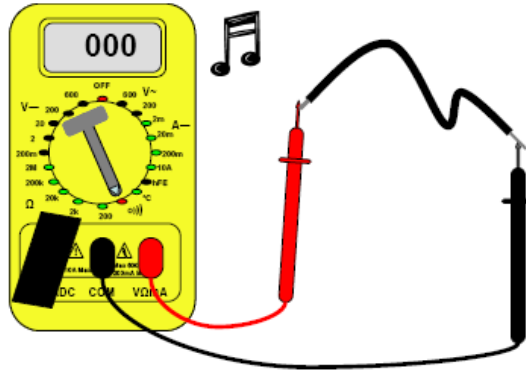
5 60W bulbs ON for 1h use:
 $5 \times 60\text{ W} \times 1\text{h} = 300\text{Wh}$

One 60W bulb On 5 hours also uses:
 $60\text{ W} \times 5\text{h} = 300\text{Wh}$



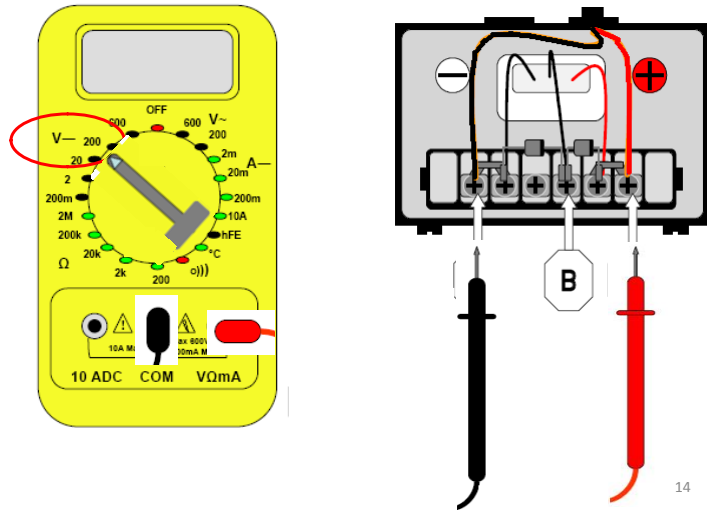
Your energy bill depends on your energy consumption in kWh

Checking continuity



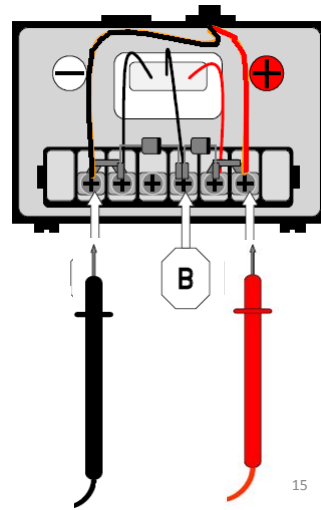
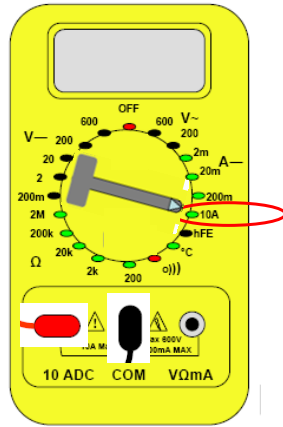
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Testing a PV panel: Voc



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Testing a PV panel: I_{sc}



Small PV Systems for Developing Countries



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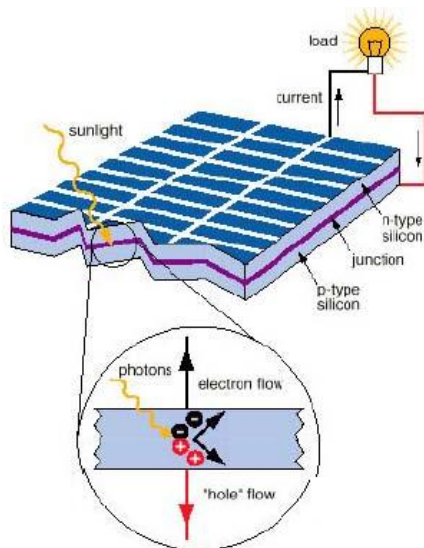


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Photovoltaic Effect



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- PV cell produces 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

- Silent
- No pollution
- Simple
- Reliable
- Modular

Photovoltaic modules & Panels



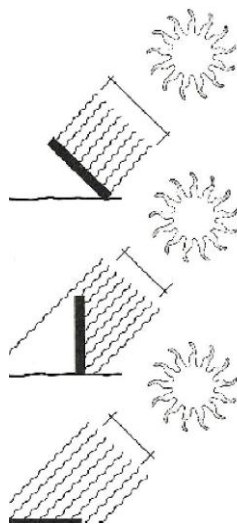
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- Comprised of separate cells (usually 36 cells for a 12 volt panel)
- **Each Si cell generates the same voltage (~.5 V) regardless of size**
- **The current generated depends on the light intensity** and size of the cell
- Modules are composed of solar cells wired in series
- Usually one solar panel is comprised of 2 modules
- 1 m² solar panel generates 60-120 Wp in 'standard conditions', depending on the technology

Panel Orientation



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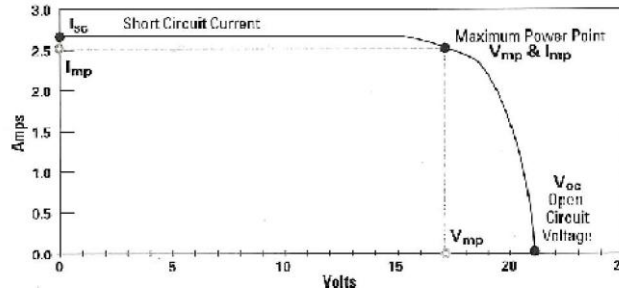


- Maximum power is received when the panel is **perpendicular to the sun rays** (facing the sun)
- For a fixed panel, usually the **best yearly average power is received for an angle = latitude + 10° to 15°**, **except if there is a season with very little sun or usage concentrated in one specific season**
- The angle can be adapted according to seasonal needs
- In some cases, the angle can be adjusted every month, or can even be tracked during the day (expensive)
- **Close to the equator** (latitude = 0° to 10°), **10° is the recommended minimum tilt angle** to allow rain to run off panels



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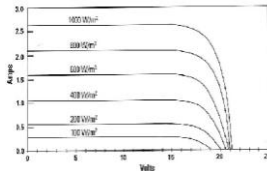
PV Panels: Electrical Characteristics



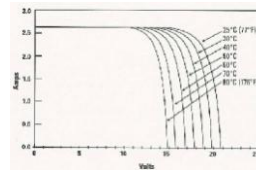
I_{sc} = short circuit current (depends on incident solar power)
 V_{oc} = open circuit current (changes with temperature increases)

I_{sc} & V_{oc} are easiest to measure, but I_{sc} x V_{oc} > W_p

V_{mp}, I_{mp} = maximum power I and V (changes with both temperature and power)



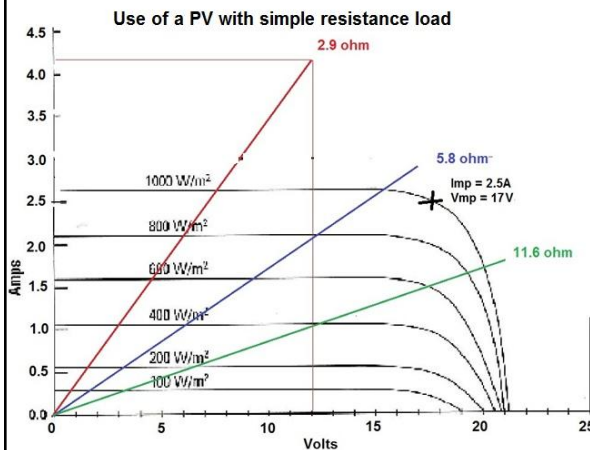
I_{sc} is proportional to incident radiation (W/m²)



Temperature Effect

In large systems, we can use MPPT controllers, which allow the system to get maximum power out of the system

Interpreting the I-V curve

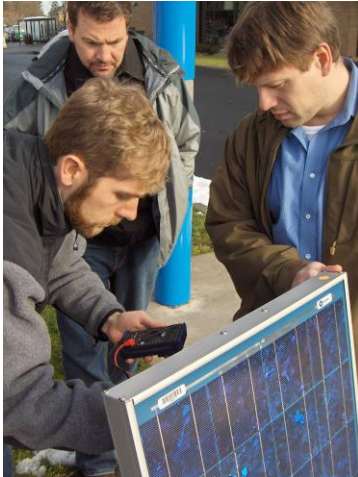


- Connecting a 50Wp panel to a 50W bulb might not work well. It depends on how much solar radiation is received.



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Hands-on lab



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

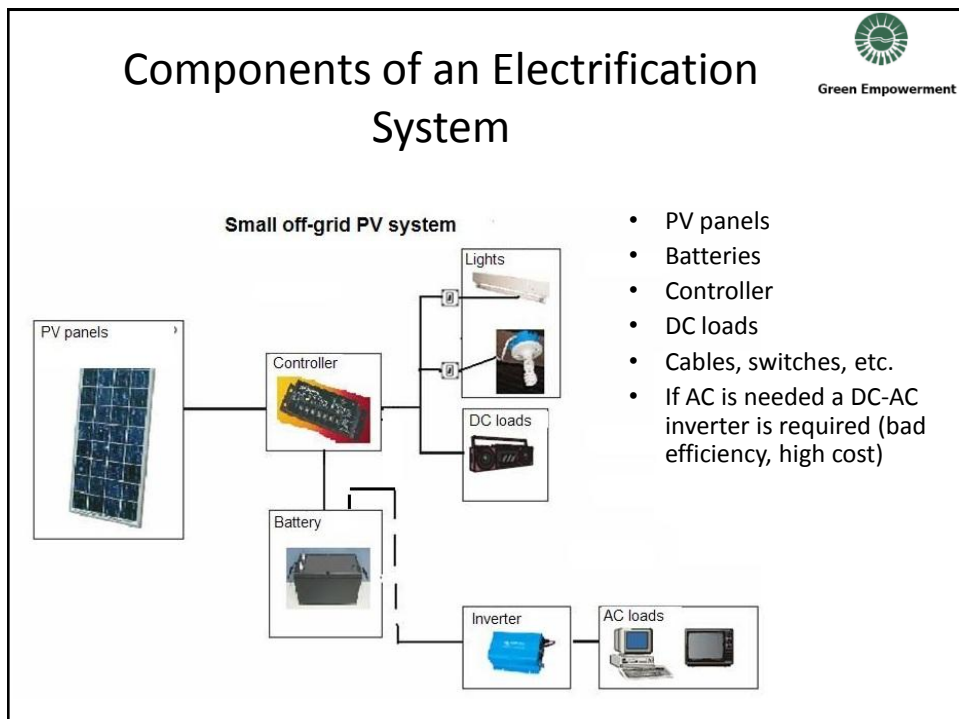
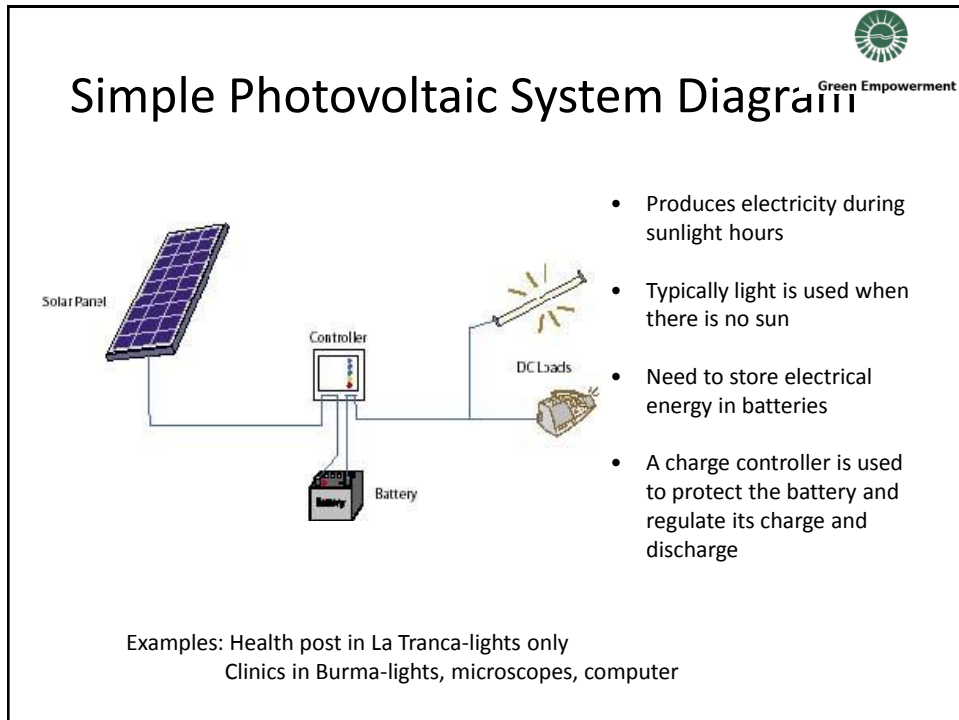
- 1) Facing the sun, measure Voc and Isc (careful about how to use DMM for Voltage vs Current!)
- 2) At different angles vs the sun, repeat Voc and Isc measurements
- 3) Shade one or more cells, and repeat Voc & Isc measurements
- 4) Connect 1 panel directly to a light bulb and observe what happen if orientation / exposure of the panel change
- 5) Connect 2 similar panels in series, then in parallel. Measure Voc and Isc and discuss.



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PV System Components







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Battery

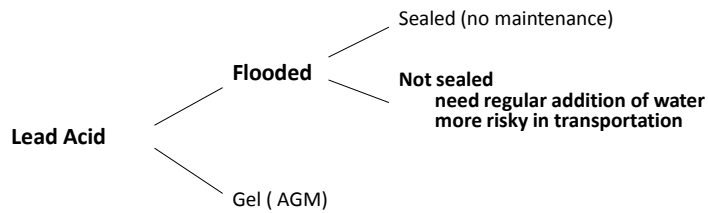


- Stores electrical energy to use when there is no sun
- 12 V is the most common for small systems
- Use “deep cycle” models designed for slow charge and discharge and longer life
- Car batteries are designed to supply quick bursts of energy and only partial discharge. They don't last long in PV systems.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



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Types of Lead-Acid Batteries





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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

Spec sheets usually show **C/100, C/20, or C/10**, capacities, respectively for 100hrs, 20hrs, or 10 hrs discharge .

If the discharge current is high, the battery is discharged quickly and usable capacity is lower.

For example, a battery with a C/100 capacity of 100 Ah, would have a C/20 capacity of 88 Ah, or a C/10 capacity of 80 Ah.

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.

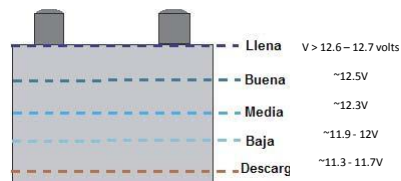
Note: battery capacity decreases when the temperature is low.



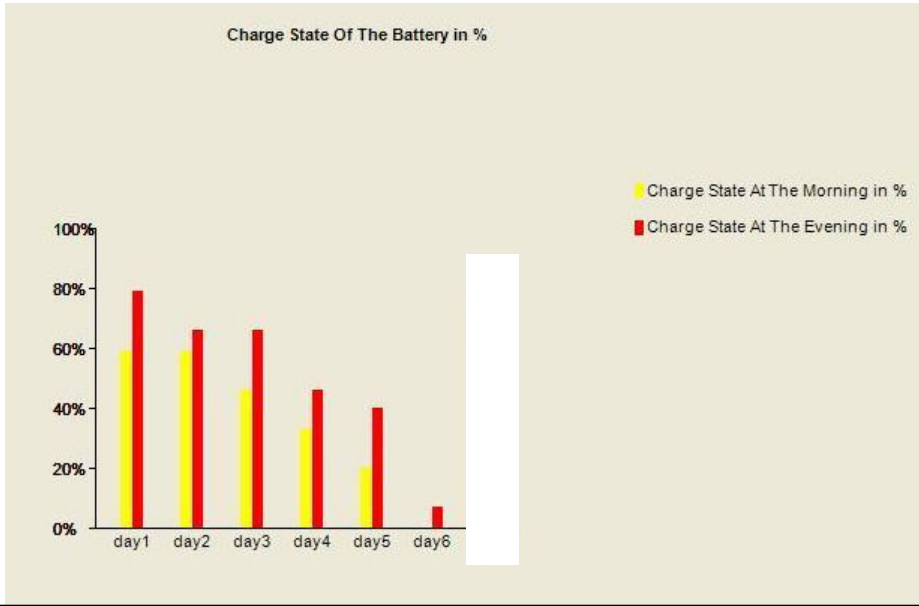
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Depth of Discharge

- This term indicates how much the battery gets discharged
- 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
- To estimate the charge level of a 12 V battery, measure its voltage when:
 1. It is disconnected from the charge controller
 2. It has not been used for 30 minutes
- The state of charge can also be measured by specific gravity (linked to the acid strength), less common in remote areas



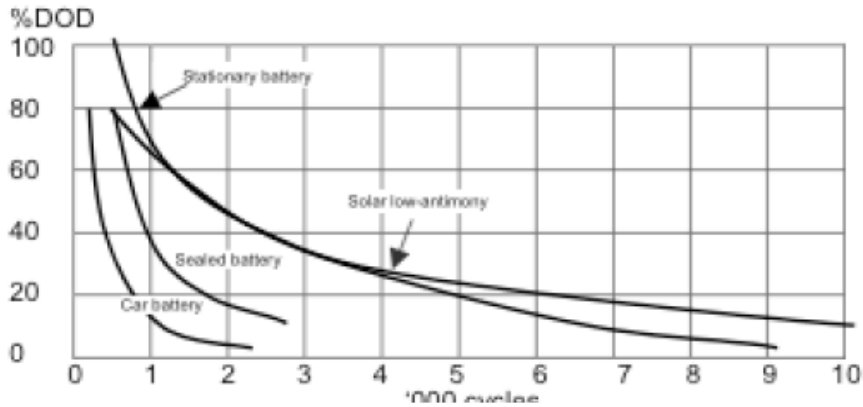
State of charge over time - example



Life expectancy in cycles vs. Depth of Discharge



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Dangers and Precautions with batteries



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Aggressive chemicals



If the acid from a battery gets on a person's 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 or 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



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Function:

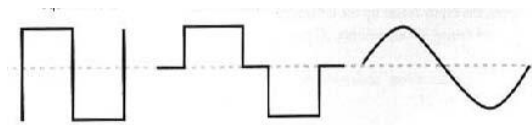
- Protect battery against overcharge
- Protect against deep discharge (optional but recommended)
- "Floating charge" to maintain battery fully charged (13.3 V for a standard 12 V battery)
- Desired optional protections
 - Overcurrent
 - Reverse polarity
 - Short circuit
 - Blocking diode to avoid current 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



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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%
- 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

Hands-on System Assembly:

Wiring/using a small PV system



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- Each group:
 - 1 panel, 1 battery, 1 control panel board
 - 1 small parts kit, screwdrivers, plier, etc.
 - 1 incandescent, 1 CFL, 1 LED
- Connect control panel to battery and PV panels
 - Check controller manual/instructions
 - Observe controller lights
- Use a digital multimeter (DMM) to check:
 - Continuity of connections before turning on
 - PV panels Voc and Voltage w/ loads
 - Isc and other I if DMM allows it
 - Battery voltage
 - Voltage drops
- *Observation/measurement of: current flow to/from various components depending on solar exposure, battery charge, load*
- *Wire sizing, termination and connections: discuss*



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Small PV Systems Sizing

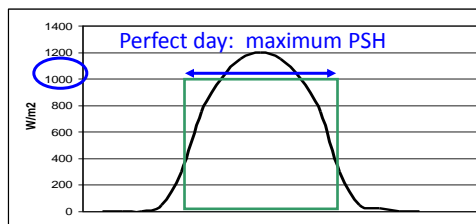


January 2011



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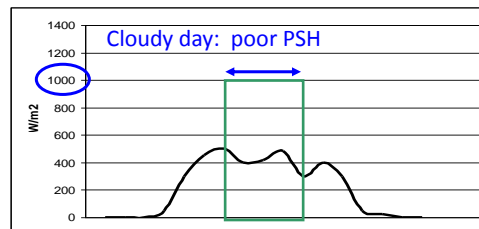
The Solar Resource



“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 either in PSH or kWh/m^2

$1 \text{ PSH} @ 1 \text{ kW/m}^2 = 1 \text{ kWh/m}^2$



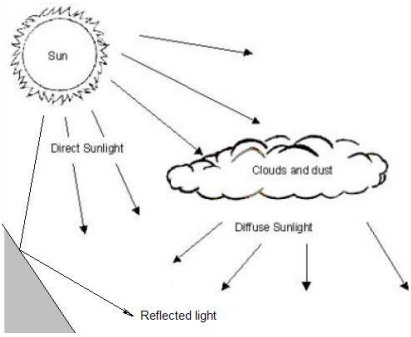
In tropical zones PSH can be:

- Up to 7 on sunny days
- From 2-4 on cloudy days



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Types of Solar Radiation



The total radiation is comprised of:

Direct Radiation: Straight from the sun

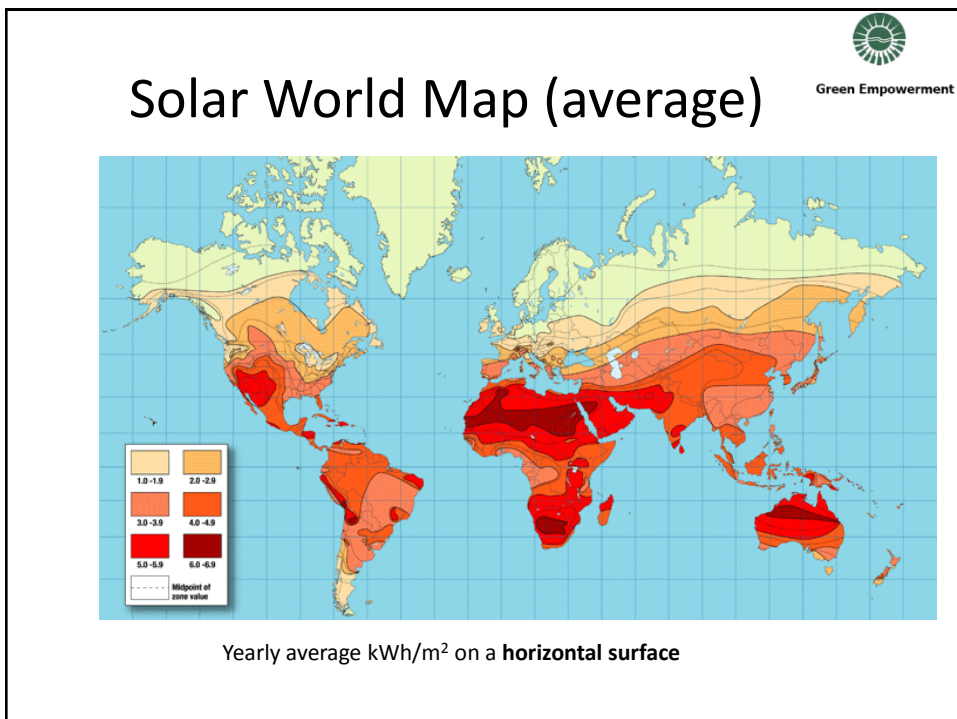
Diffuse Radiation: Dispersed by water drops in clouds

Reflected Radiation: From snow, water, white walls, etc.

On a sunny day, diffuse radiation may account for 2% of total radiation, while on a completely cloudy day, 100% of radiation may be diffuse.

If one cell is shaded the panel electrical production (efficiency) drops drastically

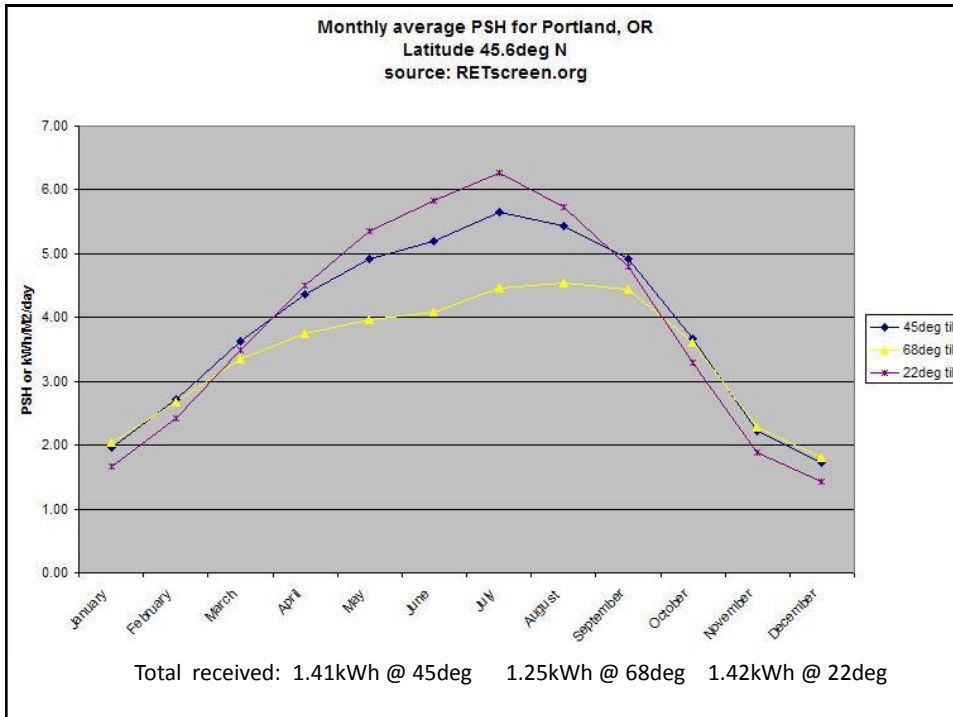
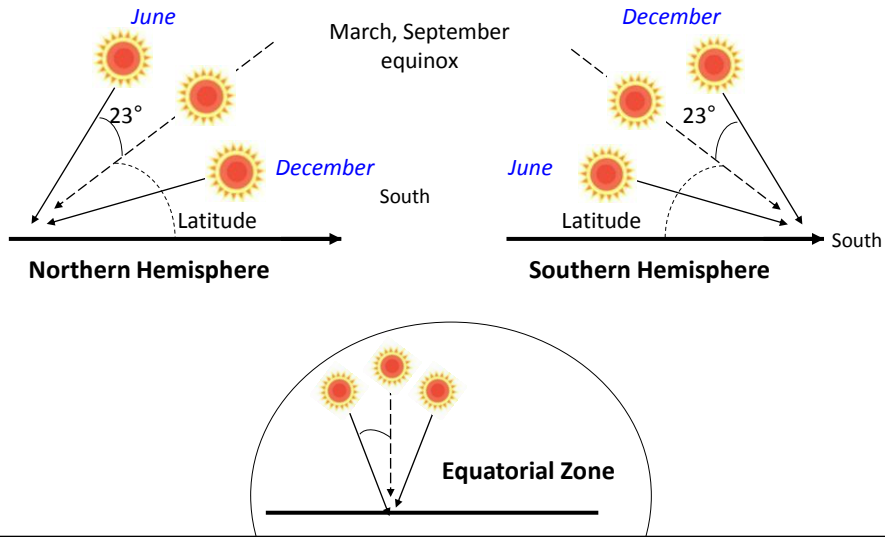
PV panels are much more sensitive to shade than thermal collectors





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Seasonal Variation – incident angle





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PV System Sizing Method



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?
4. > What size panels are needed?
5. > How much battery capacity is needed?

Step 1: Evaluation of the Load



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	Quantity	W	Inverter Efficiency	Hours/day	Wh / day
CFL	4	11W	n/a	4	176 Wh
	4	20W		3	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

Notes:

- 1) A "factor of simultaneity" can be used if the equipment is never all used at the same time ($f_s < 1$)
- 2) This information needs to result from a credible survey of the user community, or be generated within the community



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Step 2: Weather Data (PSH)

e.g.
Mindanao,
Philippines

<http://www.retscren.net/>

Latitude	6.5					
Longitude	125.5					
	NASA data		RETscreen 'Monthly average daily radiation in plane of PV array (kWh/m ² /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

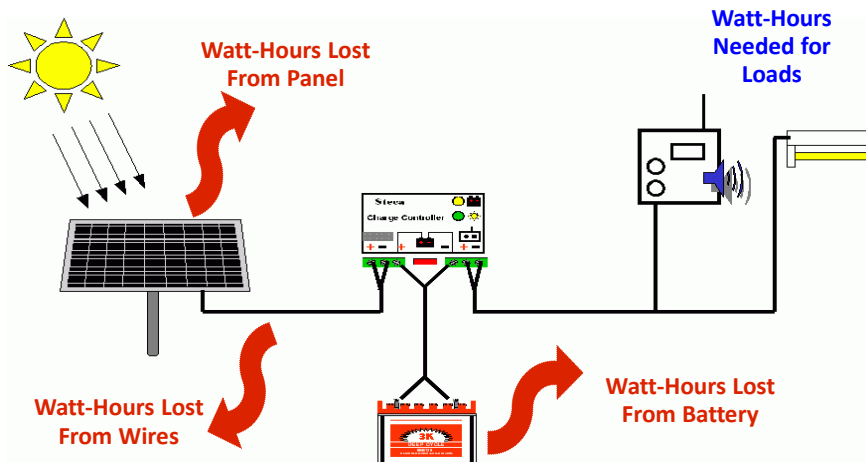
Estimation of daily temperature during hours of operation

Daily avg + 1/2 swing ~ 31 C operating



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Losses & Efficiency



Step 3: Losses and Efficiency



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- **3.1 The PV panel efficiency drops when its temperature rises**

Panel is black and can heat up to 15°C or more above ambient temperature
The power output drops by ~0,5% for each °C above 25 °C

Loss factor = [Ambient (°C) +15°C -25°C] x 0.5%
Temp Efficiency = 100% - Loss factor

Usual panel efficiency ~85% to 90%

- **3.2 Average battery efficiency is ~85%**

Energy is lost through mechanical deformation (>fatigue), heat (>evaporation), and chemical inefficiencies (>corrosion)

- **3.3 Inverter Efficiencies are typically 80-90%**
refer to vendor spec sheets

Step 3: Losses and Efficiency



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- **3.3 Losses in wiring**

Voltage drop due to wire resistance and current ($V=R.I$)

- The longer the wire, the higher the resistance and the voltage drop
- The smaller the wire cross-section, the higher the resistance and drop
- Since $P = V*I$, there is a loss of power proportional to the voltage drop

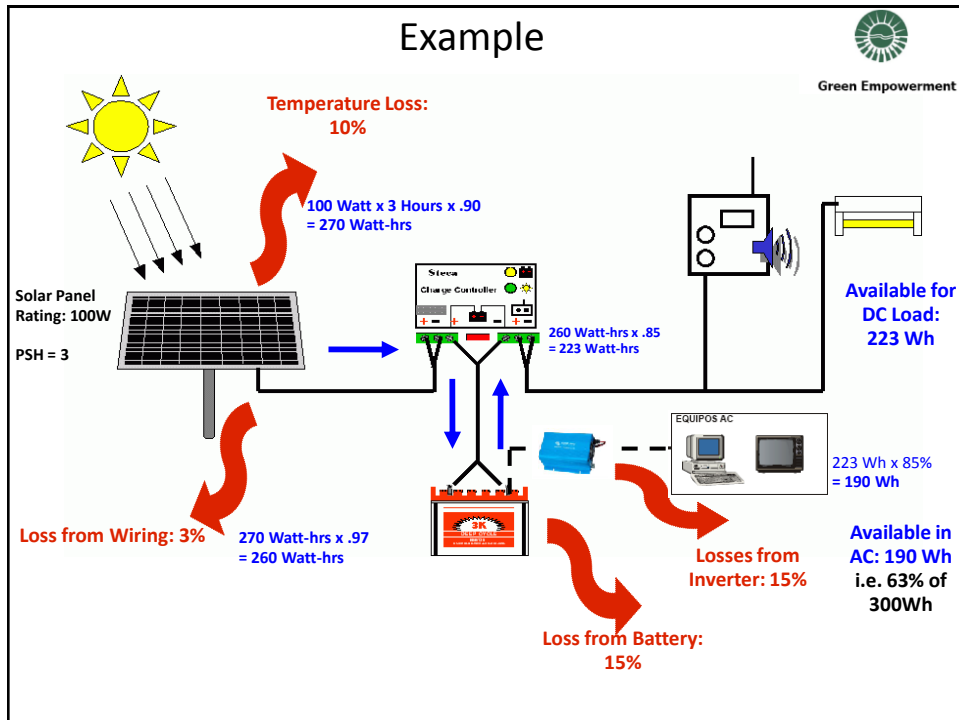
In 12V DC systems, currents are high and voltage drops are impactful:
a 1V drop means an 8% power loss

In AC circuits (110 or 220 V), voltage drops are negligible because currents are lower
and a 1V drop means < 1% of loss

Panels, controller, and batteries should be close to each other to limit the length of wires.

Wires sections (AWG or mm²) must be selected to **limit voltage drop to 2-5%** of the total system voltage

Voltage drop charts or formulas can be used to properly size system wiring –
see chart or spreadsheet



Step 4: Panel Sizing

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- The amount of energy available from the battery (in Wh) is:
 - = Peak panel power (Wp)
 - x PSH
 - x temperature efficiency (%)
 - x wiring efficiency (%)
 - x battery efficiency (%)
 - (the inverter efficiency can be incorporated into the load calculation)
- If this energy meets the average load, then panels must be sized to meet:

$$\text{Power of panel (Wp)} = \frac{\text{Load (Wh)}}{\text{PSH (h)} \times \text{combined efficiencies (\%)}}$$
- Local weather data:
 - Use the PSH value for the worst month of the year
 - Use the average temperature *during hours of operation*, i.e. higher than average daily temperature
 - Data can be found through RETScreen, regional maps, other sources (NASA)

Panel Sizing - Example



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

temperature losses: $100\% - 0,5\% \times (34.5^\circ + 15^\circ - 25^\circ) = 88\%$
battery efficiency = 85%
wiring efficiency = 97% (assuming wiring losses of 3%)

Power needed (Wp) =

$$\frac{641 \text{ Wh}}{4.23\text{h} \times 88\% \times 85\% \times 97\%} = 209 \text{ Wp}$$

This needs to be rounded up to an integer quantity of commercially available solar panels,
e.g. 4 panels of 60 Wp (240 Wp); 3 panels of 75 Wp (225 Wp), etc.

Notes:

- 1) Madrid University recommends using the rated panel Wp - 5 W to obtain the 'real' panel output
- 2) If amorphous Si panels are used instead of mono/poly- crystalline, the area of the array will be doubled

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 50-60%)
- Battery and system voltage (for example a 12 V system can be supplied with 2 batteries of 6 V in series)
- In terms of energy supply:

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

Battery capacity is usually provided in amp hours (Ah), since
Watts = Volts x Amps, Amps = Watts/Volts and:

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



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Battery Capacity Sizing Example

For the same Chirinos load lets use:

- 3 days of autonomy
- 50% DOD
- 12V system and battery
- 641Wh daily load with:
battery efficiency = 85% and wiring efficiency = 97%
The effective load will be: $641\text{Wh} / (85\% \times 97\%) = 777\text{Wh}$

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

In Amp hours this will be:

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

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

$$4 \times 104\text{Ah} = 416 \text{ Ah,}$$

$$2 \times 200\text{Ah} = 400 \text{ Ah, etc.}$$



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Battery Capacity Sensitivity to Design Choices

If instead we use:

- 2 days of autonomy instead of 3
- 60% DOD instead 50%
- Leave everything else the same

$$\text{Capacity (Ah)} = \frac{777 \text{ (Wh)} \times 2 \text{ days of autonomy}}{60\% \times 12\text{V}} = 216 \text{ Ah !}$$

Almost half the previous result!

- Be careful in selecting design values (over the life of the system, batteries can be the biggest expense)



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Sizing Exercise (1)

- Size a system for Huancayo, Peru, w/o AC load and doubling the weekly use of the sound system
- Try 2 scenarios with different depth of discharge and days of autonomy

RETScreen® Solar Resource and System Load Calculation - Photovoltaic Project

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Huancayo	See Weather Database
Latitude of project location	°N	-12.1	-90.0 to 90.0
PV array tracking mode	-	Fixed	
Slope of PV array	°	12.0	0.0 to 90.0
Azimuth of PV array	°	180.0	0.0 to 180.0

Monthly Inputs

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m ² /d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m ² /d)	Monthly solar fraction (%)
January	1.00	7.38	12.5	6.93	-
February	1.00	6.71	12.5	6.50	-
March	1.00	6.54	12.0	6.58	-
April	1.00	6.54	12.0	6.91	-
May	1.00	6.18	11.0	6.86	-
June	1.00	6.28	9.5	7.22	-
July	1.00	6.30	9.5	7.14	-
August	1.00	6.74	11.0	7.30	-
September	1.00	7.18	12.5	7.37	-
October	1.00	7.47	13.0	7.31	-
November	1.00	7.75	13.0	7.31	-
December	1.00	7.21	12.5	6.72	-
		Annual	Season of use		
Solar radiation (horizontal)		MWh/m ² 2.50	2.50		
Solar radiation (tilted surface)		MWh/m ² 2.56	2.56		

Also see FVdesign+\$.xls



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Sizing Exercise (2)

- 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

RETScreen® Solar Resource and System Load Calculation - Photovoltaic Project

Site Latitude and PV Array Orientation		Estimate	Notes/Range
Nearest location for weather data		Huancayo	See Weather Database
Latitude of project location	°N	-12.1	-90.0 to 90.0
PV array tracking mode	-	Fixed	
Slope of PV array	°	12.0	0.0 to 90.0
Azimuth of PV array	°	180.0	0.0 to 180.0

Monthly Inputs

Month	Fraction of month used (0 - 1)	Monthly average daily radiation on horizontal surface (kWh/m ² /d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m ² /d)	Monthly solar fraction (%)
January	1.00	7.38	12.5	6.93	-
February	1.00	6.71	12.5	6.50	-
March	1.00	6.54	12.0	6.58	-
April	1.00	6.54	12.0	6.91	-
May	1.00	6.18	11.0	6.86	-
June	1.00	6.28	9.5	7.22	-
July	1.00	6.30	9.5	7.14	-
August	1.00	6.74	11.0	7.30	-
September	1.00	7.18	12.5	7.37	-
October	1.00	7.47	13.0	7.31	-
November	1.00	7.75	13.0	7.31	-
December	1.00	7.21	12.5	6.72	-
		Annual	Season of use		
Solar radiation (horizontal)		MWh/m ² 2.50	2.50		
Solar radiation (tilted surface)		MWh/m ² 2.56	2.56		

Also see FVdesign+\$.xls

Observation of Variability in Results



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FV SIZING SUMMARY		COMMUNITY: example 1				date: 15-Oct-06					
Design variables		Qty	Watts	inverter efficiency	hours per day	days per week	avg hours per day	avg Wh per day	Maxi W		
Site	Chirinos	CFL	4	11	n/a	4	7	4	176	44	
Ambient op. temperature °C	34.5		4	20		3	7	3	240	80	
min PSH:	4.23	LED	2	1.5	n/a	11	7	11	33	3	
efficiencies		Other DC load (sound)	1	35	n/a			1	35	35	
Inverter	85%	Other				3.5	2				
batteries	85%	AC load (TV+DVD)	1	110	85%			1.2	157	129	
wiring	97%	TOTAL				4.25	2		641	291	
charge controller	100%										
PV panel (temperature effect)	88%										
system efficiency excl PV	82%										
system efficiency incl PV	72%										
Depth of discharge battery days of autonomy	50% 3										
Panel nominal Voltage	12										
Array nominal Voltage	12										
Battery nominal Voltage	12										
DC load voltage	12										
Safety coefficient for current to controller	1.25										
		PANELS				BATTERIES				CONTROLLER	
		calculated array size	standard panel	panels qty	panels qty in each series	calculated capacity	standard capacity	battery qty	battery qty	Maxi PV current	Maxi Load current
		Wp	Wp	total		Ah	Ah	in parallel	total	Amp	Amp
		209	60	4	1	389	104	4	4	31	30
						Ah per day				53	

Switch to FVdesign+\$.xls for demo

Reverse Sizing Exercise

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

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

Select one of those and see how much usage it would give for 15W CFLs and 40W TV in various climates:

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

Battery Charge Management

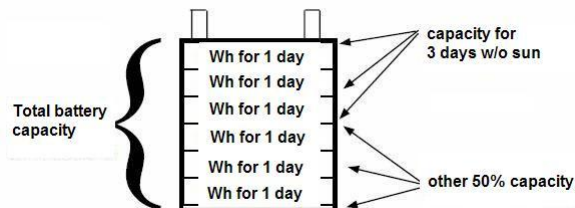


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To maintain charge level and increase battery life:

- 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



Charge Controller Selection



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- The main spec is the maximum current (Amps), both on the load side and the PV side:
 - For the PV side, use I_{sc} and add 25% for weather related peaks and another 25% for added safety
 - For the load side, use the maximum total W of all the loads in use at the same time and the minimum allowed battery voltage (LVD):

$$\text{Max current} = \text{max Watts} / \text{minimum Volts}$$
- Also, select input voltage (usually 12 V or 24 V) and load/system voltage (usually 12 V) Some controllers can have different input and output voltage, e.g. 24 & 12.
- Select the desired types of protection, e.g. Overcurrent, overcharge, low voltage disconnect, reverse polarity, short circuit current, etc. and the type of display or LEDs
- Avoid use of fuses: the first time they blow, the user often replaces it with wire; the next time is fatal. Better use electronic protection.

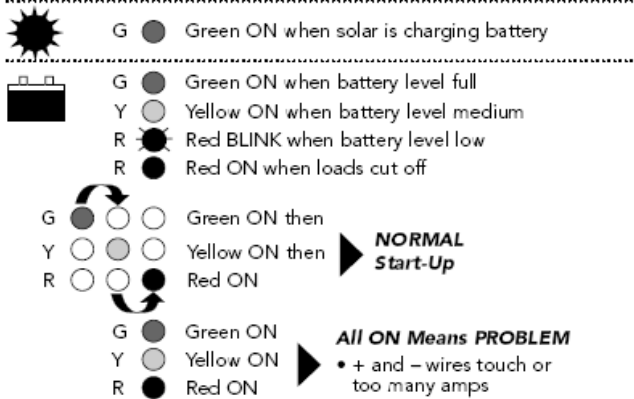


Controller LED meaning – SHS example



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LIGHTS



Each controller is different

Consult the user manual

NORMAL Start-Up

All ON Means PROBLEM

• + and – wires touch or too many amps

To correct problem:

1. Check wires
2. Reduce amps if needed
3. Reset controller
 - Disconnect battery +
 - Reconnect battery +

Controller LED meaning – SS example



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4.0 LED INDICATORS

GREEN LED:

The green LED indicator will light whenever sunlight is available for battery charging. The green LED will turn off at night.


Because the SunSaver uses a PWM constant voltage charging process, there is usually some amount of energy going into the battery at all times. Although the charging current falls to very low levels when the battery reaches full charge, the green LED will continue to stay ON (during the daytime). This is to indicate that the controller is working and that energy is available from the PV array for charging.

RED LED:


If your SunSaver model includes an automatic load disconnect (LVD) feature, a red LED indicator is also provided. Whenever the battery charge state falls below the LVD setpoint, the load will be disconnected and the red LED will light. This indicates that the controller has disconnected the load to protect the battery from further discharge and possible damage.

After some period of recharging the battery such that it recovers to approximately 40 to 50 percent of its rated capacity, the load will automatically be reconnected and the red LED will turn off.

Wire Sizing Tool



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Green Empowerment
Interactive Voltage Drop / Wire Size Calculator

For Copper Wire with DC Circuits
 Based on resistivity of COPPER conductors, at 75 deg C rating, COATED.
 Distance Equals ONE WAY distance

Wire Size		Max Dist @ 5.00 Amps	Max Amps
mm2	AWG		
1.5	4.5540	ft 8	15
	4.5540	m 2	15
14	3.2600	ft 11	15
	3.2600	m 3	15
2.5	2.7324	ft 13	25
	2.7324	m 4	25
12	2.0500	ft 18	25
	2.0500	m 5	25
4	1.7077	ft 21	30
	1.7077	m 6	30
10	1.2900	ft 28	30
	1.2900	m 9	30
6	1.1385	ft 32	50
	1.1385	m 10	50
8	0.8090	ft 44	50
	0.8090	m 14	50
10	0.6831	ft 53	65
	0.6831	m 16	65
6	0.5100	ft 71	65
	0.5100	m 22	65
16	0.4269	ft 84	85
	0.4269	m 26	85
4	0.3210	ft 112	85
	0.3210	m 34	85

Procedure for Using Interactive Voltage Drop Calculator


- Enter System Inputs in Block Below - A, B, C
(These are the only cells where you enter data)
- Read the maximum allowable distance in column D that will allow a given wire size to carry the amps that you have selected, maintaining no more than the voltage drop you selected.
- Double check with the maximum amperage capability in column E to be sure that your selected wire size is rated to carry at least your selected load amps.

System Inputs

A	System Voltage (Battery)	12	Volts
B	Max Percent Voltage Drop	3	%
C	Current in Amps	5	Amps

Maximum allowable amperages are based on National Electrical Code 310-16 for 3 conductors, with 75deg C insulation rating, at an ambient temperature of 30 deg C.
 Correction factors may need to be applied for temperature derating, and conduit fill.

See: GEVoltage Drop Interactive.xls



Green Empowerment

Power Rating of Common Appliances

ITEM	LOAD (Watts)
Air Conditioner	1500
Blow Dryer	1000
Ceiling Fan	10 - 50
Clock Radio	5
Clothes Washer	1450
Electric Clock	4
Iron	1500
Sewing Machine	100
Table Fan	10-25
Refrigerator/Freezer (19 Cu Ft.)	1000 Wh / day
Refrigerator/Freezer (16 Cu Ft.)	700 Wh / day
Refrigerator/Freezer (12 Cu Ft.)	470 Wh / day
Refrigerator/Freezer (10 Cu Ft.)	280 Wh / day
Refrigerator/Freezer (4 Cu Ft.)	210 Wh / day
Blender	350
Coffee Pot	1200
Microwave (.5 Cu. Ft.)	750
Electric Range	2100
Incandescent (100 W)	100
Incandescent (60 W)	60
Compact Fluorescent (60W equivalent)	16
Incandescent (40 W)	40
Compact Fluorescent (40W equivalent)	11
CB radio	10
CD player	35
Ceular Telephone	24
Computer Printer	100
Computer (desktop)	80-150
Computer (laptop)	20-60
Stereo (average volume)	15
Stereo (Large full volume)	150
TV (12 inch black & white)	15
TV (19-inch color)	60
VCR	40
Band Saw (14")	1100
Circular Saw (7.25")	600
Disc Sander 6"	1200
Drill (1/4")	250
Drill (1/2")	750
Drill (1")	1000

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See additional documents in the CD.

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