Small PV Systems for Developing Countries – Day 1

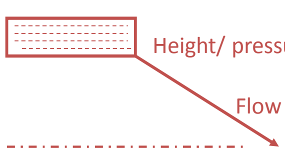
Green Empowerment

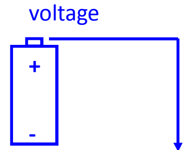
November 2010

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)





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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:

Power = Voltage x 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 Volts x 5 Amps = 60 Watts

a 60Watt light bulb designed for a 120V power source uses 0.5 Amps
120 Volts x .5 Amps = 60 Watts

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:
  - 0 Ω = no resistance = there is continuity, the current flows
  - Overload/ maximum figure = open circuit (open switch)
- Key formula (Ohm’s law): V = R x I

Voltage across the resistance (Volts) = Resistance (Ω) x Current (Amp)

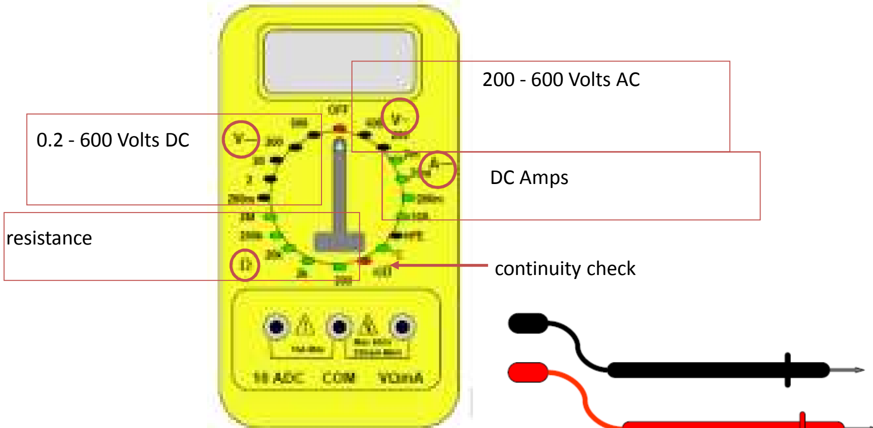
A traditional incandescent light bulb is a high resistance wire:
the current is so high that the filament gets very hot and emits light
example: Resistance of an incandescent 60W bulb?

Designed for 12V: I = 60W/12V = 5A R = 12V/5A = 2.4Ω
Designed for 120V: I = 60W/120V = 0.5A R = 120V/0.5A = 240Ω

For a given R value

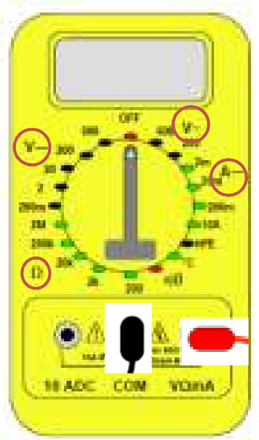
- the higher the current, the higher the Voltage drop (e.g. losses in a wire)
- The higher the applied voltage, the higher the current
  (E.G. light bulb: a bulb built for 12V or 110V will burn if plugged into 220V)
  The 2.4Ω bulb, plugged into 120V will use I = 120V/2.4Ω = 50A VERY HIGH!

Using a Voltmeter: select what will be measured



5

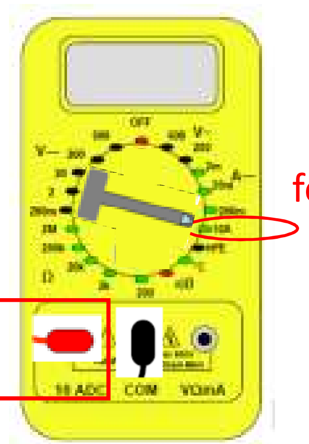
Using a Voltmeter: connect probes



for most measurements

6

Using a Voltmeter: connect probes



for DC current only

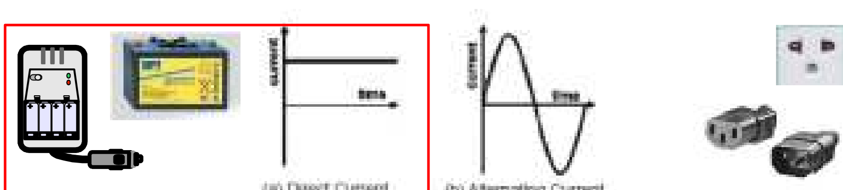
Do not leave probe connected like this!!!

7

DC vs. AC

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



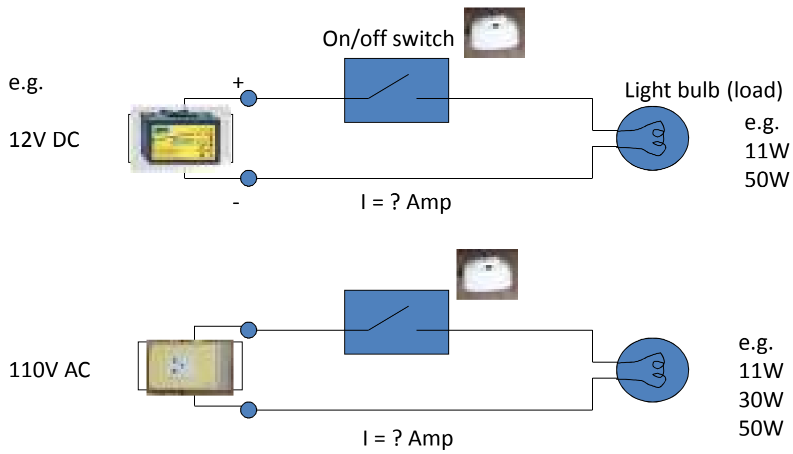
The grid electricity provided to houses, industries, etc. is Alternative Current (AC)
Each wire changes from + to – 50 (Europe) or 60 (US) times per second

- 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

8

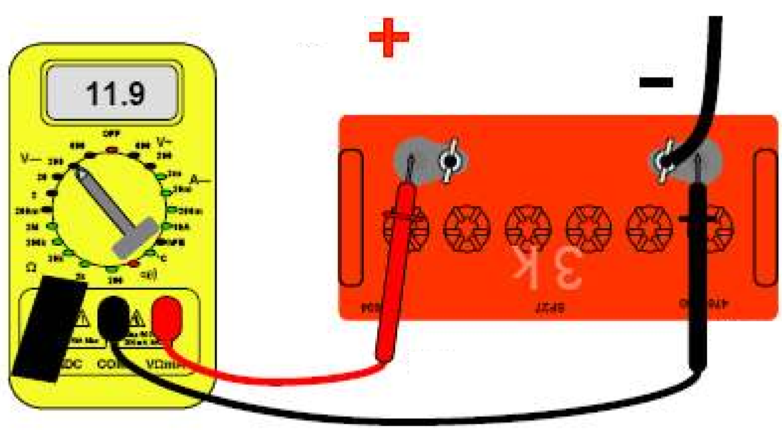
Simple electrical circuit



Remember: P = V x I   i.e. I = P /V

9

Measuring Battery Voltage



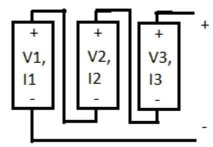
Warning!
If you try to measure a battery current without any load (like for a PV panel), you will fry the voltmeter!

10

Series vs. parallel

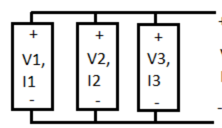
- When components (generators o loads) are connected i**n series**, The positive contact of one (+) is connected to the negative of the next one (-) .
  - The same current passes through all components: I = I1 = I2 etc.
  - The voltage across the full circuit is the sum of the voltage across all components. V = V1 + V2 + V3, etc.
- When components are connected in parallel, the contacts of same polarity (+) o (-) are connected together
  - The voltage is the same across all components: V = V1 = V2 = V3,
  - The total current is the sum of currents in each branch: I = I1 + I2 + I3.

SERIE



V = V1 + V2 + V3
I = I1 = I2 = I3

PARALELO



V = V1 = V2 = V3
I = I1 + I2 + I3

Power vs. Energy

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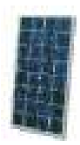


- Power is an instantaneous measurement, in Watts (compare to flow rate of water)
- A constant power of 1 W received for 1 hour provides 1 Whr of energy (energy can be stored, analogous to the capacity of a bucket or a tank)

For electrical applications:

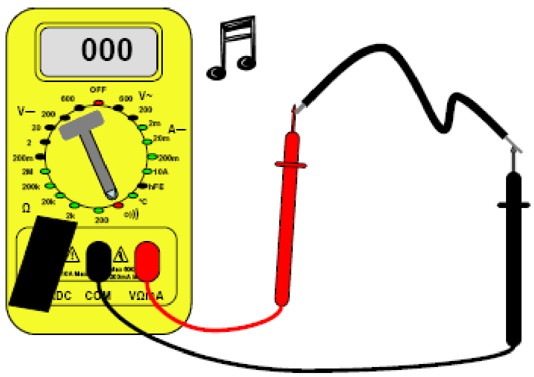
- Power (W) = Voltage (V) x Current (A) *1kW = 1000W*
- Energy consumed (Wh) = Power (W) x Time (hr)

One 60W light bulb ON for 1 hour uses 60Wh
60 W x 1h = 60Wh
5 60W bulbs ON for 1h use:
5 x 60 W x 1h = 300Wh
One 60W bulb On 5 hours also uses:
60 W x 5h = 300Wh

Your energy bill depends on your energy consumption in kWh

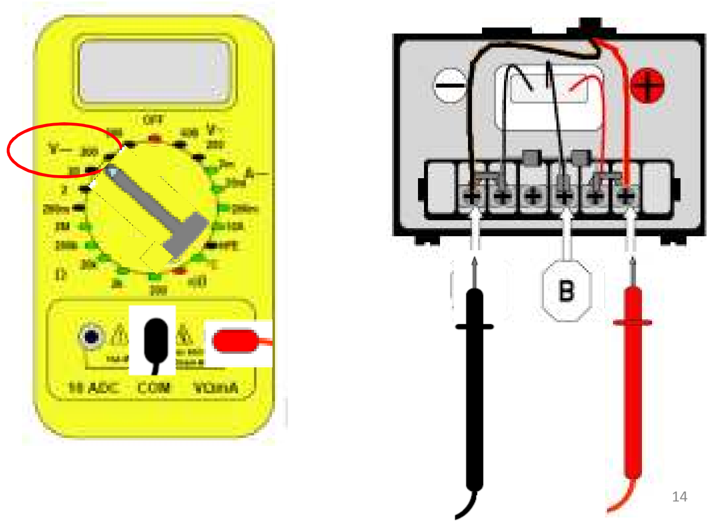
12

Checking continuity



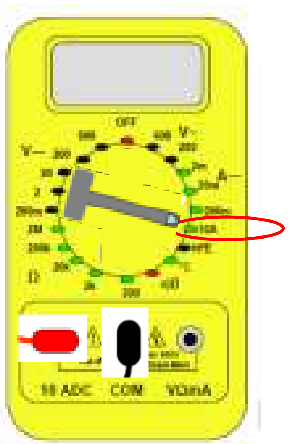
13

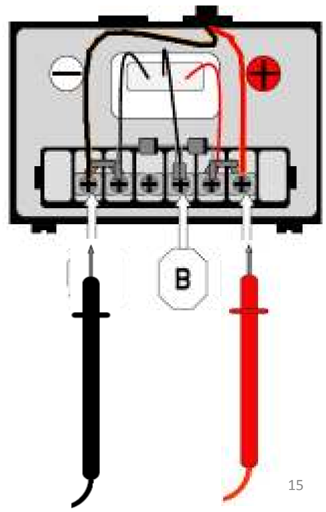
Testing a PV panel: Voc



14

Testing a PV panel: Isc





15

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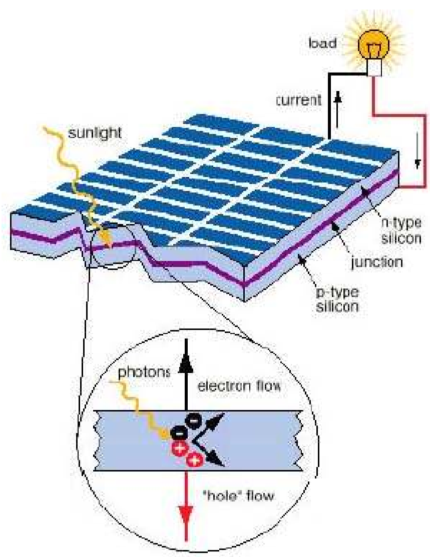
Photovoltaic Effect

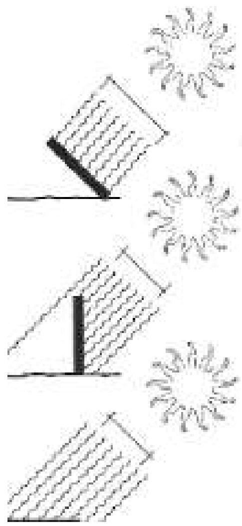


- PV cell produces electricity from sunlight (photons)
- To work properly each cell needs to receive sunlight
- Electrical energy needs to be stored for use if needed when there is not enough light
- Silent
- No pollution
- Simple
- Reliable
- Modular

Photovoltaic modules & Panels

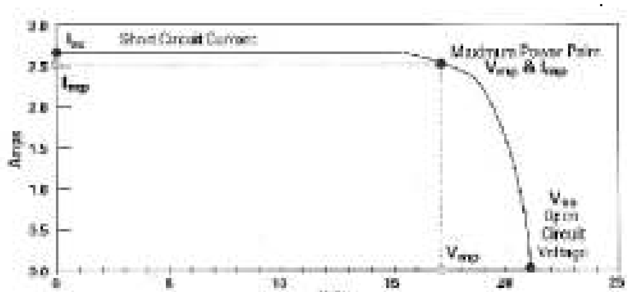
- Comprised of separate cells (usually 36 cells for a 12 volt panel)
- **Each Si cell generates the same voltage (~.5 V) regardless of size**
- **The current generated depends on the light intensity** and size of the cell
- Modules are composed of solar cells wired in series
- Usually one solar panel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

Panel Orientation



- 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

PV Panels: Electrical Characteristics

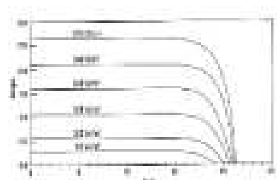


- Isc = short circuit current (depends on incident solar power)
- Voc = open circuit current (drops when temperature increases)

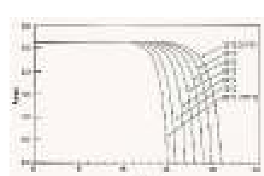
Isc & Voc are easiest to measure, but Isc x Voc > Wp

Vmp, Imp = maximum power I and V (changes with both temperature and power)

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

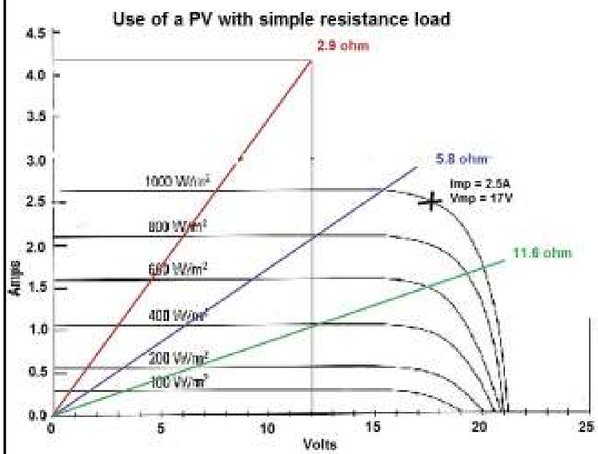


Isc is proportional to incident radiation (W/m²)



Temperature Effect

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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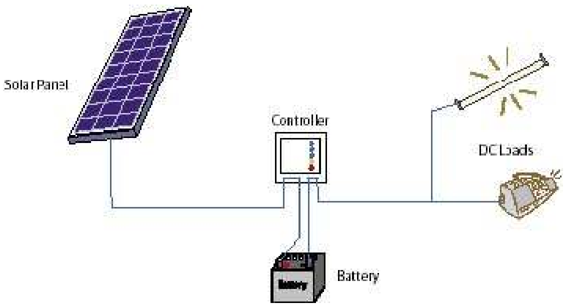
Hands-on lab

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.

PV System Components

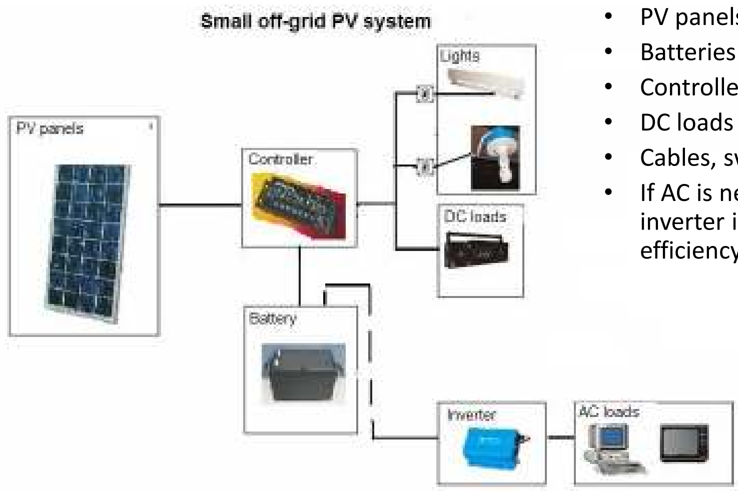
Simple Photovoltaic System Diagram



- 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

Examples: Health post in La Tranca-lights only
Clinics in Burma-lights, microscopes, computer

Components of an Electrification System



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

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

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

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.

Depth of Discharge

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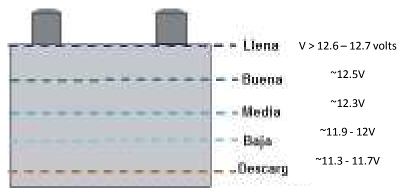
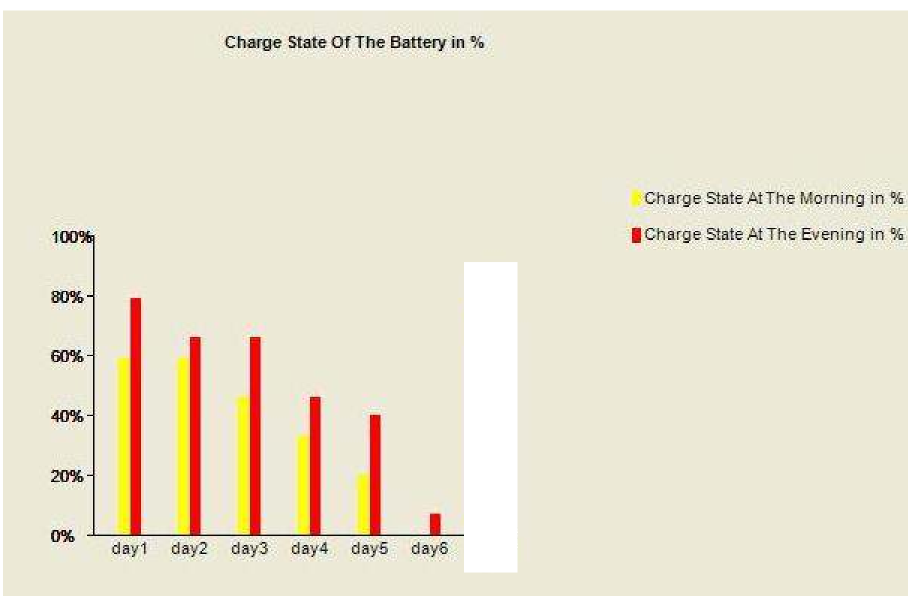
- This term indicates how much the battery gets discharged
- The battery life expectancy is reduced if the battery is discharged a lot on a regular basis
- A battery which is never more than 50% discharged can last twice as long as one that is regularly discharged 80%
- To keep the discharge around 50%, 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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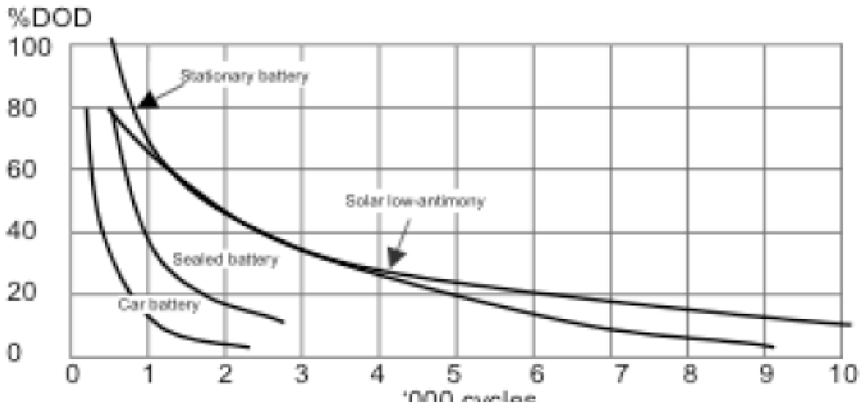

Dangers and Precautions with batteries

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Aggressive chemicals

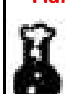
If the acid from a battery gets on a persons skin it can burn the skin. If the acid does touch someone's skin quickly apply baking soda to stop the burning.

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

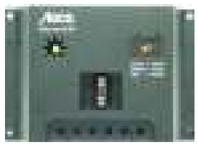


Never store batteries in an enclosed area allow the gas from the batteries to escape never have fire or smoke a cigarette near a battery

Electricity

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

Charge Controller



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

Hands-on System Assembly:

Wiring/using a small PV system

- 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*

Small PV Systems Sizing

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January 2011

The Solar Resource

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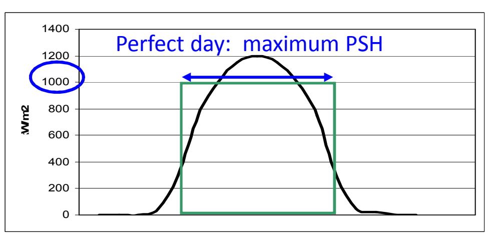

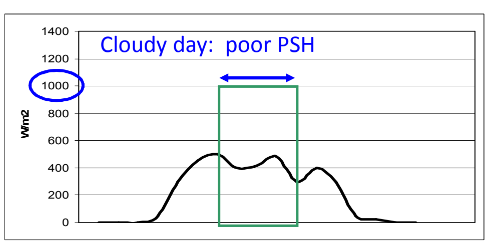

"Perfect Solar Hours" or "Peak Sun Hours" (PSH) are used to express the energy received in terms of equivalent hours at the "standard power" of 1000 W/m^2

Solar Maps / weather data can be expressed either in PSH or kWh/m^2

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

In tropical zones PSH can be:

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

Types of Solar Radiation

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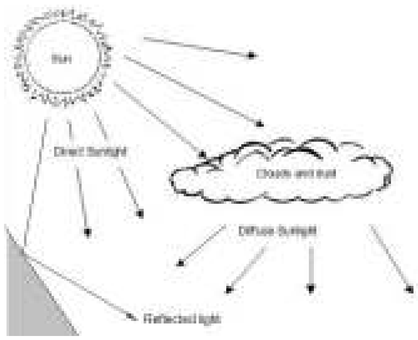

The total radiation is comprised of:

Direct Radiation: Straight from the sun

Diffuse Radiation: Dispersed by water drops in clouds

ted 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

Solar World Map (average)

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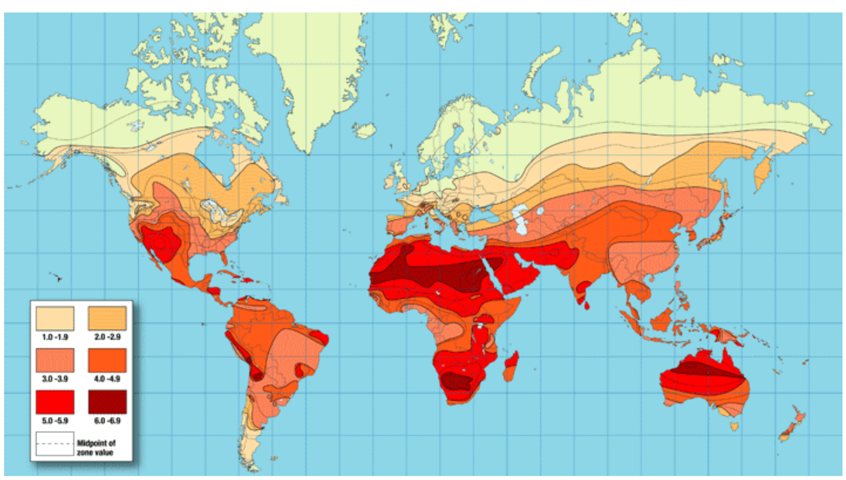
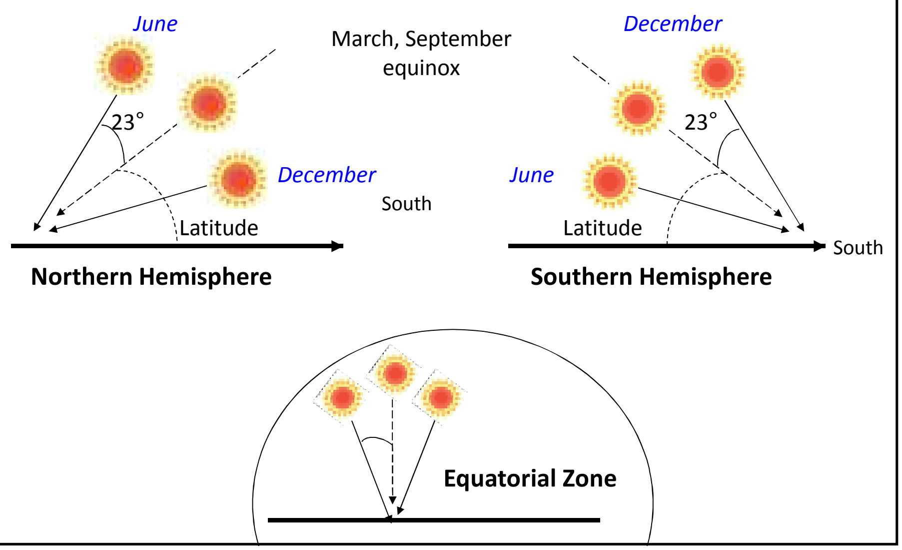
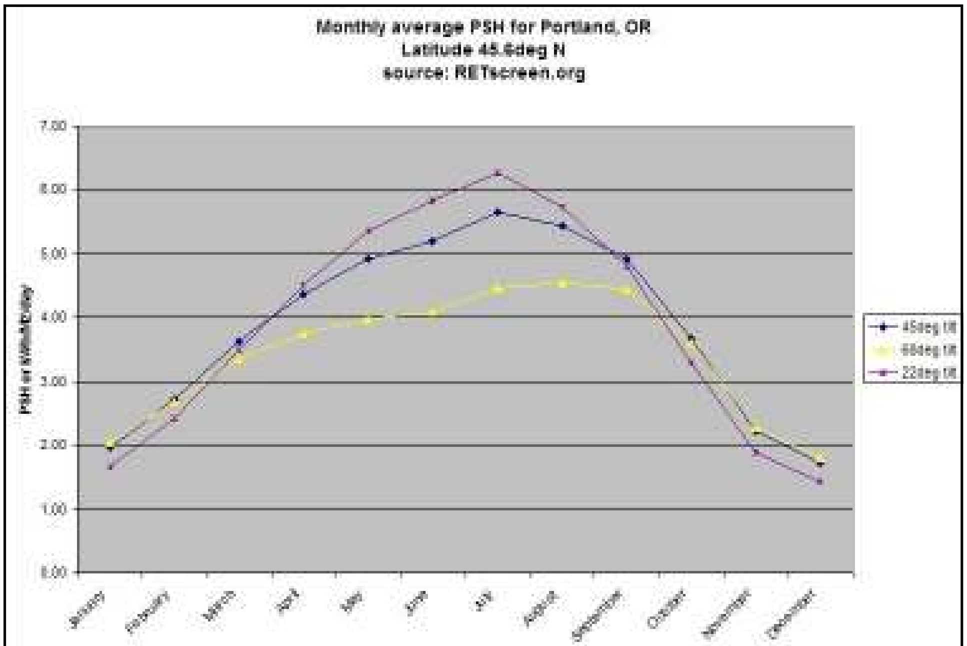


Yearly average kWh/m^2 on a **horizontal surface**

Seasonal Variation – incident angle





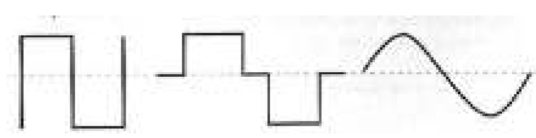
Total received: 1.41kWh @ 45deg 1.25kWh @ 68deg 1.42kWh @ 22deg

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?

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

Step 1: Evaluation of the Load

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	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

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

Step 2: Weather Data (PSH)

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http://www.retscreen.net/

e.g. Mindanao, Philippines

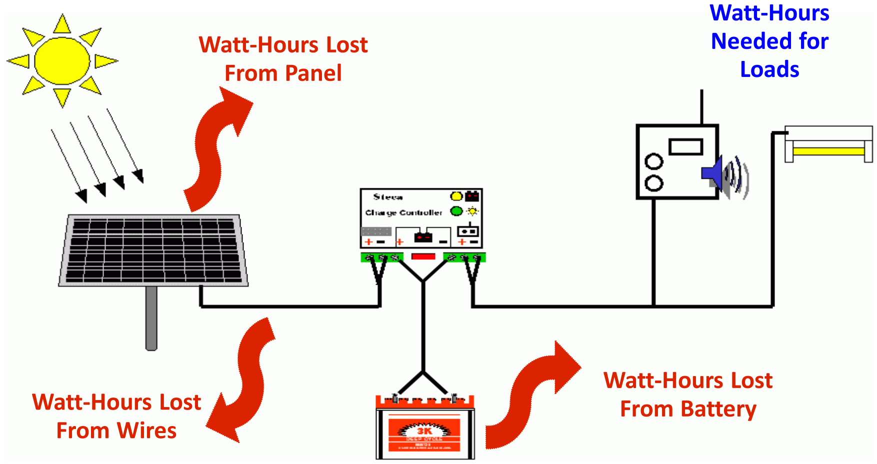
			RETscreen Monthly average daily radiation in plane of PV array (kWh/m²/d)			
Latitude	6.5					
Longitude	125.5					
	NASA data					
	Av temp	0deg horizontal	5 deg	10deg	15deg	20deg
Jan	25.2	4.68	4.75	4.84	4.93	4.99
Feb	25.3	4.94	5.05	5.11	5.15	5.17
Mar	26.1	5.29	5.32	5.33	5.30	5.26
Apr	26.8	5.56	5.50	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	4.56	4.36
Aug	25.9	5.15	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		4.68	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 + ½ swing ~ 31 C operating

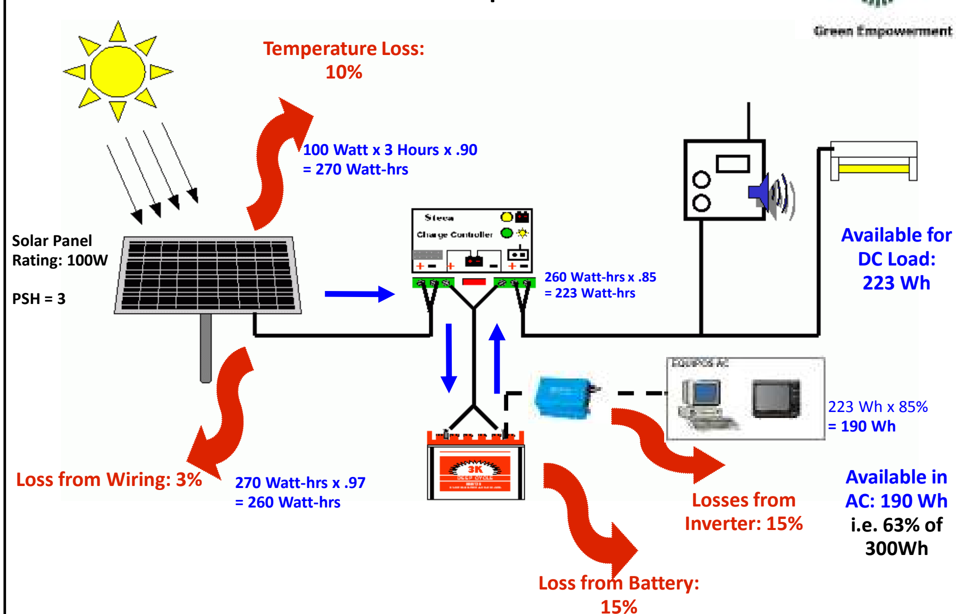
Losses & Efficiency

Green Empowerment



Example

Green Empowerment



Step 4: Panel Sizing

Green Empowerment

- 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:
  Power of panel (Wp) =

$$\frac{\text{Load (Wh)}}{\text{PSH (h) x combined efficiencies (\%)}}$$

- 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

Green Empowerment

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

temperature losses: 100% - 0,5% x (34.5° + 15° - 25°) = 88%
battery efficiency = 85%
wiring efficiency = 97% (assuming wiring losses of 3%)

Power needed (Wp) =

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

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

Green Empowerment

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:

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

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

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

Battery Capacity Sizing Example

Green Empowerment

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: 641Wh / (85% x 97%) = 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 Capacity Sensitivity to Design Choices

Green Empowerment

If instead we use:

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

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

Almost half the previous result!

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

Sizing Exercise (1)

Green Empowerment

- 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/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/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	7.76	13.0	7.31	-
December	1.00	7.21	12.5	6.72	-

		Annual	Season of use
Solar radiation (horizontal)	MWh/m²	2.50	2.50
Solar radiation (tilted surface)	MWh/m²	2.56	2.56

Also see FVdesign+$.xls

Sizing Exercise (2)

Green Empowerment

- 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/m²/d)	Monthly average temperature (°C)	Monthly average daily radiation in plane of PV array (kWh/m²/d)	Monthly solar fraction (%)
January	1.00	7.38	12.5	6.93	-
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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/m²	2.50	2.50
Solar radiation (tilted surface)	MWh/m²	2.56	2.56

Also see FVdesign+$.xls

Observation of Variability in Results

Green Empowerment

FV SIZING SUMMARY

Design variables	
Site	Chirinos
Ambient op. temperature °C	34.5
min PSH	4.23
efficiencies	
inverter	85%
batteries	85%
wiring	97%
charge controller	100%
PV panel (temperature effect)	88%
system efficiency excl PV	82%
system efficiency incl PV	72%
Depth of discharge battery	50%
days of autonomy	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

COMMUNITY: example 1 — date: 15-Oct-08

	Qty	Watts	inverter efficiency	hours per day	days per week	avg hours per day	avg Wh per day	Maxi W
CFL	4	11	n/a	4	7	4	176	44
	4	20		3	7	3	240	80
LED	2	1.5	n/a	11	7	11	33	3
Other DC load (sound)	1	35	n/a	3.5	2	1	35	35
Other								
AC load (TV+DVD)	1	110	85%	4.25	2	1.2	157	129
TOTAL							641	291
						Ah per day	53	

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

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)

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)	260 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
Cellular Telephone	24
Computer Printer	100
Computer (desktop)	80-150
Computer (laptop)	20-50
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")	900
Disc Sander 9"	1200
Drill (1/4")	250
Drill (1/2")	750
Drill (1")	1000

Sources & References

Green Empowerment

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See additional documents in the CD.

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www.nrel.gov US National Renewable Energy Lab