Exercise #8: Dimensioning a Solar System

Summary: Photovoltaic systems are a dependable and cost effective power source for places out of reach of the power grid, especially where the sun energy is plentiful, like in many tropical countries.

This guide will provide basic instructions for sizing the solar panels, battery requirements and other hardware for a photovoltaic system.

Background

When choosing equipment to meet your power needs, you will need to determine the following, at a minimum:

- The number and type of solar panels required to capture enough solar energy to support your load (the amount of energy used by your application).
- The minimum capacity of the battery. The battery will need to store enough energy to provide power at night and through days with little sun, and will determine your number of days of autonomy.
- The characteristics of all other components (the regulator, wiring, etc.) needed to support the amount of power generated and stored.

The method we will use for sizing the system is known as the ***method of the worst month***. ***The worst month*** is the month of the year which has the largest ratio of demanded energy to available energy.

Using this method, ***reliability*** is taken into consideration by fixing the maximum number of days that the system can work without receiving solar radiation, that is, the ***maximum number of days of autonomy*** (**N**), and can be thought of as the number of consecutive cloudy days when the panels do not collect any significant amount of energy. As usually, a compromise must be found between reliability and cost, and it will depend on the critical importance of the installation.

The following table provides a rough indication of the required days of autonomy:

Available sunlight	Domestic installation	Critical installation
Very cloudy	5	10
Variable	4	8
Sunny	3	6

Steps in sizing a photovoltaic system:

1) Estimate the electrical load

2) Estimate the maximum number of consecutive cloudy days

3) Estimate the battery capacity required

4) Estimate the type and number of photovoltaic panels required

5) Determine the minimum requirements for the load regulator and wiring

Procedure

1) Electrical load estimation

The power consumed by an electrical appliance is given by the product of the voltage and the current. The energy is the product of power and the time this power is consumed. Energy is measured in Joules, but the practical unit is Wh (watts*hour). The total load is the sum of the loads active **at a given time**. The load is expressed in W, but if the voltage is known it is common to specify the load as a current, and even the energy is often quoted in Ah.

Most communication equipment work on a DC voltage, extracted from the mains AC grid by means of a power supply which produces the required 5, 12, 24 or 48 V, depending on the equipment. These power supplies waste energy, so for a photovoltaic system it is best to do without the power supply and work directly with DC. and, if really needed, use a DC to DC converter as required.

The choice of the DC operating voltage is thus determined by the load requirements but most often will be 12 V, given the wide availability of batteries and solar panels for this value.

2) Estimation of maximum number of consecutive cloudy days

To estimate the maximum number of consecutive cloudy days it is better to resort to local climate data, usually gathered by different organizations. Very often the aeronautic or environmental agencies will collect this kind of information, but one can also resort to data from all over the world obtained from satellite observations by NASA over the last 22 years. They can be downloaded for free (after registration) from *http://eosweb.larc.nasa.gov/*.

For insolation data you can also use:

http://www.synergyenviron.com/resources/solar_insolation_tool.asp

That site does not require registration, but it is less complete.

3) Estimation of battery capacity required

Once we have a reasonable estimate of the number of days during which the calculated load must be supplied by the battery, we can determine the required battery capacity. It is important to remember that batteries should never be fully discharged.

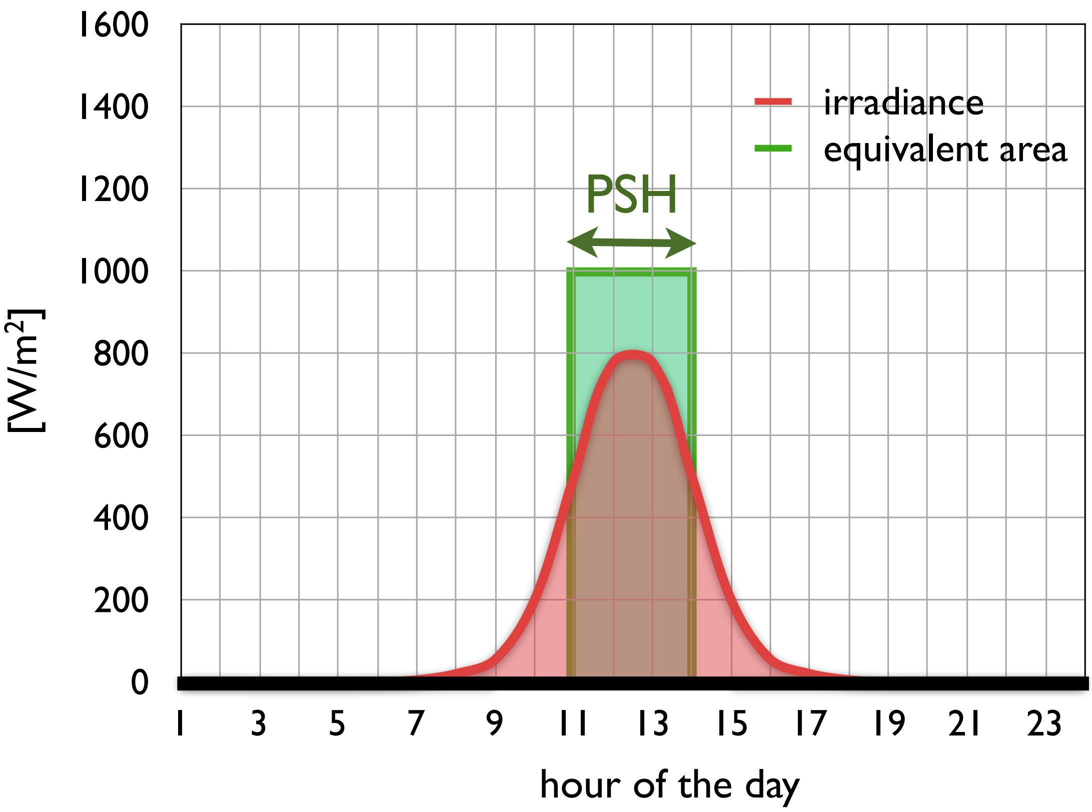
Deep cycle batteries should not be discharged by more than 50% and, if one must resort to automotive batteries (discouraged), the maximum discharge should be 20%. This means that we are able to use only half of the rated capacity of a deep cycle battery, and only one fifth the rated capacity of an automotive battery.

4) Estimation of type and number of photovoltaic panels required

The next step is to calculate the type and number of solar panels required to charge the batteries in a reasonable amount of time. Again, this is a matter of compromise and sometimes the optimal solution might not be economically viable.

A ballpark figure can be obtained multiplying the load by 1.5 to allow for the charging of the batteries simultaneously with the load. So the design load is now 50% greater than the calculated load. Next we should estimate the amount of solar energy per day available in the area of interest. The above mentioned NASA site also provides this information, but it can be obtained as well from other sources, or guess-estimated from other sites with similar climatic data. You should bear in mind that the latitude and altitude are the most important factors to consider.

There are several ways to present the amount of solar energy available in a given site in terms of total number of Joules/m^2 per day, watts/m^2*hour per day, and so on, but the most useful is obtained by considering a standard value of irradiance of 1000W/m^2, called **peak sun**. By dividing the total energy captured during a day by this value we obtain the number of **peak sun hours**, that is the number of hours that a constant radiation of 1000W/m^2 would produce the same amount of energy. This number coincides with the number of kW/m^2 per day, but is easier to visualize as the number of hours of radiation at a constant value, as can be seen in the following figure:



From the figure, the number of "peak sun hours", PSH is about 3, and so is the number of kWh/m^2 for that day. We have to choose the daily average for the worst month in the year to play it safe.

The size of the solar panel array is determined dividing the daily energy requirements by **PSH**. The resulting number will be divided by power output of each panel **Wp** to determine the number of panels.

5) Determining the minimum requirements for the load regulator and wiring

The last step is to calculate the capacity of the charge controller and the size of the required interconnection wires. This must be higher than the maximum expected current at the nominal voltage. Keep the wires as short as possible to minimize the voltage drop and wasted power.

The following table shows the maximum length in meters for copper wires to keep the voltage drop below 5% at 12V operating voltage.

Maximum conductor length (meters) for various wire sizes and currents

Wire cross section / Current (A)	35 mm²	25 mm²	16 mm²	10 mm²	6 mm²	4 mm²	2.5 mm²	1.5 mm²
1	540	389	246	156	93	62	39	22
2	270	194	123	78	46	31	19	11
3	180	130	82	52	31	20	13	7
4	135	97	62	39	23	15	10	5
5	108	78	49	31	18	12	8	4
6	90	65	41	26	15	10	6	3
7	77	55	35	22	13	9	5	2.8
8	67	49	31	19	12	8	4.5	2.5
9	60	43	27	17	10	7	4	2
10	54	39	25	16	9	6	3.5	1.8
12	45	32	20	13	8	5	3	1.5
15	36	26	16	10	6	4	2	1
18	30	22	14	9	5	3	1.8	0.8
21	26	18	12	7	4	3	1.6	0.7
24	22	16	10	6.5	3.5	2.5	1.5	0.5
27	20	14	9	5.5	3	2	1	-
30	18	13	8	5	2.5	1.5	0.8	-

Example

A wireless repeater is built with a single board computer (SBC) that draws 3.5 watts. It can operate at a voltage between 9 and 25 V.

It is fitted with a radio that uses 8 watts during transmission and 3.8 watts during reception.

We want to install it in hill in the outskirts of Cotonou, Benin.

1) Determine the load:

We choose to operate at 12V and assume that the SBC operates 24 hours a day, while the radio spends 40% of the time transmitting and 60% receiving, so the total consumption per day will be:

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3.5 * 24 + 8 * 24 * 0.4 + 3.8 * 24 * 0.6 = 215.52 Wh
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Round this to 220 Wh, or:

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220 / 12 = 18.3 Ah
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2) Estimate the maximum number of consecutive cloudy days

From the NASA site, entering the coordinates 7°N, 2°E:

Parameters for Sizing Battery or other Energy-storage Systems:

Equivalent Number Of NO-SUN Or BLACK Days (days)

Lat 7 Lon 2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	0.66	0.74	0.65	0.82	0.87	0.90	0.82	0.69	0.76	0.75	0.69	0.50
3 day	0.71	0.96	1.06	1.42	1.51	1.42	1.85	1.41	1.10	1.23	0.89	0.65
7 day	0.92	1.09	1.55	1.95	2.00	2.21	2.60	1.86	2.08	2.27	1.07	1.00
14 day	1.69	1.46	2.31	1.82	2.35	3.10	3.11	2.54	2.58	3.72	1.28	1.49
21 day	2.12	1.50	2.17	1.71	3.39	3.97	3.41	2.94	3.09	3.34	1.53	2.02
Month	1.35	1.59	1.83	1.77	3.86	2.53	3.18	3.58	2.88	3.43	1.83	1.16

We can see that the worst is May, in which we can expect an average of 3.86 cloudy days in a row.

3) Estimate the battery capacity required

From the above table, we choose **N = 4** as the maximum number of days that the battery shall supply the whole load. We multiply the amp hours by N, and by a factor representing the percentage of allowed discharge. For deep cycle batteries, the factor is 2 (twice the required capacity, to allow for a total 50% discharge).

Therefore the capacity of the 12 V battery should be:

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18.3 Ah * 4 * 2 =~ 147 Ah
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If we were using automotive batteries, which should only be discharged by 20%, then the factor would be 5 instead of 2 (to allow for five times the required capacity in amp hours).

4) Estimate the type and number of photovoltaic panels required

For the solar panel, we apply the ballpark figure of 1.5 times the calculated load to obtain **330Wh**.

The irradiation can be obtained also from the NASA site:

Monthly Averaged Insolation Incident On A Horizontal Surface ($kWh/m^2/day$)

Lat 7 Lon 2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	5.48	5.78	5.73	5.58	5.30	4.74	4.28	4.05	4.37	4.97	5.24	5.34	5.06

The worst month is August, which on average receives only 4.05 sun peak hours, so:

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330Wh / 4.05h = 81.5 W
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We need a panel that can provide at least 82 W.

The NASA site also indicates that **optimum annual inclination angle** for the panel is 16°, although there is a considerable monthly variation:

Parameters for Tilted Solar Panels:

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface ($kWh/m^2/day$)

Lat 7 Lon 2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE HRZ	5.48	5.78	5.73	5.58	5.30	4.74	4.28	4.05	4.37	4.97	5.24	5.34	5.06
K	0.59	0.58	0.55	0.53	0.51	0.47	0.42	0.39	0.42	0.49	0.56	0.59	0.51
Diffuse	1.65	1.84	2.11	2.23	2.15	2.15	2.19	2.26	2.29	2.09	1.78	1.59	2.03
Direct	6.10	5.90	5.17	4.74	4.55	3.82	3.05	2.56	2.94	4.23	5.40	6.09	4.54
Tilt 0	5.43	5.72	5.66	5.50	5.21	4.66	4.21	4.00	4.31	4.91	5.19	5.29	5.00
Tilt 7	5.71	5.90	5.71	5.50	5.28	4.74	4.26	4.01	4.31	5.01	5.42	5.60	5.11
Tilt 22	6.10	6.06	5.60	5.32	5.24	4.75	4.23	3.91	4.17	5.05	5.70	6.04	5.18
Tilt 90	3.95	3.24	2.26	1.93	2.37	2.37	2.10	1.78	1.71	2.55	3.52	4.11	2.66
OPT	6.18	6.06	5.71	5.51	5.30	4.77	4.27	4.01	4.31	5.06	5.74	6.17	5.25
OPT ANG	32.0	23.0	9.00	4.00	12.0	15.0	12.0	6.00	3.00	17.0	29.0	35.0	16.4

5) Determine the minimum requirements for the load regulator and wiring

The maximum load current will be during transmission, when the consumed power is 3.5 + 8 = 11.5 W, that at 12 V is just shy of 1 A. The regulator must handle this current and the device can be safely powered through UTP cable using PoE.

Keep in mind that for bigger loads the UTP might not suffice, so a dedicated power cable of the proper size should be used.

It is also recommended to insert a fuse between the battery and the load.

Further readings

Page 211 of the WNDW book and the following site: *http://www.sandia.gov/ERN/index.html*

Exercise

Design a solar system (panel + regulator + batteries + other required equipment) for the following systems:

1) A remote repeater site with a Nanostation2 and a Powerstation5, to be installed on the Andes (Merida, Venezuela. Latitude: 8° 35' N, Longitude: 71° 8' W). The repeater should operate 24/7, and have an autonomy of 5 days in absence of sunlight. Deep cycle batteries can be used here.

2) A client station (Nanostation2 and Netbook) to be installed in a school (Blantyre, Malawi. Latitude: 15° 46' S, Longitude: 35° 0' E). The required autonomy of the station is 24 hours without sunlight, and the radio is always switched on. The netbook requires 220Volts AC power to run and it consumes 5 Watts, and it is used for 5 hours every day. Deep cycle batteries are not available, so automotive batteries must be used for this installation.

3) Suggest possible solutions for the optimization of the power system of the two sites.

4) Redesign #2 so the system uses deep cell batteries rather than automotive batteries, and applying the optimizations you suggested in #3.