The Advanced Solar Power Sizing Spreadsheet

Quick Start Manual

Version 1.0
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Contents

1. Site Details

Section A. Location Details

The details of your site are entered here.

Line 1: Enter your site's latitude. The value should be entered as a decimal (1 minute = 0.0167°). If you are unsure a good website to try is http://www.heavens-above.com/countries.asp#N.

Line 2: Enter your site's altitude in meters.

Line 3: Enter the albedo of the ground that surrounds your site. The albedo is the reflectivity of the surrounding ground, values can be found in Table 1 (or in the spreadsheet, columns N to V to the right of the input cell). If you are unsure enter a value of 0.2.

Ground Cover	Default	Dry Earth	Dry Grass	Desert Sand	Snow	Pale Soil	Dark Soil	Water	Vegetation
Albedo	0.2	0.2	0.3	0.4	0.5-0.8	0.3	0.1	0.1	0.2

Table 1: Albedo values for different ground cover.

Line 4: Enter the average ambient daytime temperature for each month. The ambient temperature is the air temperature measured in the shade. A large database is located at http://www.weatherbase.com . If you are unsure guess.

Line 5: Enter the average nigh time temperature. A large database is located at http://www.weatherbase.com . If you are unsure guess.

Line 6: The monthly average daily irradiation on a horizontal plane at your location should be entered for each month. Most databases quote irradiation values for a horizontal plane however care should be taken that the value is not for a plane tilted at an angle equal to the site's latitude. Theses values should be in the units of kilowatt hours per day (kWh/d) and will be in the range of about 0.5 to 7 kWh/d depending on your site's location and the time of year. A large database is available at http://energy.caeds.eng.uml.edu/fpdb/irrdata.asp . These values should not be guessed.

Line 8: Enter the angle of your panels from the horizontal for each month of the year. *Line 7* contains the optimum angle, for solar panels at your location, as a guide. If you are going to be changing the angle of your panels every month enter these optimum values. If your panels are going to be fixed enter their angle from the horizontal in each month. If you are going to be changing the angle of the panels seasonally, refer to the notes in red below Section B.

Line 9: Enter the compass direction in which your panels face. If your panels are fixed so that they only face in one direction enter this value for each month, for example if your panels face due south enter 180° for each month.

Section B. Calculated Irradiation Data

The spreadsheet returns irradiation values for your panels in *Line 10*. These values have been corrected from the horizontal plane input data to take account of the angle and direction of your panels. Values for the average number of daylight hours per day in each month are also returned in *Line 11*.

The clearness index for each month is returned in *Line 12*, this value is used in the algorithm that returns the values in *Line 10*. For this algorithm to work correctly the clearness index should fall between 0.3 and 0.8. Latitudes approaching the Arctic and Antarctic circles may be out of range at some times of year, a warning is shown in *Line 13*.

2. Requirements

Section C: System Voltage

The basic system voltages are entered here.

Line 14: Enter the voltage of your battery bank. This will normally be 12 or 24 volts. For systems less than 2000 Wh/day 12V is suggested (look at the maximum value in *Line 17*). You can come back and alter this value latter if required.

Line 15: Enter the output voltage of your inverter. This will normally be 120 or 240 volts depending on your location.

Section D: Calculation Of AC Power Demand

Line 16: The details of your AC electrical appliances are entered here.

Fill out the columns as follows:

Room: Enter the room that contains the device.

Device: Enter the name of the device.

Include?: This value can be toggled from 1 (for include) to 0 (for exclude). This column can be used to temporarily take devices out of the calculations to gauge their effect on the overall system size (and therefore system cost). It is suggested that you start off by including all devices and enter a value of 1.

Rate: Enter the power ratting of the device quoted in watts. This may be written on the device itself or quoted in the manufactures data. If you are unsure see Table 2 (also available in the spreadsheet below Section H). If the device is rated in Horse Power multiply this value by 746 to convert it to watts.

Efficiency: If the value entered in the previous column is an output value (i.e. a mechanical power delivered by the device, rather than an electrical input or consumption power) then an efficiency must be included. Devices such as motors which have a Horse Power rating must have a value entered in this column, since Horse Power always refers to a mechanical power. For example a small AC motor rated at 1HP will deliver 1 x 746 = 746W of mechanical power and will be about 80% efficient; therefore enter 746 in the previous column and 80 in this column. If the value entered in the previous column is an electrical consumption value (more usual for light bulbs and most domestic appliances) enter a value of 100 in this column.

Power Factor: Power Factors for purely resistive loads, such as filament bulbs and heating elements, are 1. Power Factors for devices that have inductance and capacitance, such as motors and florescent bulbs, will be less than one. Refer to the manufactures literature. If you are not sure, this value can be estimated as 0.8 for electrical motors however, energy efficient light bulbs can range from 0.25 to 0.65 therefore a manufacture's value is preferable.

Surge Factor: Many devices containing motors require a larger power when starting than their normal rated value (entered in the *Rated Column*). This column contains a multiplier which equals the surge power divided by the normal rated power. A value for surge power should be available from the manufacturer, otherwise many values for common devices are quoted in Table 2 (and in the notes section below Section H in the spreadsheet).

Device	Rated Watts	Surge Watts	Surge Factor
Fridge (¼ hp)	500	2000	4.0
Freezer (¼ hp)	600	1200	2.0
Sump Pump	800	2000	2.5
Water Pump (1 hp)	1900	5700	3.0
Water Pump (2 hp)	2500	7500	3.0
Table Fan	800	2000	2.5
Computer	1500	1500	1.0
CD Player	100	100	1.0
VCR	100	100	1.0
Radio	100	100	1.0
TV	300	300	1.0
Microwave	800	800	1.0
Blender	300	900	3.0
Coffee Maker	1500	1500	1.0
Electric Hob (1 element)	1500	1500	1.0
Toaster (2 Slices)	1000	1600	1.6
Dishwasher	1500	3000	2.0
Electric Oven	3410	3410	1.0
Iron	1200	1200	1.0
Washing Machine	1150	3400	3.0
Clothes Drier	5400	6750	1.3
Band Saw	1100	1400	1.3
Circular Saw	800	1400	1.8
Air Compressor (1 hp)	1500	4500	3.0
Submersible Pump	200	400	2.0
1/6 hp Motor	300	850	2.8
¼ hp Motor	400	1150	2.9
1/3 hp Motor	475	1325	2.8
½ hp Motor	650	1800	2.8
3/4 hp Motor	900	2500	2.8
1 hp Motor	1000	2800	2.8
2 hp Motor	2000	5900	3.0
3 hp motor	3200	9000	2.8
5 hp Motor	5000	13750	2.8

Table 2: Power rating, surge power and surge factors for common devices.

Real Power: A value for the real power consumed by a single device is returned here.

Apparent Power: A Value for the apparent power of a single device is returned here. The apparent power is calculated from the real power and the power factor and is used to calculate the true current drawn from the inverter.

Surge Power: A value for the surge power of a single device is returned here.

The power requirements are calculated for each of the four seasons. If you think that the power requirement will not change much from season to season (e.g. your site is equatorial so that the days remain about the same length throughout the year) you should enter the same values in each season: note that you should not leave any of the seasons blank. To help you the number of daylight hours for an average day in each month at your location are shown above the column headings. The power requirements are also split into the number of hours that each device is used during the daylight and at night. Continue filling out the columns thus:

Number in use: The number of the device being used in each season should be entered.

Total hours of usage in day: The number for hour for which the device is used during daylight hours should be entered here. Note that this is the total hours of usage for all of the device: for example if there are 2 light bulbs being used in a room for 3 hours each enter 6 hours.

Total hours of usage at night: The number for hours for which the device is used at night should be entered here. Note that this is the total hours of usage for all of the device: for example if there are 2 light bulbs being used in a room for 3 hours each enter 6 hours.

Number contributing to peak power: The peak power load is the maximum sustained power that is draw during the day. All devices that may be running simultaneously contribute to the peak power. Enter the number of this device that will contribute to the peak power load, if it none of these devices contribute to peak power enter zero. An example of the peak power load could be at night when the TV, fridge and several lights are all running simultaneously.

Number contributing to surge power: Enter the number of this device that could possibly switch on (and therefore surge) at the same instant as other devices else. For example a fridge will constantly switch on and off, it switching on may coincide with you switching a light on. If none of the device contribute to the surge power enter zero.

Repeat the above steps for the remaining three seasons. You should not leave any of the seasons blank. The AC power requirement table is summed and the values returned in *Line 17*.

Section E. Calculation Of DC Power Demand

Line 18: Fill in the values for each device in a similar manner to Section D.

Line 19: The total DC power demands are returned here.

Section F. Power Requirements (AC+DC)

The value for the total power requirements for the average day in each season are returned in *Line 20*. The maximum peak power, apparent power and maximum surge power that can occur throughout the year are returned in *Line 21* to *Line 23*.

Section G. Total Power Requirement (with wire losses & inverter efficiency).

Line 24: Enter the efficiency of your inverter. This should be obtained from the manufactures literature. If you are unsure, a sine wave inverter will be in the region of 85 to 90% efficient and a semi-sine wave inverter will be about 95% efficient.

Line 25: Enter the percentage power loss due to the resistance of the wires in the distribution system. Normally the wire gauge is chosen so that for the length of wire you are using there will only be a 2% power loss, therefore a value of 2% is recommended.

Line 26: This spreadsheet takes account of different losses and inefficiencies separately however, an extra safety factor can be added here. A value of 5 to 10% would be appropriate for an autonomous system with no backup. If no safety factor is required enter zero.

Line 27 gives the total AC and DC power demand adjusted for losses. The value from *Line 21* to *Line 23* are corrected for the above losses and returned in *Line 2*8 to *Line 29*.

Section H. Inverter Sizing

Line 31 to *Line 39* calculates the amount of current that will be drawn from the inverter under peak power and surge conditions. The current that will be drawn from the batteries during peak power conditions is also calculated. Note that if the current drawn from the batteries by the inverter (quoted in *Line 39*) Exceeds 120A you should consider increasing the voltage of your battery bank (*Line 14*).

Line 41: It is possible to combine identical inverters in parallel so that the maximum amount of current delivered is increased while the system voltage remains the same. It is suggested that you start with 1 inverter and then check the values in subsequent lines, if the inverter can not meet the requirements either add another in parallel or select a larger inverter.

Line 42 to *Line 4*: Enter your inverters specifications. These should be obtained from the manufactures literature. Any short fall in inverter capacity will be indicated by a red "NO".

3. Battery

Section I. Battery Bank Requirements

The total power required from the battery bank for each month of the year is shown in *Line 4*8 and *Line 49*.

Line 52: Enter the days of autonomy you require. This is the number of cloudy days for which the batteries can provide the total power requirements without being replenished. This could be about 5 days for a fully autonomous system (depending on the location). However, if cost is an issue and there is a backup power source 2 days should be sufficient. The spreadsheet considers zero days autonomy to mean that the battery bank contains enough capacity to supply one night of power. One day autonomy means that there is enough power stored to supply one night, the following (cloudy) day and then an additional night. Each subsequent day autonomy adds one more day and one more night to the capacity (i.e. n days autonomy = n days + (n+1) nights).

Line 53: Enter the maximum battery discharge depth. Deep cycle batteries should not be discharge fully and a battery's life span can be significantly increased if they are not discharged beyond 50% of there capacity. Suggested values are between 60 and 40% depending on financial constraints.

The total battery bank capacity required, adjusted for the fraction that will not be discharged and the days of autonomy, is returned in *Line 55*.

Section J. Battery Details

Line 56 to Line 60: The details of your selected battery model should be entered.

Line 59: The capacity of a lead-acid battery depends on the rate at which it is discharged, the faster current is drawn from it, the less capacity it will have. Manufactures normally provide a 20 hour rate but since the batteries will probably be discharged over a time period that is greater than 20 hours (especially if you have entered 1 or more days autonomy) this value may result in excess battery capacity. It is difficult to predict an exact discharge rate since different amounts of current will be drawn at different times of day. However, using the 20 hour rate should give sufficient capacity unless you specify zero days autonomy. This spreadsheet allows 5, 20, 50, 100 or 500 hour rates to be used.

Line 60: Enter the capacity of a single battery for the rate that you have entered in the previous line. This spreadsheet allows 5, 20, 50, 100 or 500 hour rates to be used.

Section K. Battery bank Sizing

Line 61: Enter the average battery discharge temperature, to the nearest 5°C, the average night time temperature that you entered in Section A are provided as a reference. This is the night time temperature where your batteries are stored and you should take account of the fact that the average night time temperatures are out door values.

A temperature correction is now performed on the battery capacity and the corrected value returned in *Line 64*. Lead-acid batteries have a smaller capacity at temperatures below 25°C. This reduction in capacity is a function of discharge rate as well as temperature; a battery discharged at a high rate will be affected more by temperature than a battery discharged at a low rate.

> *Line 67*: The number of batteries needed to meet the power requirements and days autonomy for each month is shown *Line 66*. Using this value as a reference enter the number of batteries required in parallel in this line.

The number of batteries needed in series is calculated (from the voltage of the battery bank and the voltage of the individual batteries) and returned in *Line 68*. The total number of batteries in the battery bank is returned in *Line 6*9.

The actual days of autonomy that you will get out of the battery bank is indicated in *Line 71*. Try adding and then subtracting 1 from the value in *Line 67,* note the changes in *Line 71* and compare it to the desired number of days autonomy (*Line 52*). The actual and desired values will not tally exactly from month to month because of the variations in the load between seasons and the changes in night time temperature between months.

Line 72 gives the maximum possible continuous discharge current of the battery bank at the specified rate. *Line 73* gives the duration for which this current can be drawn continuously (e.g. a battery to be discharged by no more than 50% of its capacity, giving 5A at the 20 hour rate, can maintain 5A for 10 hours).

The actual discharge rate will not be constant because devices are switched on and off throughout the day. A battery discharged at the 20 hour rate at peak times will "recover" at times of less demand and ultimately deliver more ampere-hours than one may expect. It is therefore difficult to accurately asses whether the battery bank will meet the demand. Two rough test are provided in *Line 74* and *Line 75*.

The battery bank's maximum continuous discharge current at the specified discharge rate (*Line 72*) should not be significantly smaller than the inverter input current when the peak power is demanded (*Line 74*), especially if you expect the peak power demand to last for significant periods. Also *Line 75* indicates if the estimated continuous current drawn throughout the day (*Line 51*) exceeds the maximum continuous discharge current (*Line 72*). *Line 75* uses the 'Total' value from *Line 57*; this indicates the current that would be drawn if the total load for one day was drawn evenly throughout a 24 hour period.

4. Array

Section L. PV Panel Details

> *Line 72 to Line 78*: Enter the details of your PV panels. These should be obtained from the manufacturers specifications sheets. The details of many manufactures' panels can be found at http://www.oksolar.com/.

> *Line 79*: If the manufacturing tolerance is ±2%, enter 98%. If there is no manufacture's value for manufacturing tolerances enter a 97% as a default value. This value takes account that there will be a slight variation in performance from panel to panel and that the performance of an array of panels will be dictated by the worst panel.

> *Line 80*: Unless the manufacture specifies otherwise, enter 97%. This value takes account of the accumulation of dirt and dust on the panels.

> *Line 81*: If you want to enter a value for the output per panel that you have calculated manually do so here. In the normal course of events make sure that this cell is set to zero.

Section M. Battery Charger And Charging

Line 82: Enter the preferred number of sunny days that are required to recoup the power consumed from the batteries during cloudy days. For example if you have specified two days autonomy (*Line 52*), after two cloudy days your batteries will have discharged to the depth that you specified (*Line 53*) and no more power may be drawn from them, if you now specify 20 days recoup time the batteries will be fully recharged after 20 sunny days. If money is no object enter a small value such as 5 days. If money is tight and you have a generator you should enter a larger number such as 20 or more days. Once you have examined the data in *Line110* to *Line 117* you can come back and alter this value.

Line 83: Enter the efficiency of your batteries. Because of the internal resistance of the batteries you will need to put more power into the battery than you will get out, this phenomena is expressed as a battery efficiency. This value should be obtained from the manufacture's literature, however a value between 85% and 95% will suffice.

Line 84: Enter the bulk charging voltage of your battery bank. Check your battery and charger manufactures' data. This value will probably be about 14.8V for a twelve volt 'wet' battery bank, although it could be as high as 15.5V. Gel batteries may have a value as low as 13.8V.

Line 85 to Line 90: Enter the specifications of your battery charger here. These should be obtained from the manufacture's data. If you are unsure make *Line 85* = 0, *Line 86* = 97% and leave the rest blank.

Section N. PV Array Sizing

Line 86: If your battery charger has maximum power point (MPP) tracking enter a value of 1, otherwise enter zero. If you are unsure or for an added margin of safety enter zero. The manufacture's literature should detail how the charger operates.

Line 87: Enter the efficiency of your battery charger from the manufacture's literature. If you are unsure a value of 97% should suffice.

Line 88: Enter the maximum output current of your battery charger. This value does not effect the calculation but is used as a reference to check that your charger will not be overloaded. Therefore you can leave this value out initially, however you should find this value out before the final design is confirmed.

Line 89: Enter the maximum voltage that can be supplied to your charger from the PV panel array. This should be available from the manufacture's data. This value does not effect the calculation but is used as a reference to check that your charger will not be overloaded. Therefore you can leave this value out initially, however you should find this value out before the final design is confirmed.

Line 90: Enter the maximum output voltage of your battery charger. Like the previous two lines it is not essential to enter this value on a first run through.

Line 91 to *Line 98* return various values concerning the calculation of how many panels are needed (*Line 99*). For these calculations the total ampere-hours required from the PV array, during one sunny day, is broken down into three parts:

1. the daytime load – this is the amount of ampere-hours needed to supply devices that are switched on during daylight hours;
2. the night time load – this is the amount of ampere-hours that are used by devices switched on during the night, this power must be stored in the batteries during the day;

3. the recoup load – this is the extra amount of ampere-hours needed to recoup the power used during cloudy days, the greater the number of days autonomy (*Line 25*) the greater this recoup load will be. Note that this load is only required if there have been some cloudy days and some of the reserve battery power has been used.

Line 99 returns the number of panels that are needed to meet the three loads during a sunny day. Note the value changes from month to month, the sunniest months need the least panels. *Line 100* tells you how many panels wired in series are needed based on your panel's nominally voltage (*Line 73*) and the nominal voltage of your battery bank (*Line 14*).

> *Line 101*: Look at the values returned in Line 99 and decide how many panels in parallel you require. For an autonomous system with no generator backup the worst (least sunny) month should be optimised, otherwise enough panels can be added to satisfy the load during the majority of the year. After studying the data returned in *Line 110* to *Line 116* you can come back and try different value.

Line 102 returns the total number of panels in the array (the number in series multiplied by the number in parallel). Line 103 to Line 109 contain returned data concerning how well the number of panels you have chosen meets the requirements, the same data is presented in a more convenient form in Line *110* to *Line 117*.

If you have entered two days autonomy (*Line 52*) you will have enough battery capacity for 1 night, a cloudy day, another night, another cloudy night and then a third night. At sunrise on the third morning the batteries will be discharged to their maximum depth (*Line 53*) and no more power should be drawn from them: i.e. the batteries are exhausted.

Line 110 reminds you of how many days autonomy you specified and the following lines assume that the battery bank is in an exhausted state, being unable to supply any power during the following day.

Line 111 states whether your specified array will provide enough power on a sunny day to meet the power drawn by the devices that are switched on during the day. If the value is "No" you must have a backup generator to have electricity during this month.

Line 112 states whether the array will meet the day load and provide enough power to charge the batteries sufficiently to see you through the night. If the returned value is "No" you are not providing enough power for this month, even with fully charged batteries and no cloudy days your batteries will become depleted meeting the normal night load. In this scenario backup will be required for these months.

Line 113 tells you how many sunny days are needed to store enough energy for a single night's full load (if the batteries are stating from an exhausted state) while still meeting the day load. This line returns "never" if the array is not even capable of providing enough power to meet the day load, as it could obviously never charge the batteries. If the array provides enough power to meet the day load and the whole night load, then one sunny day is sufficient to store the power needed for one night's normal load and a value of 1 is returned. If a value greater than 1 is returned the array can meet a normal daytime load but only a fraction of the night load. If, for example, a value of 2 is returned enough energy is being stored for a full load every other night, but you could probably get away with running only essential devices every night. However. If this value is greater than one you will more likely than not need a generator for that month.

Line 114 returns the actual number of sunny days needed to recoup the autonomous reserve. You stated the preferred number of days to recoup this amount of power in *Line 82*, however the actual monthly value will be greater or smaller than this depending on how sunny the month is and how many panels you chose in *Line 101*. If the array is incapable of providing enough power to meet the day and night loads there will be no extra power available to recoup the autonomous battery capacity and "never" will be returned. Under these conditions once the batteries are exhausted they will not recharge until a sunnier month.

With exhausted batteries, *Line 115* tells you how many sunny days are needed to recoup enough power to see you through another cloudy day, while still meeting the normal day and night loads. For example if you have specified 2 days autonomy and the value returned here is 10, after two consecutive cloudy days you would need a minimum of ten sunny days to see you through another cloudy day (meeting the full day and night loads).

Once you have studied the data returned in Line 110 to Line 115 you should go back and try altering the value in *Line 8*. Once you have observed the changes that occur and balanced the cost with the power supplied you can decide on a final number of panels.

The temperature of the cells that make up a PV panel will be considerably higher than the ambient air temperature. *Line 116* warns if the operating temperature of the cells is above 50°C. If this occurs the algorithms used to determine the ampere-hours produced by each panel (*Line 94*) may return erroneous values and these values should be checked. Unfortunately, the method of performing the check is beyond the scope of this text.

Similarly, if the voltage at the array's maximum power point is less than the voltage at which the batteries are charged the algorithms will give an erroneous value; this situation, should it occur will be reported in *Line 117*. This will probably only happen when the operating temperature is above 50°C. Note that if Line *116* indicates that the operating temperature is above 50°C but *Line 117* returns OK, the algorithms are more than likely to give a sound result.

If either *Line 116* or *Line 117* gives a warning for any month you may wish to override the algorithm by entering a manually calculated value for the panel output in *Line 81*. Unfortunately the methods for deriving these values are beyond the scope of this text.

Section O. Battery Charge Size Checking.

Line 122 to *Line 124* report if the battery charger is up to the task or whether it is under sized.

5. Generator

Section P: Generator Requirements

The power that the generator is needed to provide is returned in *Line 125* and *Line 126*.

Section Q: Generator Details And Charger

Line 127 to Line 131: Enter the details of your generator here. Make sure that the units in *Line 130* and *Line 131* are correct, if you can not find this data use the values 1.3 % per 100m and 2 % per 25°C respectively.

Section R: Generator Output

Your generator output is corrected for the heat and altitude of your location.

Section S: Running Hours

The estimated time for which the generator will run for each day in each month is returned here.

6. Symbols, Units and Abbreviations

A	Amperes
AC	Alternating Current
Ah	Ampere-Hours
Ah/d	Ampere-Hours per day
DC	Direct Current
Hr	hour
I_{SC}	PC Panel Short Circuit Current
K_T	Clearness Index
kVA	Kilovolt-Ampere
m	Meters
n/a	not applicable
NOCT	PC Panel Normal Operating Cell Temperature
P_{MAX}	PV Panel Power At Maximum Power Point
PV	Photovoltaic
V	Volts
VA	Volt-Amperes
V_{MAX}	PV Panel Voltage At Maximum Power Point
V_{OC}	PC Panel Open Circuit Voltage
W	Watts
Wh	Watt-Hours
Wh/d	Watt-Hours Per Day

7. Useful Links

Latitude Data – Http://www.heavens-above.com/countries.asp#N

Ambient Temperature Data – http://www.weatherbase.com

Irradiation Data – http://energy.caeds.eng.uml.edu/fpdb/irrdata.asp

PV Panel, Charger Controller and Inverter Data – http://www.oksolar.com/

Lecture notes from the Asian Institute of Technology - http://courses.ait.ac.th/ED06.22/first.html

A solar textbook online - http://powerfromthesun.net/book.htm

Free solar design software – http://www.retscreen.net

For general information on PV panels, batteries, AC power and much more, visit – http://www.catas1.org