Desert Creek House

Practical ecology - Solar electric system

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1) Summary: 14 solar panels produce the electricity we need

We do not use electricity for cooking or for heating or for cooling; only for light and simple appliances, like vacuum cleaner, tools, computer, toaster.

We are not connected to the grid and rely on our own power production.

- 14 solar panels rated 64W produce the power for an average daily maximum consumption of 2.4 kWh
- 12 x 2V batteries store the power for a total capacity of 1380 Ah at 24V (33kWh), of which not more than 10% should be used daily, including losses.
- 1 inverter transforms the 24V DC power from the batteries into 240V AC which can be used for any normal appliance.

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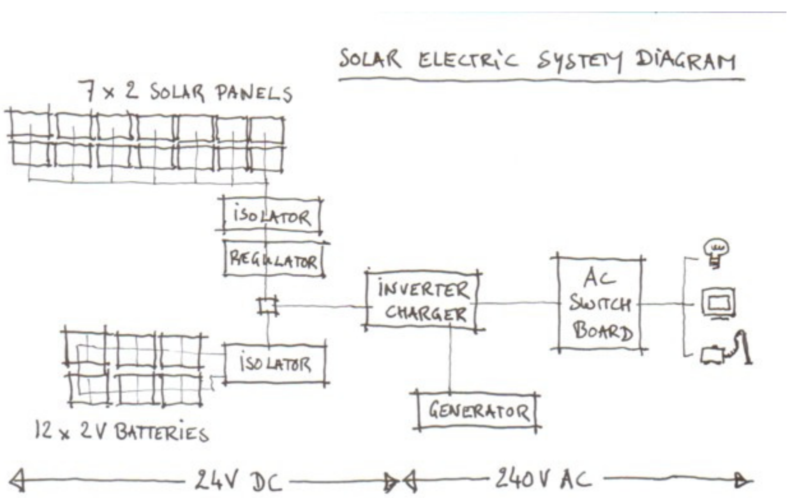
2) General description of the solar electric system



- The 14 solar panels are made out of photovoltaic silicium cells which produce electric power (DC current) under the effect of direct or indirect sunlight.
  The panels are set in series of two in order to produce the right voltage (about 28-30V). Many series of two (7 in our case) increase the intensity of the total power (more Amps for the same voltage).

- A first isolator allows to cut off and to protect the circuit of the panels from the batteries (and reciprocally).
- The power produced by the panels is stored in the batteries. The voltage of the panels (about 28-30V) generated by the effect of light must be higher than the voltage in the batteries (about 24V) to recharge them. The batteries store DC current at 24V.
- The regulator controls the flow of current which comes from the panels and manages the way the batteries are recharged. At the beginning of the recharging process, the voltage is higher (more Volt) and the flow of current is stronger (more Amps), and then it is reduced by the regulator when the batteries are almost full.
- A second isolator protects the batteries and allows to disconnect them from the rest of the system.
- An inverter uses the 24V DC current from the batteries to produce normal 240V AC current for the general use of the appliances and of the lights in the house.
- The inverter can also be used to recharge the batteries with a generator, when there is no sun for a longer period of time. The inverter will then convert the 240V AC from the generator into 24V DC into the batteries.
- The general switch board of the house allows inner subdivisions of the circuit (lights and powerpoints, distinct groups).

3) Cost of the system

Cost of the different parts (in Australian $, April 2006):

14 solar panels US64	AU$ 9'600.-
7 frames, each one for 2 solar panels	AU$ 1'300.-
1 regulator PL40 PM	AU$ 850.-
6 pairs of 2V batteries RL 1380-46 (6x2x2V=24V)	AU$ 7'150.-
1 inverter SSC24-2K3	AU$ 5'000.-
Electrical accessories and cables	AU$ 1'900.-
Installation	AU$ 1'900.-
TOTAL BEFORE SUBSIDIES	AU$ 27'700.-
State subsidies	AU$ - 3'600.-
TOTAL COST	AU$ 24'100.-

If the system works for 25 years, with an average consumption of 2.4 kWh/day, it will produce 21'900 kWh at an average price of AU$ 1.10/kWh; or AU$ 1.30 for a daily consumption of 2.0 kWh. With solar, the more you consume, the more you save!!
It is well possible that the inverter will have to be replaced before 25 years. After 25 years, the system will certainly need new batteries.

4) Evaluation of the needs - size of the system

In order to design the system, the needs have to be evaluated. Each appliance or light or any use of power must be integrated in the following table:

Room	Name appliance	Power (in W)	Number	Duration/week (in h)	Power/week (in Wh)
all rooms	light	20	10	15	3000
all rooms	vacuum cleaner	1200	1	3	3'600
kitchen	food processor	500	1	0.5	250
kitchen	toaster	600	1	0.5	300
laundry	washing machine	600	1	5	3000
laundry	iron	1200	1	0.5	600
living room	TV	120	1	10	1200
living room	computer	50	1	4	200
living room	stereo	60	1	10	600
workshop	drill / saw / grinder	500	1	2	1'000
etc					
TOTAL					**13'750**

Of course this is only an example which should be more complete, probably with more appliances; every appliance or form of use of power should be mentioned and measured. The power of each appliance must be the average power during the time the appliance is running, and not the starting power (the surge) which is always much higher. Notice that appliances which produce heat use a lot of power. Gas can offer an alternative source of energy; yet it is not a renewable energy.

In our example, the necessary power of 13'750 Wh, i.e. about 14 kWh per week, means a daily consumption of about 2'000 Wh (2kWh).

In order to estimate your own consumption, you can use the XL file you can download from our website. This is the example of our own consumption. You have of course to adapt it to your own case; it means you have to add the appliances you use that are not mentioned in this file. You can download it in XLS format: under: /ecology/estimsolarconsumption.xls (27 kb); or in PDF format under: /ecology/estimsolarconsumption.pdf" (19 kb.

As solar electric systems are expensive, it is very important to reduce the consumption to its minimum. Any waste should be avoided; it means incandescent light bulbs should be replaced by fluorescent light bulbs which use only 1/5 of the energy. Any stand-by appliance should be completely disconnected from the house network when not in use. Power-hungry appliances should be also avoided like electric heaters, hair-dryers, air conditioners, or essentially what produces heat; they should be replaced by other sources of energy.

Appliances which use a lot of power should be running during the day, when the sun shines (vacuum cleaner, iron). In this way they will use directly the power of the sun under a higher voltage and will not exhaust so much the batteries. Of course it is only effective if it does not deprive the batteries from being recharged.

The refrigerator is generally the problem, because it is running most of the time. The best fridges consume about 1kWh a day. The addition of 2 solar panels can help as the fridge is running mainly during the day when it is hot and when sunlight is available: more heat means usually more sunshine. The size of the batteries do not need thus to be adapted in the same proportion.

1) Necessary power production: the efficiency of the batteries and of the inverter is only of respectively 80% and 85%. The power production must then be proportionally increased by 80% and 85% to cover the real needs (80% x 85% = 68%). In our example we had a daily consumption of 2kWh which will be covered by a production of 2kWh x 1/68% = 2.94, i.e. about 3 kWh will be needed daily. Some more optimistic calculations consider a total effectiveness of 85% instead of 68%.

2) Choice of the system's voltage: If the total energy consumption is around 1kWh per day or less, then a 12V system voltage would be fine. One may also wish to use DC appliances directly from the battery bank, in which case a 12V system would be the most suitable, as most DC appliances are designed for 12V. It can be even very advantageous to have the light network on 12V, because it would avoid the conversion by the inverter into 240V AC which is the cause of a loss of about 15%. A 12V DC network can also be combined with a 240V AC network with an inverter; in this case one can combine the use of 12V DC appliances with 240V AC appliances, with of course two different networks.
If one uses more energy than 1kWh a day, or have several appliances that draw more than 1000W each, then a higher voltage should be used. A 24V will be fine for systems below 3kWh per day; beyond this limit a 48V system should be considered.

3) Number of solar panels: Although the voltage of a panel is about 17V, it will produce a voltage of only 12V in the battery bank. If the system is in 12V, each string of panels will contain only one panel, but if the system is in 24V, each string will have two panels; for 48V, 4 panels in each string. To count the number of necessary panels, we must then count the number of necessary strings. First the type of panel has to be chosen. If the panel's power rating is for instance 64W, it will produce 64W/17V = 3.7A at full sunlight. The solar map (see below) indicates the number of previsible sunshine hours in a day (example 4.2h); each string of panels will then produce 3.7A x 4.2h = 15.5 Ah/day. Secondly, the necessary power production (3kWh/day) has been calculated before by increasing the consumption (2kWh/day) by the losses of the system (1/68%). The number of strings will be equal to the necessary production divided by the production of each string.
Example: system in 24V, i.e. 2 panels for a string; 64W panels, i.e. 3.7A for each string; 4.2 sun hour a day, i.e. 15.5 Ah / day and string; necessary production of 3kWh/day, i.e. 3kWh/24V = 125Ah. Number of panel strings: 125Ah / 15.5 Ah = 8 strings of 2 panels each, i.e. 16 panels.
IMPORTANT: As solar panels become ever cheaper, it is worth installing more panels than what the calculation tells you to; more panels help recharge more quickly the batteries, and they can cope with overcast weather. You can easily multiply your calculation by 1.5 or even 2! The calculation remains yet adapted for sunny days. The decision depends on your capacity for investment.

4) Size of the battery bank: As the battery bank should not be discharged by more than 10% daily (some say 15%, but batteries then do not last so long), the necessary production should be multiplied by 10. In our example: daily consumption of 2kWh and necessary production of 3kWh; system in 24V; 3kWh / 24V = 125 Ah; 125 x 10 Ah = 1250 Ah. The battery bank will be made out of a string of 12 x 2V cells with each a capacity of 1250 Ah or above.

5) Size of the inverter: What is important is the maximum power which must be provided at a given time, including all appliances which have to run simultaneously. Usually inverters have a peak capacity which lasts only for a short while and an average capacity for longer periods. It means

that they are capable to provide the necessary power to start an appliance, i.e. the surge which is normally much higher than the running power. For instance a fridge with a motor rated at 150W may draw over 1'000W when starting. Most tools use only 500W, but a vacuum cleaner will use 1'000 or even 1'400W for the time it runs. For an average household, an inverter in the range of 1'200 or 2'400W continuous output power would be appropriate.

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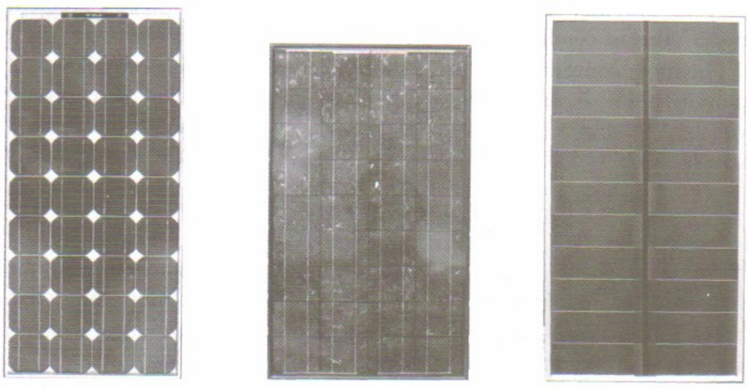
5) The solar panels

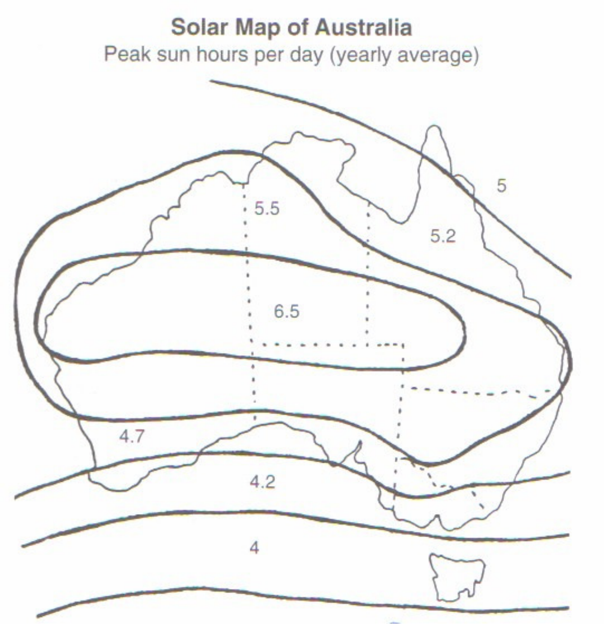
It is important not to make any confusion between the 2 types of solar panels which produce either hot water or electricity:

1) A solar absorption panel for hot water is a big black metal sheet on which runs a water pipe and absorbs the heat from the sun to heat up water for sanitary appliances,
2) A solar photovoltaic panel is made out of a string of silicium cells, wired together to provide the required voltage and current rating, and produces electricity under the influence of direct or indirect sunlight.



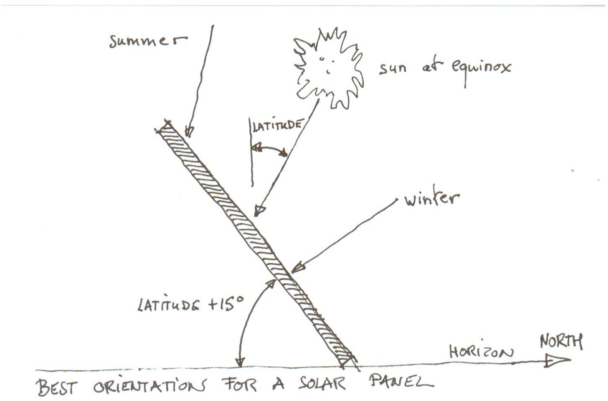
There are 3 categories of electric solar panels:

1) Monocrystalline panels (left on the picture) are made from silicone slices cut from a single large crystal. This provides the highest efficiency but is more expensive to produce.
2) Polycrystalline panels (middle on the picture) are made from silicone which has been cast in blocks. They are cheaper to produce and their performance is similar to a monocrystalline panel.
3) Amorphous silicone panels (right on the picture) are made out of silicone spread in thin layers on a backing material or glass plate. This material can be applied directly to stainless steel sheeting, allowing solar panels to replace the roof.



Solar panels measure currently about 1m x 0.6m and are usually made of 36 cells which create a voltage of 17V (about 0.5V/cell). Some panels have only 32 cells, but they do not produce a high enough voltage to allow for voltage losses in the system. The voltage in the panels (17V or 2x17V) is higher than the voltage in the batteries (respectively 12V or 24V). This difference allows the panels to charge the batteries, and compensates for the voltage losses in the system. The power rating of panels varies usually between 50 and 83 W; at 17V, a power rating of 64W means a production of 64W / 17V = 3.7A in full sunlight for each panel.

This solar map indicates the number of sun hours which can be considered in daily average. Where we live near Bega (South Coast NSW), we have 4.2 hours/day. The production of each panel of 64W will be 3.7A x 4.2h/day = 15.5 Ah/day.



- Panels should face north (in the South hemisphere) and be at an angle from the horizontal equal to the latitude of this location plus about 10° or 15° (average fix position).
- The position of the sun at midday at the equinox is at an angle = 90° - latitude. At the summer solstice this position is increased by 23° and at the winter solstice it is diminished by 23°. Example: at the latitude 36°, the position of the sun at midday at the equinox will be 90° - 36° +/- 23° = 54° +/- 23°; this position will then vary through the year from 31° as the minimum in winter to 77° as the maximum in summer.
- The best position for the panel consists in being perpendicular to the sun at midday; it will then capture a maximum of energy; as this position of the sun varies through the year the panel should be adaptable and its position should be adapted twice through the year, with a summer position and a winter position. There is yet an easier way, which nevertheless means some losses in comparison with an adaptable system: as the days are shorter in winter and the sunlight is weaker because of the lower position of the sun, it is better to orient the panel in order to catch more light in winter than in summer. The rule "latitude + 15°" seems ideal.

See picture: the structure can be adapted to different positions (vertical angle) according to the season. Panels are here assembled in strings of two (24V system).

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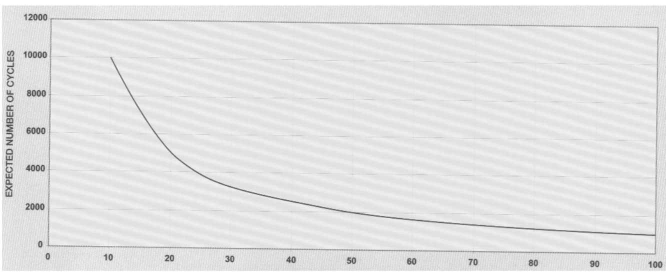
6) The battery bank

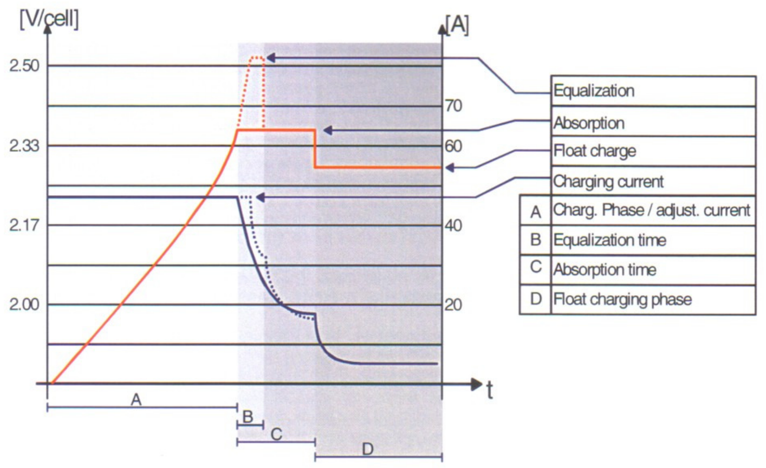
There are different kinds of batteries:

- Car batteries are designed to give short bursts of very high current to start the engine. They are not suitable for use as storage batteries because they are made to be fully charged all of the time and will have a very short life if subjected to the deep discharge cycles that are required with solar electricity storage systems.
- By far the most common type of batteries is the lead-acid battery, and these are usually of the flooded-cell type, though sealed lead-acid batteries are becoming more popular.
- Nickel-cadmium (nicad) batteries are also available and, while very expensive, do have the advantages of very long life and more stable voltage during discharge. Yet they have the disadvantage of needing high charging voltages which can be outside the operating range of some inverters, causing them to shut down temporarily.

Discharge: It is important not to discharge the batteries by more than 10% or 15% daily. The more one discharges the batteries, the less they will last. The graphic nearby shows how a daily discharge of 15% instead of 10% reduces the life of the batteries by 20% (8'000 cycles instead of 10'000). 8'000 cycles last for about



22 years (= 8'000 cycles / 365 days / year). In any case, the batteries should never be discharged by more than 70%.

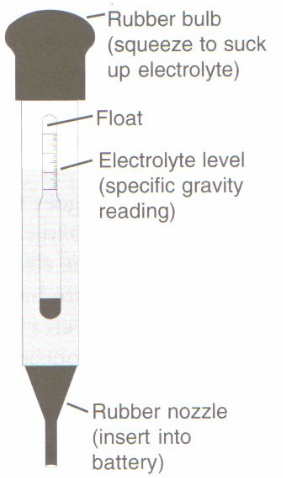


Recharging the batteries: the batteries should never be recharged at a rate quicker than C/5 (where C is the capacity of the batteries). In our example it means 1250Ah / 5h = 250A. The charging current from the solar panels is usually nowhere near this value, but care needs to be taken with backup generators and battery chargers, which can put out large currents. The voltage of the panels must be higher than the one in the batteries: between 2.4 or 2.5 per 2V cell, it means between 14.4 and 15.0V for a 12V battery or between 28.8 and 30.0 V for a 24V battery.

There are usually three phases in the charging process when it is managed electronically:

A) Charging phase: The load is maximum according to what the panels or the charger provide.
B) Equalisation time: a higher voltage is applied to the batteries for a specified period of time. This extended charge, which should be given at least once a week, reduces the differences of charges between the different cells.
C) Absorption time: this is the peak voltage which brings the battery load to its maximum.
D) Floating charging phase: this is a reduced charge which maintains the state of charge of the batteries.

The state of the charge of batteries: It can be measured by three methods:



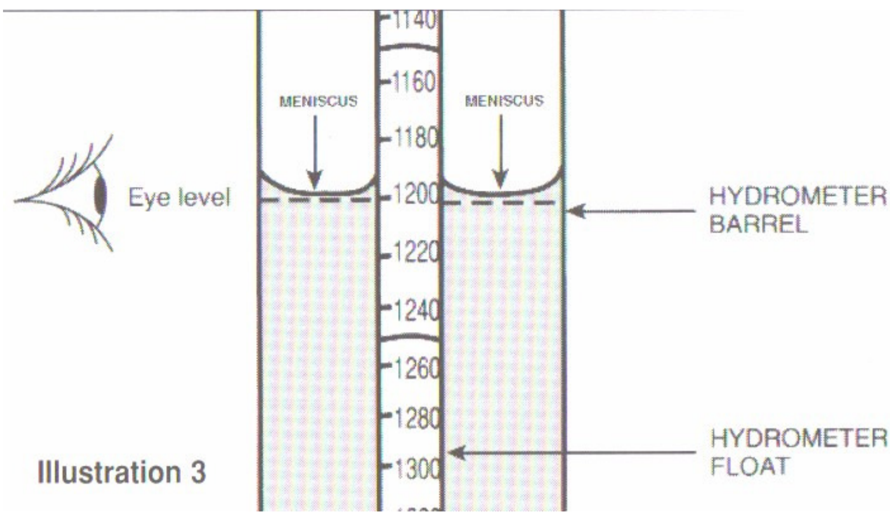


Illustration 3

1) Hydrometer: when a battery is about 90% charged, the density of the electrolyte increases rapidly. A hydrometer is used to measure this density: the electrolyte normally has a specific gravity of 1.15 but rises to 1.24 when fully charged.
2) Battery voltage: at a current charge of C/10, the following voltages give an approximate indication of how charged a 12V flooded-cell lead-acid battery is: 12.7V for a 30% charge; 13.2V for 60%; 13.8V for 80%; 14.4V for 85%.
3) Regulator: the regulator indicates generally the state of charge, according to the quantities of input and output and to the time when the battery has been last fully charged.

The best place for the batteries: They should be in a protected cupboard, outside the house, well ventilated and well protected from heat and cold. It is better if they are well separated from the inverter and regulator, yet not too far, as the acid can create a deterioration of electronic parts when it evaporates.

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7) The regulator

The regulator manages the way batteries are recharged. It protects the batteries from overload.

It registers also data which can be downloaded to a computer, like daily total input and ouput, charge or load at a certain time, maximum or minimum charge and load of the day, floating time, etc. These data are memorised for something like 30 days.

It is very valuable to be able to check the state of charge of the battery bank, to observe the evolution during a whole month in order to detect any problem, to check how a new appliance fits into the system or to adapt the regular consumption to what is available.

On the photo the regulator indicates the batteries voltage (BATV): the panels are loading the batteries with a voltage of 27.8V in boosting phase (charging).

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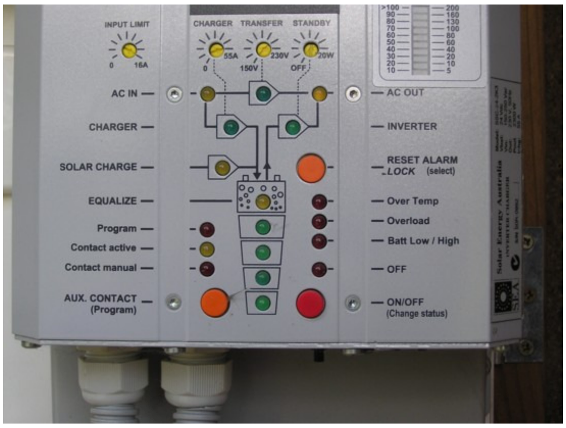
8) The inverter

The inverter converts the DC current from the batteries into AC 240V current which can be used by any kind of usual appliances



There are two kinds of inverters:

- Modified square wave type: they produce a very rough imitation of alternative current according to a square wave which changes by steps from 0 to (+) than back to 0 than to (--) than back to 0, instead of creating a regular undulation which varies progressively between these same extreme tensions.
- Sinewave type: they produce a regular wave which undulates between two extreme (+ and --).

The power the inverter provides can be increased for a short while, depending on the ambient heat, as it will cut off when it becomes too hot: a nominal power of 2'300W could be increased to 2'500W for 30min, or to 3'000W for 3min, or to 6'000W for 1min.

Inverter work also in the reverse way as they usually can be used as chargers; it means that they transform AC current from the generator into DC current of low voltage for recharging the batteries.

On the picture of the previous page, one can see the switch board: the inverter on the right, with the regulator on the left, and the circuit breakers in the middle. The lower powerpoint is for the generator (recharge of the batteries).

If the system is well dimensioned and the consumption adapted to what is available, this recharging function is never used.