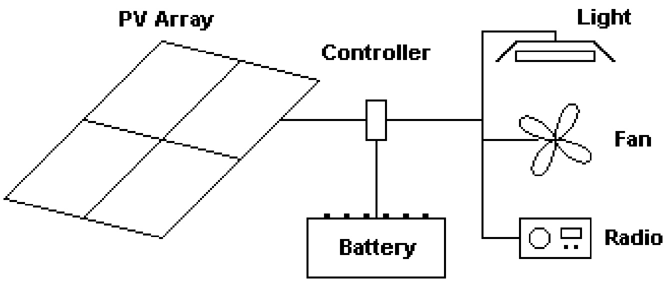
Simple Domestic Photovoltaic Systems

Example of a Domestic PV System



Photovoltaic Arrays

Most solar PV panels have 30 to 36 cells connected in series. Each cell produces about 0.5V in sunlight, so a panel produces 15V to 18V. These panels are designed to charge 12V batteries. A 30 cell panel (15V) can be used to charge the battery without a controller, but it may fail to charge the battery completely. A 36 cell panel (18V) will do better, but needs a controller to prevent overcharging. The current depends on the size of each cell, and the solar radiation intensity. Most cells produce a current of 2A to 3A in bright sunlight. The current is the same in every cell because the cells are connected in series.

Panels are rated in **peak watts** (Wp), namely the power produced in an optimally matched load with incident solar radiation 1000W/m^2. A typical panel rating is 40Wp. In a tropical climate a 40Wp may produce an average of 150Wh of electricity per day, but as the weather changes the energy varies, typically between 100Wh to 200Wh per day.

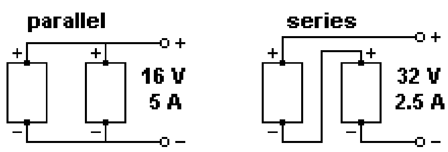


Fig. 1. PV panels connected in parallel and series.

If two 40Wp panels, each giving 2.5A at 16V in bright sunlight, are connected in parallel (Fig. 1, left) they give 5A at 16V. If they are connected in series (Fig. 1, right) they give 2.5A at 32V. In both cases the power is the same: 80W.

Since the intensity of sunlight is rarely at the peak value, the power output from a panel is usually much less than the peak rating. At low solar radiation intensities the voltage remains almost the same, but the current is low.

Panels should normally be mounted facing the point where the celestial equator crosses the meridian, but should be tilted at least 5° to allow rain to drain off. Since the power output of solar cells is reduced by high temperatures there should be at least 100mm clearance for ventilation under the panels. There must be no shading of the panels by obstructions, and the panels should be kept clean. Even partial shading of one or more panels can create a resistance in the circuit and reduce the performance of the system.

Batteries

Batteries used for energy storage are the most expensive part of a PV system. This is because they last only about five years, whereas PV panels last over 20 years. Batteries are easily damaged and need careful maintenance. **Nickel-cadmium** and **lead-acid batteries** are used in PV systems. Nickel-cadmium batteries are reliable, but they are expensive so lead-acid batteries are more common.

Lead-Acid Batteries

The lead-acid battery has lead plates immersed in sulphuric acid. The chemical reactions involved are summarized by the following equations:

Negative Plate:

Pb	+	SO_4^{2-}	discharge -->	$PbSO_4$	+	$2e^-$
plate		electrolyte	<-- charge	plate		current

Positive Plate:

PbO_2	+	$4H^+$	+	SO_4^{2-}	+	$2e^-$	discharge -->	$PbSO_4$	+	$2H_2O$
plate			electrolyte			current	<-- charge	plate		electrolyte

The efficiency of lead-acid batteries is 80%. If 100Wh are used to charge a battery, only 80Wh can be obtained during discharge.

Lead-acid batteries may be designed as **starting batteries** for starting automobile engines, or as **deep discharge batteries** to power electric vehicles.

Starting batteries are designed to produce large currents for a short time. They have many plates to form a large area, and thin coatings of porous chemicals to give a low electrical resistance. Because lead sulphate on the plates occupies a larger volume than lead metal (on the negative plates) and lead oxide (on the positive plates), the plate coatings expand when the battery is discharged and contract when the battery is charged. This causes small amounts of coating to fall off during a discharge-charge cycle. If a starting battery is fully discharged the coatings on its plates are damaged. Therefore, starting batteries rarely use more than 5% of their total charge when starting an engine, and they are kept fully charged in the intervals between use. Obviously, starting batteries are not suitable for solar PV systems.

Deep-discharge batteries are designed to provide moderate currents continuously for a long time. They have fewer plates and thicker coatings than starting batteries, and they may be discharged almost completely without damage (provided they are not short-circited!). Therefore, the batteries used in solar PV systems are deep-discharge batteries.

Each cell in a lead-acid battery gives 2V. Therefore, a 12V battery has six cells connected in series. If a higher voltage is needed, two 12V batteries connected in series can be used to give 24V. To obtain a high current at 12V, two or more batteries may be connected in parallel. (See Fig. 2.)

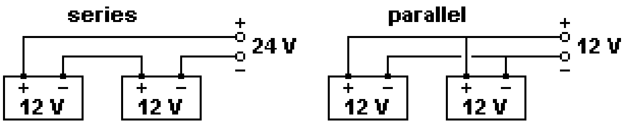


Fig. 2. Batteries connected in series and parallel.

The capacity of a battery depends on how much chemical material the battery contains. The capacity is measured in ampere-hours. Thus, a 100Ah battery will give 1A for 100h, 5A for 20h, etc. The energy in a 12V 100Ah battery is:

$$12V \times 100Ah = 12V \times 100A \times 3600s = 4.32MJ.$$

Controllers

A **charge controller** prevents the PV panel overcharging the battery. In a *parallel charge controller* the PV panel is short-circuited when the battery is fully charged. In a *series charge controller* the panel is disconnected from the battery when the battery is fully charged. (See Fig. 3.)

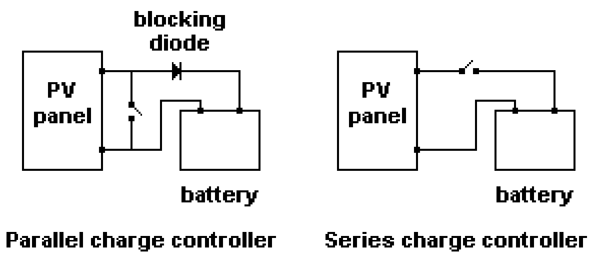


Fig. 3. Charge controllers.

Controllers sense the battery voltage to determine the state of charge of the battery. When a battery is fully charged its voltage rises. A charge controller for a 12V battery cuts the charging current off by means of a transistor switch or a relay when the voltage rises to 14.4V. It resets the charging current when the voltage falls to 13.4V.

A **discharge controller** is used to protect the battery from excessive discharge. When a battery is discharged, its voltage falls. A discharge controller for a 12V battery is set to cut the load off when the voltage falls to 10.7V. The user may then have to reset the controller manually to reconnect the load after the battery has been recharged. Indicator lights, meters, or audible alarms may be used as warnings when the charge in the battery is low. Automatic resetting may be used for refrigerators, but not for lights, otherwise lights may be turned on automatically during the day and waste the valuable electrical energy.

Appliances

Lights

The efficiency of a lamp is measured in lumens per watt (lm/W). The efficiency of an incandescent lamp is about 20 lm/W, and the lamp may last only 1000 hours. The efficiency of a good fluorescent lamp is about 60 lm/W and the lamp may last 10,000 hours. Therefore, fluorescent lamps are more suitable for PV systems than incandescent lamps, even though high quality fluorescent lamps are more expensive than incandescent lamps. For domestic use, 15W fluorescent lamps may be suitable. The ballasts needed for fluorescent lamps in DC systems are different from those used in AC systems.

Refrigerators

Compression refrigerators with DC motors are used in solar PV systems to store food in homes, and to store vaccines and medicines in health centers. They are purpose-designed with high quality insulation to avoid heat leakage from outside, and the door opens upwards instead of sideways to reduce the loss of cold air when the refrigerator is opened. The compressor may require 60W of power, but it is on only 50% of the time with normal usage.

Other Appliances

- Fan: 25W.
- Radio: 5W.
- Television: 15W.

System Sizing

The number of PV panels needed and the capacity of the battery must be calculated for a specified load. Allowances are made for losses in the wires and the battery. If the climate differs significantly from the average tropical climate, this may also have to be taken into consideration. The method is illustrated by an example.

Step 1

Calculate the daily energy load in watt-hours.

Example

```
Four 20W lamps used 4 hours per day:          320Wh
One 15W television used 2 hours per day:       30Wh
Two 25W fans used 6 hours per day:            300Wh
One 60W refrigerator used all day,
      compressor on 50% of the time:          720Wh
                                             ------
                      TOTAL DAILY LOAD:      1370Wh
                                             ------
```

Step 2

Add 5% to allow for battery-to-load wire losses.

Example

```
Daily energy from battery:  1370Wh × 1.05 = 1438.5Wh
```

Step 3

Calculate the required daily input to the battery using battery efficiency 80%.

Example

```
Daily input to battery:  1438.5Wh ÷ 0.8 = 1798.125Wh
```

Step 4

Add 5% to allow for PV array-to-battery wire losses.

Example

```
Daily energy from PV array:  1798.125Wh × 1.05 = 1888.03Wh
```

Step 5

Calculate the number of 40Wp panels required in the array assuming each panel produces 150Wh per day.

Example

```
Number of 40Wp panels:  1888.03Wh ÷ 150Wh = 12.6
```

Therefore, a 12V system needs 13 panels connected in parallel. A 24V system needs 14 panels connected in a 2 × 7 array (Fig. 4).

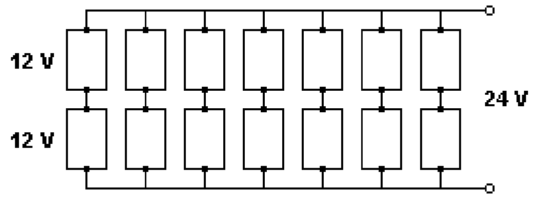


Fig. 4. A 2×7 array of PV panels.

Step 6

Calculate the number of ampere-hours required per day from the battery.

Example

```
Number of Ah per day for a 12V system:  1438.5Wh ÷ 12V = 120 Ah
Number of Ah per day for a 24V system:  1438.5Wh ÷ 24V =  60 Ah
```

Step 7

Choose a battery capacity enough for five days.

Example

```
Battery capacity for a 12V system:  120Ah × 5 = 600Ah
Battery capacity for a 24V system:   60Ah × 5 = 300Ah
```

Photovoltaic Array Ratings

A rating of **r kilowatts peak (r kWp)** means **r kW per 1.0 kW/m^2 of insolation**. It has dimensions kW ÷ (kW/m^2) = m^2.

For example, 2.4kWp means the array gives 2.4kW of power when the solar irradiance falling on it is 1.0kW/m^2. In other words, it is equivalent to 2.4m^2 of collector area at 100% efficiency. Another example: 30Wp is equivalent to 0.03m^2 of collector area at 100% efficiency.

The rating in kWp is the area in m^2 of insolation giving the same power as the array. The rating in Wp is the area in units m^2/1000 giving the same power as the array.

Example

Suppose we need an output of 1.4kWh per day, and the insolation at a site is 16MJ/m^2 per day. The insolation at the site is 16MJ/m^2 ÷ 3.6MJ/kWh = 4.44kWh/m^2 per day. It follows that the PV array rating must be 1.4kWh ÷ 4.44kWh/m^2 = 0.315m^2 = 0.315kWp = 315Wp.

By R. H. B. Exell, 2000. King Mongkut's University of Technology Thonburi.