Photovoltaic systems

Photovoltaic (PV) technology has been used to power homes for many years, and with good reason. Sufficient sunlight falls on Australia to supply the nation’s total energy needs many times over. By installing solar modules (or panels), the homeowner is able to capture some of this abundant energy. Read this article in conjunction with Renewable energy.

Solar modules

Solar modules are available in two distinct categories — crystalline silicon and thin film.

**Crystalline solar modules** are covered with tempered glass on top and have an ethylene vinyl acetate resin material on the back to protect the solar cells from moisture.

The most efficient crystalline silicon cells are monocrystalline and are made from slices of a large single ingot, or crystal boule. Multi-crystalline or polycrystalline cells are made up of many small silicon crystals and have a speckled appearance. They have a lower ‘output efficiency’.

Crystalline modules perform best in cooler temperatures. The output of crystalline PV modules is rated for a given test temperature of 25°C in the cells; output reduces by approximately 0.5% for each degree Celsius in the module above the standard test temperature (this percentage reduction can vary 0.3–0.9%, which can make a material difference at temperatures significantly higher than 25°C). Good ventilation is required at the back of modules, which should be installed so they are exposed to cool air.

**Thin film modules**, as the name suggests, comprise a thin layer that can generate direct current electricity when exposed to sunlight. This film can be deposited onto low cost substrates, such as glass or plastic, to give a variety of module sizes. Amorphous silicon was once the most widely used thin film technology, but now other thin film materials such as cadmium telluride and copper indium gallium arsenide are increasingly being used.

The advantages of thin film technology include easier deposition onto materials and assembly, low cost of substrates or building materials, ease of production and suitability to large applications.

The output efficiency of thin film modules is lower than that of crystalline modules, but they are all price competitive. This technology degrades in output by up to 10% when first exposed to sunlight but quickly stabilises to its rated output.

Thin film modules allow for various coating and mounting systems. Some are less susceptible to damage from hail and other impacts than modules covered in glass.
All solar modules can be supplied with a frame, usually constructed of anodised aluminium, or as an unframed laminate.

Increasingly, solar modules are being fabricated as building materials so that they can be integrated into the building fabric. They include solar roof tiles, wall materials and semi-transparent roof material for atriums and skylights.

The anticipated further development of thin film technology should lead to a proliferation of cost effective PV coated building materials that can be integrated with the building surface.

The anticipated further development of thin film technology should lead to a proliferation of cost effective PV coated building materials that can be integrated with the building surface to reduce costs (see ‘Building integrated photovoltaic modules’ below).

All PV modules need to be cleaned periodically to maintain their efficiency.

Output power

The output power from an array is directly proportional to power received from the sun, which varies throughout the day and year. The rated maximum output of the module might be achieved only occasionally, depending on actual site conditions.

The table shows the number of hours per day for a given month and city when solar power is available at its rated maximum of 1,000W/m². The number of peak sun hours is thus numerically equal to the daily solar irradiation measured in kilowatt hours per square metre (kWh/m²).

For grid connected PV, the system designer might use daily or monthly peak sun hours for calculations, but usually they would show the total yearly figures in kWh/m² and then provide an estimate of the yearly energy output of a system.

For stand-alone power systems, the system designer might typically calculate the output energy from the peak sun hours, which is a measure of the available solar energy (not the number of hours of daylight or the number of hours the sun is shining unobscured). Peak sun hours vary throughout the year but are usually averaged and presented as a monthly figure.

### Daily peak sunlight hours in Australian cities

<table>
<thead>
<tr>
<th>Month</th>
<th>Melbourne</th>
<th>Canberra</th>
<th>Sydney</th>
<th>Perth</th>
<th>Darwin</th>
<th>Brisbane</th>
<th>Adelaide</th>
<th>Hobart</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>6.9</td>
<td>7.4</td>
<td>6.7</td>
<td>8.2</td>
<td>5.4</td>
<td>6.5</td>
<td>7.8</td>
<td>6.3</td>
</tr>
<tr>
<td>February</td>
<td>6.4</td>
<td>6.5</td>
<td>5.8</td>
<td>7.2</td>
<td>5.2</td>
<td>6.2</td>
<td>7.3</td>
<td>5.6</td>
</tr>
<tr>
<td>March</td>
<td>5.2</td>
<td>5.3</td>
<td>5.7</td>
<td>6.0</td>
<td>5.6</td>
<td>5.7</td>
<td>6.3</td>
<td>4.1</td>
</tr>
<tr>
<td>April</td>
<td>3.8</td>
<td>3.8</td>
<td>4.4</td>
<td>4.3</td>
<td>5.9</td>
<td>4.8</td>
<td>5.0</td>
<td>2.8</td>
</tr>
<tr>
<td>May</td>
<td>2.8</td>
<td>2.7</td>
<td>3.6</td>
<td>3.1</td>
<td>5.6</td>
<td>4.2</td>
<td>3.8</td>
<td>1.8</td>
</tr>
<tr>
<td>June</td>
<td>2.4</td>
<td>2.1</td>
<td>3.4</td>
<td>2.5</td>
<td>5.3</td>
<td>4.1</td>
<td>3.5</td>
<td>1.4</td>
</tr>
<tr>
<td>July</td>
<td>2.7</td>
<td>2.5</td>
<td>3.3</td>
<td>2.7</td>
<td>5.5</td>
<td>4.2</td>
<td>3.4</td>
<td>1.7</td>
</tr>
<tr>
<td>August</td>
<td>3.3</td>
<td>3.3</td>
<td>4.4</td>
<td>3.5</td>
<td>6.0</td>
<td>5.2</td>
<td>4.4</td>
<td>2.4</td>
</tr>
<tr>
<td>September</td>
<td>4.3</td>
<td>4.5</td>
<td>5.2</td>
<td>4.7</td>
<td>6.3</td>
<td>6.0</td>
<td>5.3</td>
<td>3.5</td>
</tr>
<tr>
<td>October</td>
<td>5.3</td>
<td>5.9</td>
<td>5.8</td>
<td>6.1</td>
<td>6.5</td>
<td>5.9</td>
<td>6.5</td>
<td>4.8</td>
</tr>
<tr>
<td>November</td>
<td>6.1</td>
<td>6.8</td>
<td>6.3</td>
<td>7.2</td>
<td>6.4</td>
<td>6.0</td>
<td>7.0</td>
<td>5.7</td>
</tr>
<tr>
<td>December</td>
<td>6.6</td>
<td>7.4</td>
<td>6.9</td>
<td>8.1</td>
<td>5.9</td>
<td>6.3</td>
<td>7.46</td>
<td>6.2</td>
</tr>
<tr>
<td>Average</td>
<td>4.6</td>
<td>4.9</td>
<td>5.1</td>
<td>5.3</td>
<td>5.8</td>
<td>5.4</td>
<td>5.6</td>
<td>3.9</td>
</tr>
<tr>
<td>Total annual solar irradiation* *(kWh/m²/year)</td>
<td>1679</td>
<td>1789</td>
<td>1862</td>
<td>1935</td>
<td>2117</td>
<td>1971</td>
<td>2060</td>
<td>1424</td>
</tr>
</tbody>
</table>

*Peak sunlight hours = daily solar irradiation
Source: Australian Solar Energy Society 2006
The peak power output of solar modules is rated in kilowatt peak (kWp), and measured under standard test conditions. Energy outputs of PV modules vary over the year in line with monthly sun hours (see table). The amount of usable energy from the system is lower than the output of the modules themselves due to energy losses in system components. Grid connected and stand-alone PV systems have vastly different usable energy outputs as the systems incorporate different sets of components and hence different loss mechanisms.

The quoted output of a solar module is based on the module being exposed to full sunlight. The effect of shading on a module is greater on crystalline modules, less in amorphous modules. For monocrystalline or polycrystalline modules, if one cell is shaded, power is lost from many cells in the module and possibly from the whole module, not just the one that is shaded. Continued partial shading can damage the module itself. Therefore, solar arrays should not be located near trees that will grow and shade the modules.

The quoted output of a solar module is based on the module being exposed to full sunlight.

Modules used in grid connected systems have a low profile sealed junction box on the back from which the leads fitted with plugs/sockets originate. This low profile sealed junction box is now also used for stand-alone power systems; however, a few modules still have the older, large type junction box on the back for electrical connection.

Inside either type of junction box, the crystalline module’s bypass diodes are fitted across groups of cells. For thin film modules, the bypass diodes are fitted across each cell. These bypass diodes allow current to flow through them when cells are shaded, minimising the possibility of cell damage.

In a stand-alone system, at night-time the solar cells act as a resistive load and a small amount of current flows from the battery bank into the module. More power is lost through this process in polycrystalline modules than in monocrystalline modules. In the past, blocking diodes were fitted in junction boxes to prevent this night-time discharge; now the system controller prevents it.

In stand-alone power systems, the PV array needs to be installed as close as possible to the batteries to minimise power loss between the two. The system designer determines the size of the cable to minimise power loss between modules and batteries. (see Batteries and inverters)
Energy
Photovoltaic systems

If modules are mounted some distance from batteries, they can be wired in series to allow higher voltage and lower current, thus reducing losses. An electronic device called a maximiser is used to convert solar module output to the correct battery voltage.

Choosing your system
Take the time to consider a few things before purchasing a solar system to ensure you are getting what you pay for and selecting the system that is right for you.

What size system should you have? Any supplier should ask you this question before quoting a system for you. The size of your system depends on your expectations.

If your state has a feed-in tariff and you wish to take advantage of this for the financial return, you want to maximise your annual production by tilting your system to the location’s latitude. If you are looking to reduce the impact of time-of-use metering and avoid this additional energy cost, then facing your array NNW and having a greater tilt angle for the array could offset peak energy use. If you want a stand-alone system, your performance expectations include a fairly consistent energy supply: a greater tilt angle would increase winter energy output at the expense of the energy generated in summer.

For grid connected systems, the rated output of the inverter you install affects the power delivered from your solar array.

For grid connected systems, the rated output of the inverter you install affects the power delivered from your solar array. Match the inverter to the system size you want and to the PV array to be installed. However, if you plan to expand the solar array at a later date or there is large variation in the expected solar resource, it is often cheaper to install a larger inverter to allow scope for the system to increase.

Financial incentives like Small-scale Technology Certificates reduce the upfront cost of any system, and are usually built into the retail price. The quality of systems offered on the market varies enormously and common sense must apply: if the deal seems too good to be true, then it probably is. If you install a system using equipment from recognised manufacturers, that has good warranty coverage on the module performance, inverter and workmanship, and uses an established and/or accredited installer with proven experience, you are buying a good system that will last.

Siting

The angles, altitude and azimuth, which specify the position of the sun in the sky.

Clean Energy Council tables illustrate the effect of orientation and tilt, and are part of installer resources on their website at www.solaraccreditation.com.au

Orientation (azimuth)
Solar modules produce most power when they are pointed directly at the sun. They should be installed so that they receive maximum sunlight. As a general rule of thumb for the southern hemisphere, install the solar modules to face north (towards the equator) to produce the most energy across the year. If the particular installation requires loads during either summer or winter to receive maximum solar contribution (peak loads), the orientation of the array can be changed.

Tilt angle (angle of elevation or plane inclination or altitude)
Generally for grid connected systems the tilt angle should be within 10° of the site’s latitude, to maximise the amount of energy produced annually. For example, in Sydney, at latitude 34° south, an acceptable installation tilt would be 24° from the horizontal. As most roof pitches are 20–22°, installing the modules flat onto the roof is acceptable for all of Sydney.

For a stand-alone PV system, where usually winter operation is crucial (i.e. needing to get maximum charge into the batteries when available sunlight hours are minimal), the tilt angle should be the site’s latitude plus 15°.
Installation

Modules can be installed on the ground, on a wall or roof with a frame mount, or integrated into the building fabric.

The fixing of a solar array mounting system on a tiled roof. Tile hooks are installed by attaching a bracket to the rafter. They stick out from underneath a tile and provide a strong mounting point for the rail, the long bar to which the solar modules are mounted.

The vast majority of PV systems installed in Australia between 2000 and 2011 were less than 100kWp. Most systems were installed for the domestic market and were therefore rooftop installations. A very small percentage of installations were mounted on the ground and an even smaller number were integrated into the building fabric.

Array frames

Solar array frames are tilted so that modules face the sun. In Australia, modules are installed to face north. In tropical areas this means the sun is south of the array for part of the summer but this does not greatly affect output (see ‘Siting’ above).

Array frames can be fixed, adjustable or tracking. The system designer selects the right frame for your system.

Fixed frames are set at the optimum tilt angle for the system, which depends on the location, type of load and available solar input (see ‘Siting’ above).

For stand-alone systems, as a rule of thumb, if the main loads are in the winter months when the solar resource is reduced, make the array’s tilt angle more vertical (approximately latitude plus 15°) to maximise exposure to the low winter sun. If the installation has major cooling and refrigeration loads, reduce the tilt angle (approximately latitude minus 10°) to maximise output during summer when those loads are greater for longer.

For grid connected systems, use the site’s latitude angle to maximise the annual output of modules; +/- 10° is still acceptable and within the range of the typical roof pitch.

Adjustable frames allow the tilt angle to be varied manually to maximise output throughout the year. This type of framing is used for stand-alone systems where the installation is usually on the ground. Unless there is some guarantee that the tilt angle will be regularly varied for the life of the system (rather than the first few years of operation while the owner is still motivated), it is best to fix the array at the optimum angle.

Tracking array frames follow the sun’s path across the sky throughout the day and year. They are controlled either by an electric motor or a refrigerant gas in the frame that uses the heat of the sun to move the gas around the tracker’s frame as it follows the sun.

Trackers are more expensive than fixed array frames but by following the sun they provide more energy throughout the day. They are most beneficial at higher latitudes where the available solar energy is lower. Tracking arrays, being mechanical devices, require maintenance and this may reduce system reliability.
Energy
Photovoltaic systems

The outputs of crystalline modules are affected by temperature: as the temperature increases, the output decreases. To keep crystalline modules cool, they should be well ventilated, with a gap of at least 50mm behind them to allow airflow.

Avoid corrosion. If the array frame and module frame are made from galvanically different metals (in contact with each other, the two metallic components will corrode), they must be separated by an isolating material to prevent electrochemical corrosion. This also applies when installing the modules and mounting structure on a metal roof.

Array frames must be designed so that their installation meets Australian wind loading standards under AS/NZS1170.2:2011, Structural design actions — wind actions.

Check the ability of any roof structure to withstand the structural wind loading arising from the PV installation for that specific location and if necessary have the installation redesigned.

Building integrated photovoltaic modules

True building integration requires the PV product to be fully integrated into the building or replace an existing building element.

PV installations are currently an additional expense but, if done well, building integrated PV (BIPV) construction should add considerable value to a home. BIPV is incorporated internationally as a prestigious element of modern architecture.

BIPV products requiring few additional installation details beyond standard construction practice are beginning to appear but are not yet common in Australia. PV can be integrated into roofs, façades, skylights or awnings. Façade systems are not recommended in Australia as the potential energy output is lower due to the vertical elevation of the PV and generally high sun angles.

Many BIPV installations do not allow effective cooling of crystalline modules, which lowers output. This needs careful consideration in the design.

If you are considering BIPV, ensure new buildings are designed so that PV elements face north at the near optimum tilt angle (see ‘Siting’ above).

Roof integration

Rooftop systems can be either partially or fully integrated. In full integration the elements must also fulfill the usual functions such as strength, watertightness and drainage. The installation must be carefully planned and the appropriate products and services confirmed.

Some partially integrated systems use special mounting structures to hold the modules but require an additional waterproof membrane under the solar component.

Solar tiles or shingles are designed to replace conventional tiles or roofing. They allow easy access to the rear of the tiles for ventilation and maintenance. The roof space must be ventilated to keep the tiles cool.

The pitch of roofs is often close to the optimum PV module tilt angle. For example, the optimum tilt angle for a grid connected system in Sydney is about 34° (Sydney’s latitude) and with the acceptable margin of 10° variance from optimum, 24° is very close to the most common roof pitch.

PV roofing elements need to be compatible with any other roofing elements for structural and aesthetic reasons.

Shading elements such as BIPV awnings reduce cooling loads at the same time as generating electricity. They are also usually quite accessible for cleaning purposes.

Semi-transparent PV modules can replace glass skylights and glass roofing in many situations. The dappled light quality can be used effectively by skilled designers.

References and additional reading

Contact your state, territory or local government for further information on renewable energy: www.gov.au


Australian PV Association. www.apva.org.au


Authors

Principal authors: Geoff Stapleton, Susan Neill, Geoff Milne
Contributing authors: Chris Reardon, Chris Riedy, 2013