

Concentrating Solar - The Basic Principle

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Concentrating PV – The Basic Principle

The principle of concentrating PV (CPV) is quite straightforward. In the familiar 'flat-plate' PV modules, a large area of photovoltaic material (usually crystalline silicon) is exposed to the maximum naturally occurring sunlight. Normally, that maximum is achieved by installing the modules at an incline optimized for the latitude, but sometimes they are installed on trackers (moving frames) that can follow, or track, the sun as it passes across the sky. The PV cells perform under direct (sunny) or diffuse (cloudy) radiation conditions, but output is at its highest when the maximum amount of light falls on the cells (assuming there are no detrimental effects from overheating). The amount of light that falls on a cloudless day (this varies according to location and season) is regarded as one 'sun', which is defined as 1000 W/m².

Concentrating PV systems use lenses or mirrors to focus sunlight onto a small amount of photovoltaic material. (Usually the Fresnel lens is used, a flat lens that uses a miniature sawtooth design to focus incoming light. When the teeth are arranged in concentric circles, light is focused at a central point. When the teeth run in straight rows, the lenses act as line-focusing concentrators.) The concentration ratio can vary: if the light that falls on 100 cm² is focused onto 1 cm² of PV material, the ratio is considered as 100 suns. If the light from 10 cm² is focused onto that 1 cm², the ratio is 10 suns.

If the concentrated sunlight falls onto a well designed CPV cell, the cell will produce at least 100 times, or 10 times, the electricity. In fact the conversion efficiency of cells increases under concentrated light, so the correlation is likely to be greater than one-to-one, depending on the design of the solar cell and the material used to make it.

While commercial concentration ratios are around 200 to 300 suns, as much as 1000 suns is expected for future concentrating PV systems. As most CPV systems use only direct solar radiation, these installations almost always involve trackers (rotating about either one axis or two axes and therefore called one-axis or two-axis tracking) to keep the sun focused on the solar cell.

At low concentrations, and generally with single-axis trackers, CPV generally makes use of silicon cells. However, concentrating PV also offers the option of shifting away from crystalline silicon to use the very high-efficiency, non-silicon cells. Such cells have mostly been developed primarily for space applications. These multi-junction III–V cells (which use elements from columns three and five of the periodic table, typically gallium and arsenide) are prohibitively expensive for extensive use in large flat panel arrays. Concentrator systems, however, because they require far smaller and fewer cells, can afford the higher cost of multi-junction cells and yet still be manufactured at an acceptable dollar-per-watt cost.

Cells Working Harder

One of the key things to grasp about CPV is just how hard the systems can make a multi-junction cell work – the output from a 1 cm² cell can be hundreds of times higher than when it is not in CPV mode. One company, Emcore, puts it simply on its website: 'For example, under 500-sun concentration, 1 cm² of solar cell area produces the same electricity as 500 cm² would, without concentration'. The latest edition of *Energy from the Desert*, from the IEA's very large-scale PV power group, cites field test results from Toyohashi University (latitude 34.7°N), where a 500x CPV module 'showed energy generation as high as 277 kWh/m²/year from 2004 to 2005, while a parallel fixed flat plate PV system at this site produced only 147 kWh/m²/year. This was due in part to the high efficiency PV used'.

These high efficiency cells – upwards of 38% in the case of non-silicon cells – yield panels performing at 25% and beyond (note that some companies cite DC panel efficiencies, others AC, i.e. after the inverter and thus slightly lower). This summer, Concentrix Solar of Germany revealed efficiency figures for its demonstration system at its commercial CPV power plant in Spain, reporting that on clear days at the 2-MW Casaquemada power plant in Seville, system efficiencies of 25% AC (i.e. measured after the inverter) were consistently measured for the entire concentrator power plant under normal field operating conditions. And for its new FLATCON CX-75 the company claims an average module efficiency of 27.2% DC. Says Lerchenmueller: '27.2% was an average – the champions are even above that. The highest so far was 29%'.

Amonix of the United States introduced this March its Amonix 7700 product, the latest in a line of products going back to 1989. Interestingly, that company has now switched from using silicon to Spectrolab's gallium arsenide-based multi-junction cells, which have 37%–38% efficiency. The company now claims an efficiency of 25% AC (again, measured after the inverter.)

As manufacturers of III-V cells move towards higher volumes it will also benefit CPV manufacturers, says Lerchenmueller. There is a lot of activity from the existing cell manufacturers, plus other companies are moving in to the terrestrial CPV cells sector, particularly the companies involved in the manufacture of solar cells for space applications (mostly satellites), which today exclusively use triple-junction solar cells because of their superior performance.

The Leap into Scaled-up Manufacturing

A decade ago, says Sarah Kurtz of the US National Renewable Energy Laboratory (NREL), it would have been difficult for companies to have confidence that they could find markets for the volume they needed to justify economy-of-scale manufacturing. But the growth of the PV market, and especially the tracker segment, she says, is an important contributor to the increased interest in CPV, noting: 'After reliable prototypes have been demonstrated, companies must automate the manufacturing of these and then retest the reliability to ensure that subtle changes in the design do not negatively impact reliability. Some of the companies have planned for high-volume manufacturing from the start, but all companies must include this step in their development plan at some stage.'

While the outward signs are good, several manufacturers are still awaiting the right moment, or finance, to step up to the next level of play. Nancy Hartsoch says her company believes firmly in a 'get-on-with-it' approach: 'Once you have the manufacturing figured out you can continue to drive efficiency up from your base product,' SolFocus decided to bite the bullet and build a fully automated manufacturing capability, and then expand it, as a strategy to bring down the manufacturing cost by means of economies of scale.

This requires a certain pragmatism. In an interview she told us: 'For the past 12 months we've been focused on how we make this thing in volume. You lock the design, you quit designing, and focus on performance and manufacturability. What some companies do is have trouble saying, "we're done designing, we're going to build it now." But every time you change how you build it, you've impacted that ability to go to high volume and low cost. So with our next generation product that we are starting on now, one parameter is that we have to use the same manufacturing machinery. So you don't have to redesign your entire manufacturing line to do it! We have a manufacturing model that says it's 15 cents per watt capex to build a factory. Which means that for US\$15 million you can put in a 50 MW factory.'

Lerchenmueller says Concentrix has a similar approach, and has frozen its technology on the manufacturing side, while deploying product to several installations. Meanwhile, he points out, it's important to keep working on product development so that next generation releases can be made – as they are, say, in the computer industry.

Hartsoch says that while CPV is a real opportunity 'the challenge for any company is can you manufacture it, and deploy it? Is the technology risk too great for the cost savings? When you didn't have a cost advantage you had to find early adopters who wanted to get engaged because they thought the technology had a promising future. But now we've made that turn, it can stand on its own merit in terms of cost, so you're really only dealing with that technology challenge versus end cost.' Keeping on Track ...

CPV needs to be reliable if investors and utilities are to buy into it. Accurate and reliable tracking of the sun is needed in highly concentrating devices to maintain the focus of the solar energy on the cell and yield the best results – good systems can track accurately to within a tenth of a degree. Secondary optical lenses can help minimize requirements for tracking accuracy at higher concentration ratios.

Some critics have said that the need for moving parts and highly accurate tracking is a reason why CPV can never be reliable. However, this myth is disputed by Kurtz, who has commented in the past that there have been very few tracker problems on the existing CPV installations – and that in fact inverters have proved more problematic than trackers. Certainly the trackers have to be highly accurate and need to avoid flexing in strong winds.

However, in recent years increasing numbers of large, non-concentrating PV installations have opted to use trackers to optimize output – driven in part by feed-in tariffs. Thus the principle and practice of using trackers has become a much more standard option than in the past. 2008 data from www.pvresources.com (cited in Energy from the Desert) indicate that two-thirds of large PV plants (average capacity 18 MW) now use tracking technology.... and Keeping its Cool

Under the kinds of solar regimes favoured by CPV, photovoltaics tend to lose some performance efficiency due to the heat. Surely, the added factor of focusing the sun's rays several hundred times simply exaggerates this? High concentration ratios can potentially introduce a heat problem. Because cell efficiencies decrease as temperatures increase, and higher temperatures also threaten the long-term stability of solar cells, the cells must be kept as cool as possible.

However, this has not been problematic in concentrator systems – maintenance of temperatures is generally achieved by using a highly conductive material such as copper directly behind the cells to spread the heat, and some systems use air cooling. According to a rule of thumb, a heat spreader area is needed equal to the aperture area. In practice, concentrator cells operate in the same temperature range as flat plate PV cells. In the case of dish concentrators (such as the Australian Solar Systems design) the cells can actually be cooled to lower temperatures.

In an online discussion, SolFocus' Gary Conley explained of their product 'The concentration factor is 500 suns. The cells operate ~40°C (104°F) over ambient through passive cooling techniques, obviating the need for complex liquid cooling. All solar is good but each has its sweet spot. CPV is best in high DNI (sunny) locations, which are usually hot. Silicon panels can lose up to 30% of their rated efficiencies in such conditions while the triple-junction cells employed in HCPV designs lose just 3% at 100°C (212°F). Silicon-Based CPV

While, as mentioned above, Amonix has recently switched from using silicon to a III-V cell, others remain committed to silicon-based CPV – for the present, at least. These are mainly – though not exclusively – companies taking a low-concentration approach. For example, Whitfield Solar's CPV device has now launched as a commercial product after years of development. 'We had a huge interest shown in the product', says CTO Clive Weatherby.

This company, a spin-off from the University of Reading and based on almost four decades of CPV research and development, led for years by the late George Whitfield, says its aim in developing the product has been to create a simple, reliable, strong and lightweight product that uses some solutions that have been transferred across from other industries (notably the automotive industry), and which have proven themselves through years of operation. The system is light enough for rooftop mounting, but can also be ground-mounted without, explains Weatherby, the need for permanent concrete foundations to be poured on-site.

Each 3.6 x 1.3 metre 'panel' consists of a frame which supports 'power troughs' – each a sealed unit. Each trough contains 12 small, series-connected monocrystalline silicon cells with diode protection.

Each is covered with a single moulded lens (70x solar concentration) that concentrates the sun onto each cell – the sealed unit is based on car headlight manufacturing technology. An innovative cooling system enables the cells to run cooler than those in conventional PV panels.

Whitfield's system has an integrated dual-axis tracker that uses small electric motors. 'These have proven long-term durability and reliability thanks to their more common use in car window-winder systems', says the company. The trackers also apparently have in-built intelligence: 'This highly optimized system requires no pre-programming or site-specific data – just position and go!'

Whitfield's approach was also to design a product that can be manufactured in existing factories and, in May this year, the company signed a manufacturing agreement with Cobo SpA of Italy. The Italian base will serve as a launch site for the initial target markets, but Cobo also has the infrastructure to offer access to other international markets.

Having optimized its production engineering, Whitfield, like the other companies, plans to use this as a platform for further refinements to the product – the power troughs are compatible with a range of alternative cell technologies as they become commercially viable. And What About the Market?

As utility-scale solar ramps up in Mediterranean Europe, the US Southwest, in India (that recently announced it a huge national plan), and as markets emerge in the Middle East and North African countries, plus China, South Africa and Australia, it's interesting that two powerful solar technologies that have spent decades achieving or maintaining maturity now find themselves competitors in the sunbelts – CPV and concentrating solar thermal power, or CSP. Each has its pros and cons.

According to Kurtz, 'When compared with solar thermal approaches, CPV provides a qualitatively different approach, typically with lower water usage, greater flexibility in size of installation, and the ability to respond more quickly when the sun returns on a cloudy day.'

Lerchenmueller also stresses the issue of water in most of the target environments for CPV/CSP. 'CSP can use dry cooling but this increases cost significantly. Finally the growth rates you can achieve in PV – especially CPV are so much higher because the deployment of the technology is much more flexible.' He also speaks about the advantages of CPV's modularity compared with CSP: 'If a plot of land doesn't allow 50 MW we can do 10 MW. Or 1 MW for a customer to try. That's a huge advantage.'

According to Hartsoch, 2009 has been very flat, as was predicted. But, looking ahead to 2010, the overall PV market has seen predictions of 30%–40% growth again. She says: 'If you look at the high solar resource regions versus the low resource regions, the high resource regions are growing at 48%, compared with 24% in the lower. So for CPV as an industry, where that technology fits the best is where that market is growing.'

Clearly, developers and their financiers look very carefully at the balance of investment costs versus income. Even with (non-concentrating) PV modules priced as they were 1–2 years ago, some viewed the addition of trackers to their large-scale, flat-plate installations as an expense that it wasn't worth making. As module prices fall, perhaps one might expect there to be a lower uptake of tracking technology. But how are the current market prices likely to affect the CPV technology sector going forward?

Says Lerchenmueller of Concentrix: 'Of course the price drop in crystalline silicon and to some extent thin-film makes our market introduction more difficult, as we are not yet at full volume. On the other hand, in the mid-to-long term the perspectives are just great. We have a 25 MW manufacturing line. Once this is filled to 60%–70% capacity we can match the price of thin-film. Imagine once we are manufacturing at a larger scale. And we can certainly beat the price for CSP. I'm more than convinced, the prospects are great.' Jackie Jones is editorial director of Renewable Energy World magazine.