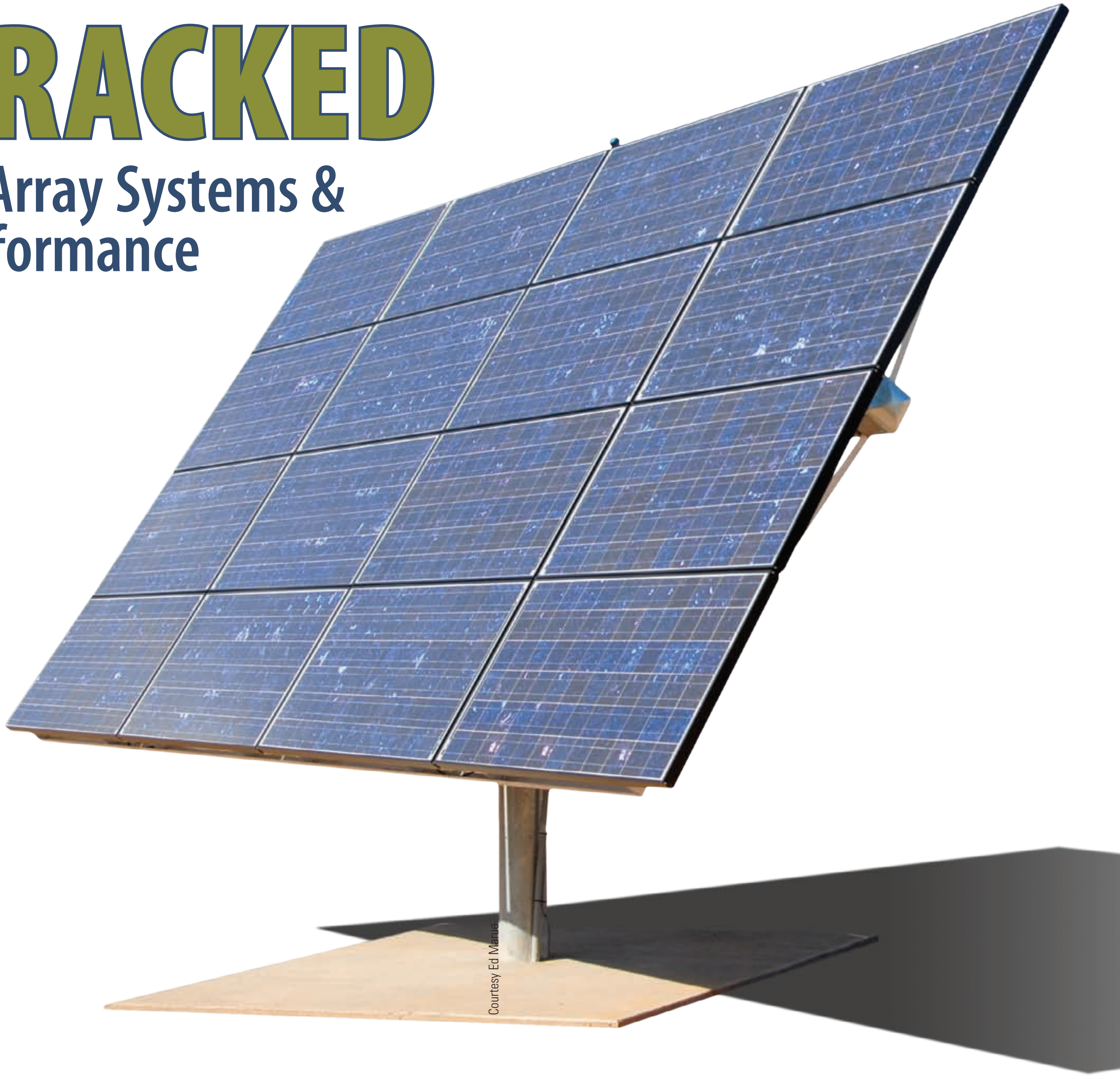
TRACKED

PV Array Systems & Performance


Courtesy Ed Marue

by Justine Sanchez

Whether it's hitting the road in sleek speedsters (electric, of course), surfing the powder on snowboards, or pounding the trails on mountain bikes, most of us love being in motion. Even those who consider themselves untethered to mainstream thrills are often mesmerized by the spinning blades of a wind generator or the swiftly moving waterways powering a microhydro turbine. But there's not much excitement in a fixed photovoltaic array in action—beyond watching the electrical meter spin backward.

Because they don't rely on moving parts to produce electricity, most PV arrays do their job without much fanfare or fuss. However, PV modules produce the most power when they are aligned perpendicular to the sun's rays, and since the turning Earth moves the sun across the sky, the *only* way to do this is to put the array in motion by using a tracking device. Under the right circumstances, tracked PV arrays can intercept much more sunlight than stationary PV arrays. While exact performance numbers will vary depending on the site location and system specifics, trackers typically can increase overall energy production by 25% to 40%.

Tracker Types

Trackers are divided into two groups: active and passive. Most active trackers use an optical sensor to determine the sun's position, and an electronic control and one or more motors to position the array. Single-axis active trackers are set to a fixed tilt angle (which can be adjusted seasonally) and then track the azimuth angle of the sun across the sky.

Courtesy www.solarplexus1.com

Courtesy Dana Orzel/Great Solar Works Inc.

Left: A Zomeworks single-axis tracker with its outboard Freon vessels. Right: A Wattsun tracker (note the optimal sensor in the upper left corner of the array).

Dual-axis devices track both the sun's azimuth and altitude angle (its angle to the horizon), and offer the most accurate tracking, but cost more (see "Cost of Tracking" table on page 54). Active trackers are susceptible to damage from nearby lightning strikes, which can damage the motor and controls.

Passive trackers use the heat from sunlight to vaporize liquid Freon contained in canisters mounted on the tracker. As the gas expands, it forces the liquid to the canister on the other side of the tracker, and the change in weight causes the rack to move. Passive trackers are single-axis and will follow the sun from east to west. These trackers will not track the altitude angle of the sun but can be tilt-adjusted seasonally. The primary advantage to passive trackers is that they do not depend on electric motors or controls to function. However, because they are thermally controlled, and dependant on the intensity of incoming sunlight, these trackers may have difficulties in extremely cold climates, and/or in hazy conditions, when delayed heating can reduce overall energy production.

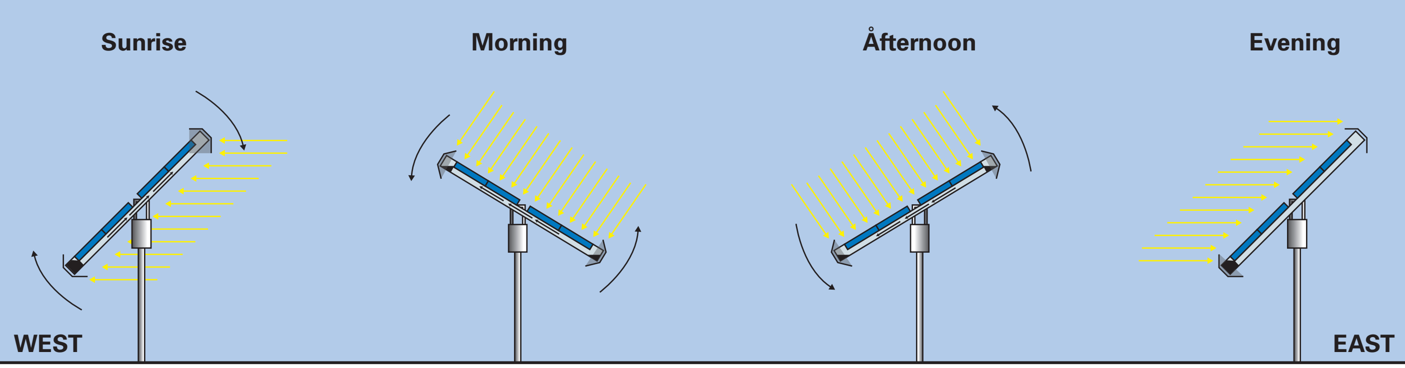
Tracking Pros

Because tracking arrays receive more peak sun-hours, energy production is improved. This allows a smaller array to be installed, shrinking the required array footprint—a benefit for sites with limited space.

Sites with wide-open solar access (shade-free from dawn to dusk with low horizons) can benefit the most from a tracking array, wringing every last electron from the sun over the seasons. The energy gained during early morning and late evening hours can be significant—especially during long

From left to right: Incoming sunlight warms the canisters unevenly. In the exposed canister, liquid Freon vaporizes and expands. As the gas expands on one side, it forces the liquid from one canister to the other; the change in weight causes the tracker to move the array.

Passive Tracker Function



AC Energy Comparison for 4 kW Fixed vs. Tracking PV Systems in Tucson & Seattle

	Tucson, Arizona					Seattle, Washington				
	Fixed Array		Dual-Axis Tracking Array			Fixed Array		Dual-Axis Tracking Array		
	Insolation*	kWh	Insolation*	kWh	Increase	Insolation*	kWh	Insolation*	kWh	Increase
Apr.	7.50	625	10.64	900	44.0%	4.37	383	5.57	499	30.3%
May	7.29	605	11.27	953	57.5%	5.31	471	7.15	647	37.4%
Jun.	7.15	567	11.38	918	61.9%	5.52	467	8.03	697	49.3%
Jul.	6.44	526	9.25	768	46.0%	5.88	508	8.65	765	50.6%
Aug.	6.85	565	9.67	810	43.4%	5.17	448	6.85	604	34.8%
Sep.	7.06	573	9.51	783	36.6%	4.98	419	6.57	565	34.8%
Total: Spring/Summer		3,461		5,132	48.3%		2,696		3,777	40.1%
Oct.	6.72	577	8.96	779	35.0%	3.00	263	3.57	317	20.5%
Nov.	5.99	515	7.85	675	31.1%	1.76	148	1.96	168	13.5%
Dec.	5.27	480	6.92	630	31.3%	1.26	103	1.38	115	11.7%
Jan.	5.70	513	7.55	685	33.5%	1.54	133	1.74	153	15.0%
Feb.	6.11	485	7.99	640	32.0%	2.50	201	2.85	232	15.4%
Mar.	7.03	620	9.48	843	36.0%	3.71	335	4.50	411	22.7%
Total: Fall/Winter		3,190		4,252	33.3%		1,183		1,396	18.0%
Annual Ave.	6.59		9.21		41.1%	3.76		4.91		33.4%
Annual Totals		6,651		9,383			3,879		5,173	

*Average daily peak sun-hours
Source: PVWatts (www.nrel.gov/rredc/pvwatts/)

summer days when, at many northern latitudes, the sun rises in the northeast and sets in the northwest.

Tracking Cons

One of the benefits of PV technology is that the modules don't *need* to move to produce electricity—it's one of the reasons why solar electricity is such a reliable form of power. Whenever moving parts are introduced, the likelihood of component failure—and the need for periodic maintenance—increases.

If a tracker stops functioning, to keep your array producing optimally, you'll need to manually position the array at an appropriate tilt angle and face it to solar south. Defunct electronically controlled trackers can be positioned with manual controls (an option at purchase). A passive tracker can be positioned by hand and secured into place by attaching ropes or ratcheting straps to fixed points provided at the four corners of the rack and tying down to fixed points placed on either the pole or in the concrete pad.

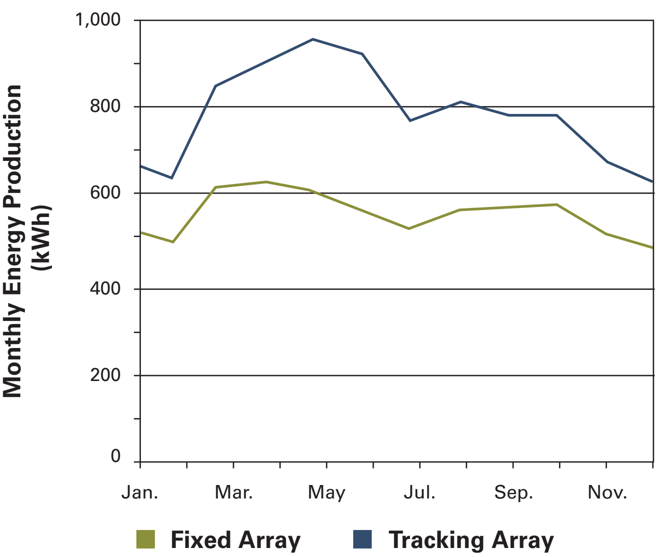
A potential disadvantage of purchasing a tracked system is that some PV rebate programs are based on the size of the PV array (installed watts) rather than PV array energy production. This means that the overall cost benefit of the tracking system could be reduced, depending on how incentive programs are structured. For example, at your site

A dual-axis tracker continually adjusts for optimal exposure, including low winter sun angles.

Courtesy www.big-thunder.com

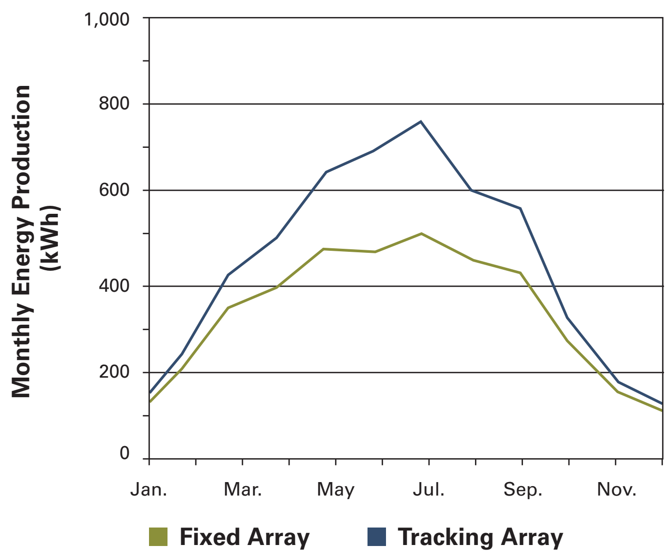
Fixed vs. Tracking Array Energy Production

Tucson, Arizona



Note: 4 kW array; fixed array facing south at 32.1° tilt. Source: PVWatts

Seattle, Washington



Note: 4 kW array; fixed array facing south at 47.5° tilt. Source: PVWatts

you might calculate that a 3 kW tracked array will produce as much power as a 4 kW fixed array. However, your local utility offers a $4 *per installed watt* rebate. Here's the catch: Even though the up-front cost of the tracked system is lower, instead of a rebate check for $16,000, you'll get only $12,000, since the rated wattage of your array is smaller. In this case, while the energy production of each array would be about the same, the system cost after the rebate would be *less* for the fixed PV array. Note that many areas have or are moving to production-based incentive programs, which make payments based on energy produced instead of installed watts. Check on available incentives with the Database of State Incentives for Renewables & Efficiency (www.dsireusa.org).

Best Applications

Extra power is only beneficial if you can use it, sell it, or store it as it is produced. A grid-connected system with a wide-open solar window can be a good candidate for a tracked array, since every kilowatt-hour gets used and, in net-metered situations, is credited to your utility bill. An off-grid system with daytime summer-dominated loads (like irrigation) is another good candidate for a tracking array.

A tracked PV array provides electricity for growing plants and rearing fish in the dome structure behind it.

Courtesy www.brotherselectricsolar.com (2)

Cost Comparison of Fixed vs. Tracking PV Arrays

	Tucson, Arizona			Seattle, Washington		
	Fixed Pole Mount	Passive Single-Axis Tracking	Active Double-Axis Tracking	Fixed Pole Mount	Passive Single-Axis Tracking	Active Double-Axis Tracking
System size (W)	4,000	3,000	2,850	4,000	3,200	3,000
System production (kWh/yr.)	6,651	6,624	6,686	3,879	3,905	3,879
Estimated system cost*	$34,400	$27,390	$28,500	$34,400	$29,216	$30,000
Cost per kWh produced annually	$5.17	$4.13	$4.26	$8.87	$7.48	$7.73

*Assumptions: Installed system costs per W = $8.60 for fixed, $9.13 for single-axis passive; $10 for double-axis active

Water-pumping systems are also ideal candidates for PV-direct tracked arrays. Because these systems often do not have batteries that would allow for water-pumping when the sun is unavailable, there is a need to pump as much water during daylight hours as possible, and a tracking array can take full advantage of the available sunlight. These systems offer inherent synergy, matching the seasonal needs for water pumping (for livestock and crops) with the longest daylight hours.

If you have an off-grid system with *winter*-dominated loads, a tracked system may not yield the best cost benefit. This is largely due to two issues. First, off-grid systems often cannot put excess power to work—if the batteries are full, the charge controller will simply shut off the PV array. Second, for most off-grid homes, energy use is highest in the wintertime—so systems are often sized for that season—yet the extra energy from a tracking array is most available in the summertime.

Costs

Given the right circumstances, tracked PV arrays can be a good design strategy, but at what cost? The answer to this question depends on several factors, including system size, solar access, and system type. See the "Cost" table (above) for a cost comparison of fixed versus tracking PV systems. Although the table shows that up-front system costs can be less expensive for a tracked system (even in areas like Seattle), this cost comparison does not include additional maintenance costs or savings from incentive programs. As noted, if the rebates are based on installed watts, this could make a *fixed* PV array less expensive.

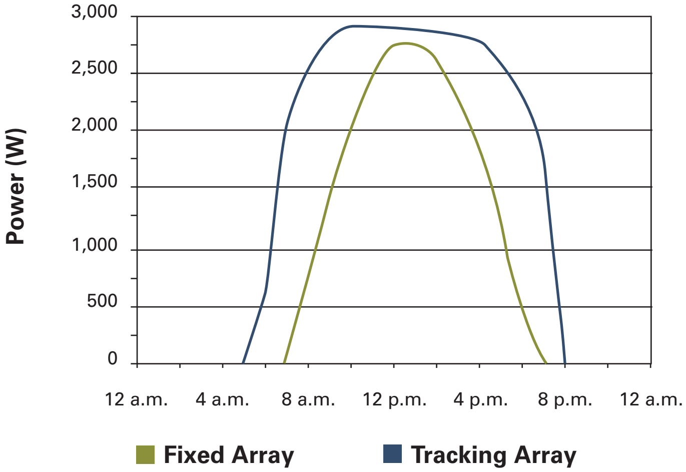
Installation Considerations

Tracking arrays, like all pole-mounted arrays, are like big sails: Set several feet above the ground, they can experience significant wind-loading. To keep them in place, arrays are usually mounted on large poles (6 to 8 inches in diameter, or even bigger for taller poles), which must be set in large concrete footers.

Tracker components, especially the drive assembly for electronically controlled trackers, can be heavy, tipping the scales at more than 200 pounds. Often, they'll need to be placed with a crane, backhoe bucket, or some other mechanical means.

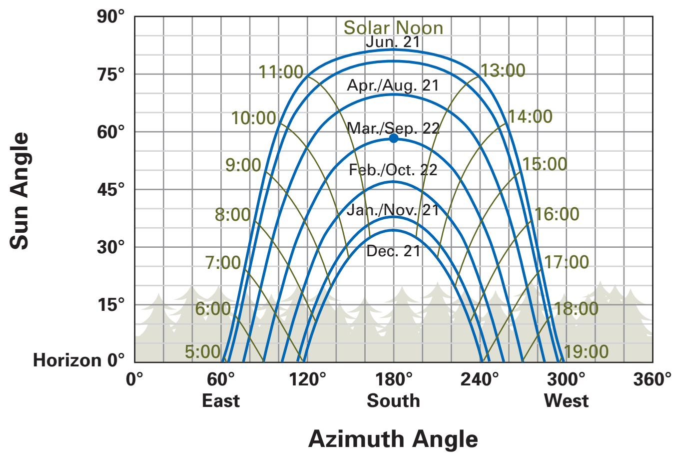
(continued on page 56)

Single-Day Production: Fixed vs. Tracking Array



Note: 4 kW array; fixed array facing south at 32.1° tilt. Source: PVWatts. Daily power values calculated for average insolation values for May 19.

Sun Path in Tucson, AZ



Tuscon, AZ: Latitude, 32°; Longitude, -111°

Tracking Success

Home builder Ed Marue offers his perspective on making the most of his PV energy production with tracked systems operating in two very different climates.

The conditions for the remote, off-grid installation were ideal—a seasonal residence on a wide-open property that takes advantage of the long summer days in central Idaho, when the sun makes a sweep from 15° north of east to 20° north of west, with more than 11 peak sun-hours daily. Under these conditions, the 960-watt PV array easily keeps the 1,000 amp-hour battery bank charged, powering a 1,000-square-foot cabin equipped with lighting, a washer, a TV, a computer, a vacuum, and a dishwasher. Because of the ample energy the batteries receive from the array, rarely does the battery state of charge drop below 70%.

The system—eight Kyocera KC120 modules and an AZ-125 Wattsun dual-axis tracker—was easy to install and has worked perfectly. A pyramidal sensor mounted on the array signals the electronic controller, which powers the DC azimuth drive motor and elevation actuator, always keeping the array perpendicular to the sun. The tracker has weathered six summers and winters, and temperatures of 112°F to -10°F, with no repairs or maintenance, other than greasing the gear head each spring. In the winter, the array is left unattended, and power to the controller is shut off with the tracker pointed due south at a steep angle to shed snow more easily. Because there is no requirement for power during the winter months, the decision to install a tracker, rather than a more costly, larger, fixed PV array, has proven to be a wise choice.

A pair of 2,720 W pole-mounted, tracked arrays at the Tucson site have generated even more energy than originally predicted.

With a wide-open summertime solar window, this small dual-tracked array produces enough electricity for the seasonal residence.

Courtesy Ed Marue (3)

The grid-tied installation in Tucson, Arizona, also had a wide-open site, but there were no good roof-mount options—the design of the home minimized southern exposure to decrease cooling loads. So two Wattsun AZ-225 trackers, each with 16 BP SX170 modules, producing a total of 5,440 watts of PV, were chosen. The trackers installed easily, and other than an initial problem with an elevation drive motor that had intermittent brush contact, there have been no reliability issues in the 18 months since commissioning. The manufacturer's documentation was clear and concise, and the company was extremely responsive in resolving the initial problem, which required a replacement motor. The array has produced 13,174 kWh in its first year of operation, slightly more than predicted.

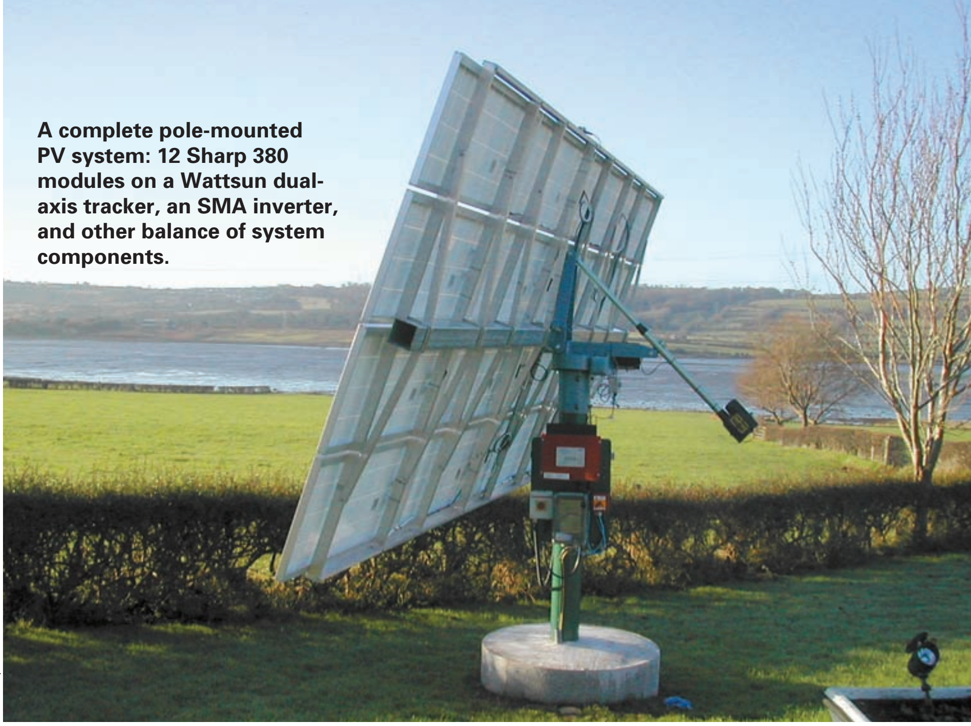
The system was installed during the home's construction, and on-site labor for the array installation was not separately accounted for. Excluding labor, the gross cost of the system was $42,247, with a net cost of $25,927 after a $16,320 utility rebate. An equivalent 7.65 kW fixed array was estimated to have cost $27,847 after rebate.

—Ed Marue

The eyes of a dual-axis tracker: Four photocells sense sunlight, signaling the tracker to keep exposure consistent.

Optional manual controls for a Wattsun tracker allow easier setup and troubleshooting.

Courtesy www.wattsun.com (3)



A complete pole-mounted PV system: 12 Sharp 380 modules on a Wattsun dual-axis tracker, an SMA inverter, and other balance of system components.

When installing module home-run wiring, leave lots of wire length from the modules to the junction box on the pole. This will ensure that when the tracker is in its farthest positions the cables are not pulled tight. (Bundle these cables together with zip ties to keep the installation as tidy as possible.)

Electronically controlled trackers have an optical sensor that needs to be mounted at the top of the array. Also, a tracker controller needs to be mounted on the drive and powered either by the battery bank or AC power, if available. In the latter case, a switching power supply, another option at purchase, converts AC to DC to power the DC tracker controller. In either case, a power line needs to be appropriately planned for and run from the power source to the controller. Although the controller can be powered directly from the PV array, this option is discouraged—because there's no power available from the PV array after sunset, the tracker must wait until the next morning to turn back to face the sun. During the summer months, the optical sensor can get confused as to which direction it should return, since it will end up pointing northwest in the evening. Tracker rotation must be limited to 180° to avoid this confusion. However, this limits the energy gain the tracker can yield in the summer months, since the sun's azimuth angle exceeds 180°.

The decision to invest in a tracking PV array is a personal one based on budget and your willingness to deal with possible maintenance (or even repair) issues, since moving parts can break down. In the right circumstances, though, tracking systems can save money up-front and keep you on track to greater energy production.

Homebrewed Trackers

Some active trackers use clockworks to approximately follow the sun's azimuth. Normally a homebrew solution, these clockworks need to be manually set each morning to face the rising sun before being powered up. As a result, they are not quite as accurate as trackers that employ optical controls.

Tracking can be even more inventive, and the *Home Power* crew has seen it all—from arrays mounted on a turntable with ropes on opposite sides so that the system owner can move the array by manipulating the ropes from inside the home, to a water-powered tracker that moved by the changing weight of water-filled buckets purposefully built to leak at a specific rate. Way back in *HP17*, we included an article on how to build your own photo-sensor controller to operate a 12 VDC windshield wiper motor to turn an array. This controller could also operate a modern actuator to move the array.

Tinkerer beware: One problem with manual tracking is that neglecting to move the array means that modules could spend a large part of the day faced *away* from the sun—resulting in the exact opposite of the desired effect.

Access

Justine Sanchez (justine.sanchez@homepower.com) is a NABCEP-certified PV installer, *Home Power* Technical Editor, and Solar Energy International instructor. Justine dreams of one day installing her own tracking PV array, but for now lives, works, and teaches from an on-grid, fixed-mounted, PV-powered home in Paonia, Colorado.

Ed Marue (emarue@msn.com) holds a bachelor's degree in physics. He's the principal of Solar Lava Development Corp., a sustainable architecture company, and the former owner of Tri-Ex Tower Corp. and chipmaker High Voltage Devices.

Tracker Manufacturers:

Array Technologies • www.wattsun.com

Small Power Systems • www.smallpowersystems.com

Zomeworks Corp. • www.zomeworks.com