

APS INSTALLATION AND OPERATION OF 300 KW OF AMONIX HIGH CONCENTRATION PV SYSTEMS

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ABSTRACT

Since early 2001, Arizona Public Service (APS) has been installing and routinely operating Amonix High Concentration Photovoltaic (HCPV) systems, using fresnel lenses and high-performance silicon PV cells for the generation of electricity. Currently, over 275 kW-ac are in grid-connected service over three sites in the Phoenix, Arizona area, with good performance that is approaching predictions.

Installations continue with over 1 MW-ac planned, representing the largest installation of HCPV technology for commercial operation in the world to date. Manufacturing experience indicates that at volumes of only 5 MW/year an installed cost of \$4000/kW-ac can be achieved, significantly lower than conventional PV.

APS SOLAR INSTALLATIONS, TEST AND RESEARCH

APS is installing over a megawatt of PV systems of various types each year. In an effort to find lower cost solar options, APS has been testing and using many kinds of PV products since the 1980's, including crystalline silicon and various thin film PVs. In addition, APS has been very active in the study and development of high concentration solar generation such as dish Stirling, central receiver, parabolic trough, and HCPV.

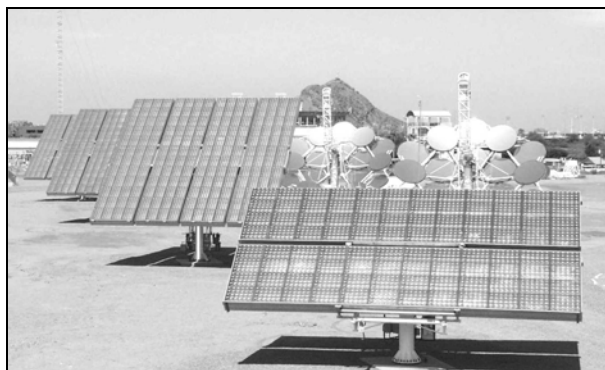


Fig. 1. Experimental Amonix HCPV and Dish Stirling systems under test at APS STAR site, Tempe AZ

During the late 1990's, APS and Amonix began cooperating in the development and test of several generations of HCPV tracker systems, following work performed by Amonix and Scientific Engineering

Incorporated (SEI) under the Electric Power Research Institute (EPRI) HCPV program. This work was to develop the performance and low cost potential of the 24% efficient Amonix Back-Contact PV cell, operating under 250 "suns" (effective concentration ratio) using acrylic fresnel lenses.

Given the success of the early tests, as well as the performance and cost potential, APS elected to continue to support the development of HCPV with Amonix. Installation and test of two generations of research prototypes occurred at the APS Solar Test And Research (STAR) site in 1999 and 2000 (see Fig. 1), leading to the ability to construct 300 kW of Amonix systems for regular operation.

GLENDALE AIRPORT

In the spring of 2001, APS completed the first 100 kW Amonix HCPV installation at Glendale Airport, Glendale Arizona. This system became the first large commercial HCPV generating plant, and has been in continuous operation since (see Fig. 2).



Fig. 2. 100 kW Amonix HCPV at Glendale Airport, AZ

Each Amonix unit is a large tracking array, complete with automatic controls and power conversion, with a net AC output rating of 24 kW. This rating is based on a complement of five Amonix MegaModules rated at 4.8 kW-ac each at 850W/m² direct-normal insolation (DNI) including optical and electrical losses. The PV DC output is converted to AC by an inverter at each unit, then connected through a standard distribution transformer to the grid.

Each unit has a width of about 55 feet, supported by a simple monopole, and rotates to track the sun within about 0.25-degree accuracy. Typical height is about 35-

40 feet, with a maximum height at sunup/sundown of about 47 feet. Attributes of the system design include:

- 24 kW-ac/ unit output rating, 208 VAC three-phase
- PV-cell strings that are sealed and passively cooled; 10 strings of 360VDC, 8A each
- Unattended automatic operation, with remote dial-up control and monitoring
- Structure/drive system designed for simplified transport and field installation
- Rapid PV module loading using large pre-assembled Amonix PV MegaModules
- Robust hydraulic motion control, using only biodegradable fluids, with rapid, fault-tolerant wind-stow function for 90 MPH wind survival
- PC-compatible tracking-controls using rotary-encoder positioning with sun-sensor correction, and GPS for time and location

Subsequent to Glendale, two more units of the same design were installed at APS STAR. During the course of turn-on, debugging and operation of all six units, anomalies were encountered. These included:

- Breakage of one hydraulic ram
- Pump motor damage due to various faults
- Several seal failures, and a few stuck valves
- Software and circuit changes needed
- Inverter noise and control problems
- Optical alignment issues

The repair of any failure generally cost in the hundreds of dollars each, however design improvements were made from the study of these issues. By November 2001 an improved version was installed at the APS STAR Site. Improvements included:

- Stiffer structure
- Reduced fabrication labor and cost
- Reduced field assembly labor
- Improved control/software features
- Improved inverters

Where possible, design improvements were retrofitted into earlier units, including the earlier prototypes, which have remained in operation. The total Amonix capacity currently in operation is 278.4 kW-ac over 12 units. Structures are already installed for an additional 67.2 kW, with Amonix MegaModules currently in production.

INSTALLATION PROCESS

The construction process for the Amonix system is generally as follows:

- Site preparation, including fencing, driveways, underground conduit, distribution transformer, telephone

- Monopole "pedestal" installation, using a 48" diameter augured hole and a steel support pipe directly embedded in concrete
- Main drive/structure installation, using a crane
- Installation of controls and equipment, including inverter, hydraulic controls and lines, electronics, meter, encoders, sun-sensor and anemometer
- MegaModule installation, requiring a crane
- System turn-on, set-up, test and alignment

A field of several units can be efficiently constructed in parallel. For example, four or more foundations and pedestals can be drilled and installed in the span of a few days. Similarly, all of the crane work for the installation of the structures and drives for four or more units can be done in a couple of days, and as MegaModules arrive, two units can now be populated in one day.

Installation and wiring of the electronics, hydraulics and controls initially took several days per unit. Most serviceable equipment is located at ground level, however given the height of some components, a man-lift is helpful or necessary for some of this work, including the optical alignment of the MegaModules. The time and difficulty of these phases has been steadily reduced through experience and improvements in design and techniques, and with full standardization a goal of a few field man-days per unit for equipment installation and turn-on seems within reach.

PERFORMANCE

The expected performance of the Amonix HCPV units is based upon the expected Direct Normal Insolation (DNI) for the location, and their DNI-rating characteristics. PV ratings are expressed in kW-ac/ kW-irradiance, then integrated over time for energy. Some light is scattered in the atmosphere and cannot be focused, so for concentrator systems a kW-rating based upon DNI of 850 W/m² is more conservative and appropriate than the 1000 W/m² rating standard used for flat-plate PV.

For the Phoenix area, insolation data available from the National Renewable Energy Lab (NREL), and consistent with APS measurements, was used to compare the potential kWh output from two orientations of fixed flat-plate systems, one-axis (north-south) flat-plate systems, and solar concentrators (see Fig. 3).

Taking the respective ratings into account, an HCPV system could provide about the same annual energy as a one-axis (north-south axis) tracker with flat plate PV. Both of these systems could produce significantly more energy than a fixed PV system. Temperature, soiling, downtime and all other conditions that affect the output versus rating would of course also affect the actual output and should be considered.

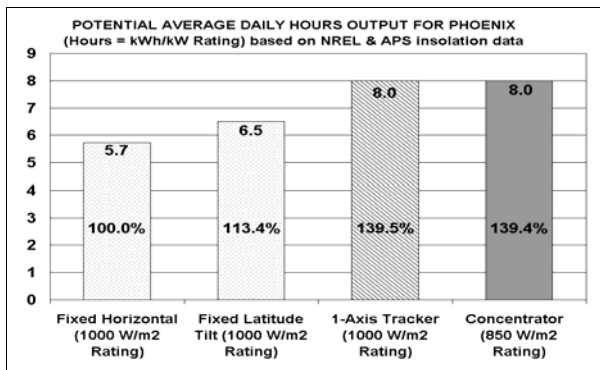


Fig. 3. Potential annual-average daily output of fixed PV, one-axis tracking PV, and HCPV systems.

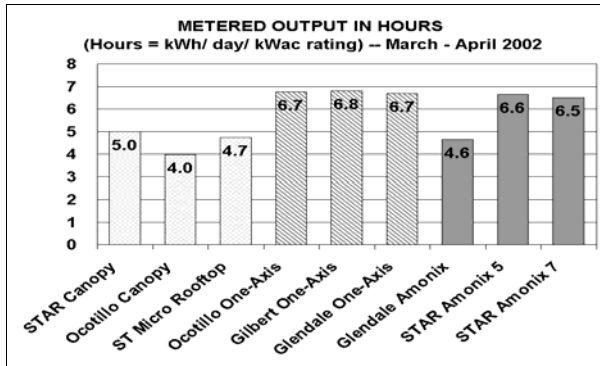


Fig. 4. Average daily output hours from fixed PV, one-axis tracking PV, and HCPV throughout March-April.

After beginning operation, every Amonix unit was operational most days. However downtime occurred, and performance was affected by repairs, testing and improvements. Fig. 4 shows the average daily metered AC kWh from several Amonix and other APS PV systems in March-April 2002, all in the Phoenix area.

As the first systems constructed, performance of the Glendale Amonix were reduced by optical alignment, controls and inverter issues, and also by a lack of lens cleaning during the entire year 2001 operation. Units S5 and S7 were installed at STAR mid 2001 and benefited from design improvements and regular lens cleaning, and had higher output.

Output data from fixed, one-axis, and HCPV systems during clear days in March and April are shown in Figs. 5 & 6. The fixed PV system is an amorphous silicon on a near-horizontal canopy that has not been cleaned and may have degraded, however the cosine shape is typical. The one-axis PV system is a polycrystalline.

The one-axis power curve is broader than fixed due to sun tracking (see Fig. 5). Power dips around noon because the array is not tilted to the south. The HCPV curve is broadest of all because the unit is fully facing the sun all day. The broader curves of both tracking systems deliver more energy through the inverter and electrical system than the fixed-system cosine curve,

lowering the effective cost of such equipment. On cloudy days, however, the HCPV system would be most adversely affected.

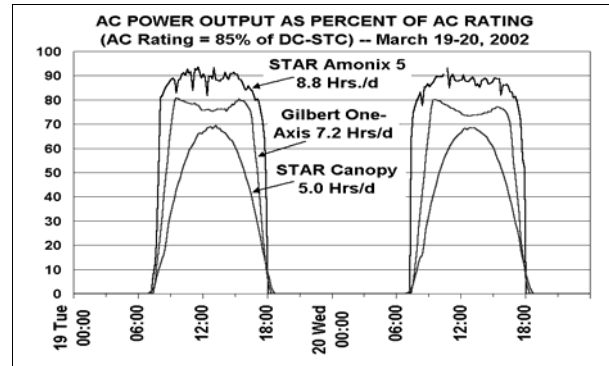


Fig. 5. Power curves from fixed PV, one-axis tracking PV, and HCPV on a clear day in March.

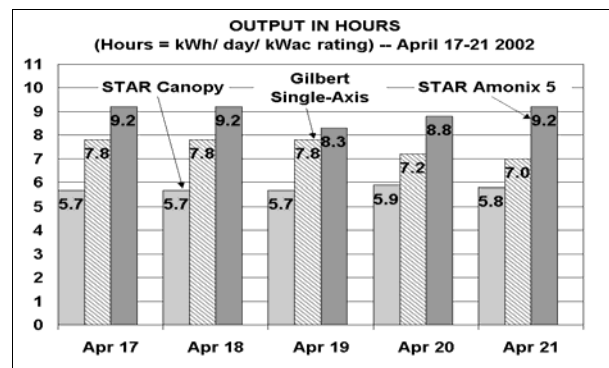


Fig. 6. Output hours from fixed PV, one-axis tracking PV, and HCPV on five clear days in April.

OPERATION AND MAINTENANCE

The Amonix systems are monitored and controlled through a dial-up software system. The systems startup and shutdown automatically each day, and in the event of high winds or power failure, automatically move to a nearly horizontal wind-survival position.

Through the dial-up system, any unit in the field can be monitored in real-time, started, shut down, or have operating set points changed. In the event of improper operation, the system has several self-stop modes and messages. In addition, periodic data log files can be downloaded for diagnostic purposes when needed.

APS maintains the Amonix systems with technicians whose training, skills, and experience are similar to those needed for other generating and mechanical systems. During this initial deployment phase, no detailed tracking of service has been made, but the activities have been generally in the areas of inverters, hydraulics, controls and optical alignment. Some early PV string and lens failures occurred, but these problems were addressed early on, and no such failures have occurred in many months.

The dry and dusty desert urban environment of Phoenix can rapidly soil and obscure the lenses, so cleaning of lenses is of particular maintenance interest. Various cleaning techniques and lens treatments are being field-tested. To help efficiently rinse the large Amonix arrays, a special water trailer with a high-pressure pump sprayer was constructed which allows a single person to rinse the entire array from the ground within minutes. The 400-gallon tank has enough capacity to rinse four or more arrays on each tank filling.

As the systems have matured, failures have become less frequent and maintenance activities have become more efficient, and an acceptable maintenance program is expected to result during this project.

NEXT PHASE PLANS

The next design iteration of the tracker system is now in fabrication for initial testing this summer. The new unit will have seven MegaModules and an output increased to 33.6 kW, requiring only three units per 100 kW-ac system rating, 30 units per megawatt. Further design refinements in controls and hydraulics are being incorporated as well to reduce maintenance and improve reliability.

APS and Amonix continue to refine the design and manufacture of the MegaModule and the trackers, with incremental improvements underway in optical alignment, material and labor, thermal performance, cleaning and maintenance. The most significant factor in driving cost reductions however will be an increase in annual production volume. Based upon cost studies of the current design, a total installed system cost around \$4000 per kW-ac is projected at an annual volume of only 5 MW. Costs of lenses, steel and aluminum will be significant factors in the volume manufacturing cost. Substantial fabrication and assembly labor could be used near the area of installation, for cost savings.

In order to further the commercial viability and acceptance of the Amonix HCPV system, APS and Amonix plan to continue installations to over a megawatt in the next two years. After additional testing at APS STAR, several systems of improved design will be installed near Prescott, Arizona.

The new APS Prescott Airport Solar facility will be a 5-Megawatt project using both flat-plate and HCPV technologies (See Figs. 7 & 8). The site is at 5000-ft. elevation and provides clear skies and cooler temperatures, which are favorable for solar operation. Construction of this project will extend over several years, which will provide an opportunity to incorporate important improvements in conventional solar technology, and demonstrate HCPV solar for the first time on a multi-megawatt scale.

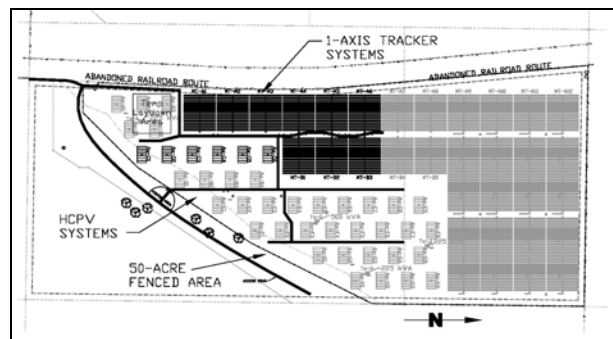


Fig. 7. Site plan for APS Prescott Airport Solar Project.



Fig. 8. Conceptual rendering of a megawatt-scale one-axis PV and HCPV facility.

CONCLUSION

Phased APS installations and continuous operation of Amonix systems are establishing the feasibility of HCPV for medium and large-scale commercial utility application. The project has already validated the Amonix HCPV concept, and is providing field experience to improve manufacturing, construction and operation of two-axis tracking and HCPV for commercial generation.

Energy output is achieving predicted values, significantly higher than fixed PV. Design and manufacturing improvements are reducing the time and cost of installations to encouraging levels, and projections are that at a modest volume of 5 MW per year, HCPV systems can be installed for \$4000 per kW-ac, significantly less than conventional PV.

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