

LONG-TERM RELIABILITY CONCERNS RESOLVED BY THIRD GENERATION INTEGRATED HIGH-CONCENTRATION PV SYSTEMS

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ABSTRACT

Integrated High-Concentration (IHCPV) systems offer one of the lowest-cost, near-term options for PV. High performance, combined with built-in solar tracking, provide enhanced power generation compared to fixed systems with similar peak watt ratings/price. Despite IHCPV's low cost potential and the successful deployment of several 20 kW demonstration systems, end users have been cautious in their acceptance of this emerging technology due to concerns regarding its perceived mechanical complexity and associated long-term reliability. This paper presents the results of 1st and 2nd generation field installations over the last four years. Lessons learned have been resolved and improvements incorporated into 3rd generation systems.

BACKGROUND

This paper describes a uniquely structured, 20 kW Integrated, High-Concentration (250X) Photovoltaic (IHCPV) system which has been developed for cost-effective, utility-scale applications [1-3]. The first 20 kW array was deployed at Arizona Public Service's Solar Test and Research (STAR) facility in Tempe, AZ in October 1994. The second 20 kW system was installed at the PVUSA facility in Davis, CA in September 1995. Four "3rd" generation 20 kW systems were installed in 1996 at participating utilities as part of the UPVG *TEAM-UP* project: two at Arizona Public Service, one at Central and South West's solar park in Ft. Davis, TX, and one at Nevada Power Company's site in Las Vegas, NV. These installations, with multiple sites and varying environmental conditions, provided the basis of nearly three years of actual field experience from which considerable practical information regarding long-term reliability has been derived.

BACKGROUND

High-concentration PV systems offer several distinct advantages for low cost power generation: (1) Major cost reduction through the optimum utilization of silicon (the cost driver in any PV system). Concentrator systems reduce the amount of costly processed silicon required to generate a given amount of electricity by an amount approximately equal to the concentration ratio. Concentration systems reduce the percentage of the

solar cell cost per system to 8%-10% compared to 40%-50% for flat-plate designs. (2) Higher conversion cell efficiency at concentration vs. one-sun. (3) Inherently higher capacity factor (compared to fixed-tilt, flat-plate systems) in high direct normal insolation (DNI) areas because of its built-in tracking.

Despite these inherent cost reducing elements, high-concentration PV systems have not previously emerged for large-scale utility use because of: (1) the lack of a stable, high performance, commercially available high-concentration solar cell, and (2) the high costs associated with the PV modules, structure, tracking system, and ancillary equipment. In addition, concerns regarding the O&M costs, the mechanical complexity of concentrating system's tracking components, and system reliability and availability have raised doubts about the viability and suitability of IHCPV for utility applications. This paper addresses these concerns and the steps taken to resolve them.

The development of the AMONIX HCPV solar cell paved the way for commercial deployment of HCPV systems. This cell achieved a world record for commercially manufactured concentration cells: >26.5% efficiency at 250X concentration. With the arrival of this stable high performance cell, high-concentration PV systems can now be realized.

Considerable effort has been applied so that all of the savings resulting from greatly reduced silicon usage do not get lost in the cost for the structure, tracker, and ancillary equipment required in concentrating systems. The result is the Integrated High-Concentration PV (IHCPV) array. The innovative (patented) IHCPV system concept eliminates much of the costly hardware used in earlier high-concentration designs. This was accomplished by the simplification of the array structure, which (1) eliminated earlier separate "box"-type modules mounted on structure assemblies, and substitutes an integrated design which combines both the load-bearing structure and the Fresnel lens/receiver plate elements thus eliminating the need for separate modules, and (2) a novel, manufacturing-worthy receiver plate which makes use of "printed circuit-board" construction techniques, eliminating costly and labor intensive cell packaging and interconnects (see Fig. 1).

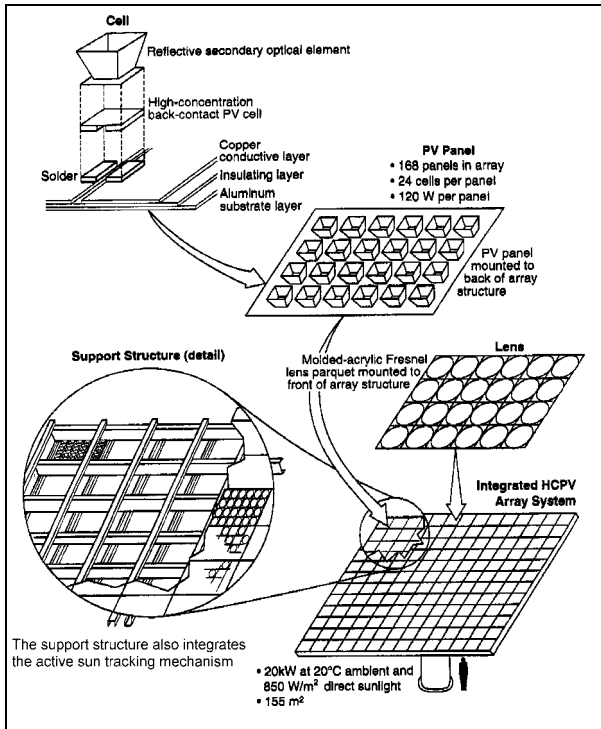


Figure 1: Schematic representation of IHCPV system

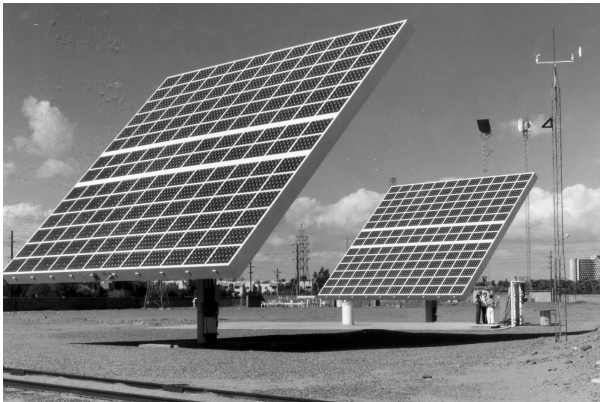


Figure 2: Two 20 kW IHCPV Systems at APS

FIELD EXPERIENCE

Reliability-by-design was validated during the field experiments. The stabilized solar cell, which had to be designed to withstand the rigors of highly concentrated sunlight with its associate UV component, has logged over 20 million device hours without degradation. The single center-pedestal array mounting configuration is optimized to withstand damage from lightning, a major concern for some locations such as Ft. Davis, TX where

the isokeraunic level for the general site is 40. The integrated receiver plates were designed to maintain electrical isolation at voltages of 2000+ volts, far exceeding industry requirements. All of the IHCPV arrays easily passed "Wet HIPOT" testing prior to their initial activation.

Earlier field experience highlighted several areas where design improvements could significantly increase the performance and/or the long-term robustness of the system. Among these were sealing improvements, refined tracking electronics, and a self-protecting electronic network for the solar cells. This paper will present details of these design improvements and results of the field projects.

SEALING IMPROVEMENTS

The IHCPV system is mechanically a large, single 'box' 45' wide, 37' high and 21" deep. Deployed in any environment, even 'dry' desert areas, this large enclosed volume will develop considerable trapped condensation if any attempt is made to hermetically seal the array structure.

The array structure was designed to 'breathe' through the side and back trim sheetmetal pieces which overlap each other. This would allow for drainage of water condensation while protecting the inside of the array structure from dust or particulate intrusion.

In field experience, the dramatic changes in temperature encountered in the Southwest caused such rapid condensation (especially during Summer thunderstorms) that water droplets formed on the inside lens surface and fell onto the receiver plate.

Third generation systems have 24 filtered vents, each 6" in diameter, fitted into the top and bottom sides of the array structure. Commercial filter material insures that dust, pollen or other particulate matter does not enter the structure. External sheetmetal baffles shield the filtered vents from direct water incursion during rain. Note that during a rainstorm, the array structure automatically goes to a safe stow position which is nearly horizontal.

Experience with this system over the past 18 months has proven that it is sufficient to prevent condensation even under the most adverse combinations of temperature and humidity.

SELF-PROTECTING ELECTRONIC NETWORK

Amonix's integrated receiver plates consist of an aluminum backplane upon which is bonded a copper 'printed circuit' trace which is electrically isolated from the backplane by a high-dielectric layer. Twenty-four solar cells are mounted onto the copper trace in a 'two

parallel by twelve series' configuration. Each receiver plate is bypassed by a diode capable of handling the current requirements of the system array string (typically 30 A).

A solar cell can be modeled as a voltage source in-series with a non-linear resistor. The resistance varies with the insolation upon the solar cell. As a load is placed across the cell, current is drawn through this resistor resulting in a voltage, of opposite polarity to the cell, developing across the resistor. When the load resistance is decreased to zero Ω the current through the resistor equals the short circuit current of the cell (I_{sc}) and the voltage across the resistor equals the voltage source resulting in a cell output of zero volts (the algebraic sum of the voltage source and the I-R drop across the resistance). When several cells are placed in-series and the load is applied across the series string, the same situation happens, except that all of the resistors are not necessarily equal due to differing solar insolation conditions and individual device parameters. One cell will reach zero volts before the others in that string. The remaining cells still have some forward voltage, the sum of which can be considerable compared to a single cell's potential. When this happens, the device becomes reverse biased and attempts to block further current flow. The voltage increases rapidly across the reverse biased cell as does the power dissipated within it. Resulting in "hot spots" which can cause receiver plate failures. To prevent this condition from occurring, solar cell are traditionally bypassed in groups by a diode which diverts the current from the remainder of the string around the group when a reverse bias condition develops. The available voltage which can develop across the reverse biased solar cell is limited to the sum of the excess voltages of the remaining cells within that group. We have chosen to reduce the grouping from 12 cells to individual bypassing of each cell which will assure that no cell will become reverse biased under any condition.

SUMMARY

In summary, a novel, cost-effective, integrated high-concentration PV system has been designed and five 20 kW arrays have been deployed. Test results validate the reliable high performance capability of the IHCPV system. Three years of field experience lead to product improvements and refinements which will significantly improve the long-term reliability of high-concentration PV systems. These improvements have dispelled earlier concerns regarding IHCPV's applicability for utility PV electric power generation and have moved IHCPV into the mainstream as a viable, low-cost, near-term option for renewable energy planning.

ACKNOWLEDGEMENTS

The authors would like to thank all those who participated in the installation and evaluation of the 1st, 2nd, and 3rd generation IHCPV evaluation systems. In particular, Mr. Herb Hayden of APS, Mr. Ward Marshall of CSW, Mr. Dale Green of NPC, Mr. Brian Farmer of PVUSA and Dr. Edgar DeMeo of EPRI, without whose support these projects would not have been possible.

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