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# Benchmark Cost and Performance of Utility Scale Photovoltaic Systems at Tucson Electric Power

L. Moore[1*], H. Post[1], T. Hansen[2], and T. Mysak[2]
[1]Sandia National Laboratories, PO Box 5800, Albuquerque, NM 87185-0753
[2]Tucson Electric Power Company, PO Box 711, Tucson, AZ 85702
[*]lmmoore@sandia.gov

## ABSTRACT

Tucson Electric Power Company (TEP) currently has nearly 5.0 MWdc of utility-scale grid-connected photovoltaic (PV) systems that have been installed in its service territory since 2000. Most of this installed PV capacity is in support of the Arizona Corporation Commission Environmental Portfolio Standard (EPS) goal that encourages TEP to generate 1.1% of its energy generation through renewable resources by 2007, with 60% of that amount from photovoltaics. The EPS program provides for multi-year, pay-as-you-go development of renewable energy, with kWhac energy production as a key program measurement. A total of 26 crystalline silicon collector systems, each rated at 135 kWdc, have been installed at the Springerville, AZ generating plant by TEP making this one of the largest PV plants in the world. These systems were installed in a standardized, cookie-cutter approach whereby each uses the same array field design, mounting hardware, electrical interconnection, and inverter unit. This approach has allowed TEP to achieve a total installed system cost of $5.40/Wdc and a TEP-calculated levelized energy cost of $0.10/kWhac for PV electrical generation. During this time, much has been learned regarding performance, cost, and maintenance. This paper presents an assessment of these topics including baseline cost, performance and operation and maintenance data.

## 1. Objective

The objective of this work is to establish baseline information for large fixed flat-plate systems. Development of this information supports the benchmarking, validation and analysis task of the system-driven approach. Documentation of baseline cost and performance data for utility-scale PV system configurations is a key element of the system-driven approach

## 2. Technical Approach

To develop and document actual field experience with PV systems requires access to qualified data. A Sandia/DOE partnership with TEP provides this access to monitor, analyze and assess the field performance of a large number of fixed flat-plate systems.

## 3. Results and Accomplishments

TEP has installed 26 fixed flat-plate crystalline-silicon systems representing over 3.5 MWdc of installed capacity during the period of 2001 through 2004. The utility-scale PV generation effort is centered at the Springerville Generating Station Solar System in eastern Arizona. Shown in Fig. 1, this facility is one of the largest PV generating plants in the world.

Fig. 1. Springerville PV Generating Plant

Covering 44 acres, this PV generating plant is grid-intertied with a 34.5-kV TEP distribution line. Each of these systems is an identical copy of a standardized array field configuration that utilizes the same hardware components, wiring topology, and structural mounting plan. The standard system configuration includes ASE Americas (now RWE Schott Solar) ASE-300-DG/50 modules and a Xantrex PV-150 inverter. The arrays are mounted at a fixed tilt of 34 degrees facing due south.

### *3.1 Performance*

The average monthly final yield for all systems is presented in Fig. 2.

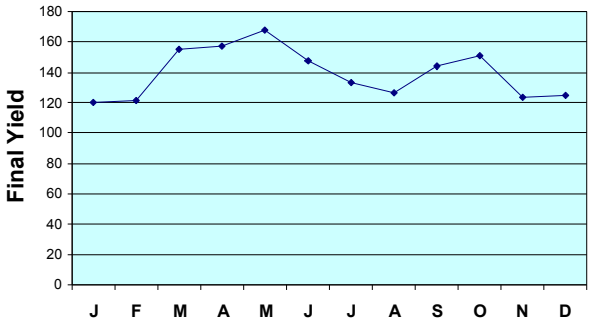


Fig. 2. Average Monthly Final Yield

The average annual final yield for all systems is 1673 kWhac/kWdc. The average final yield for 2004 is 1720 kWhac/kWdc.

The monthly reference yield for the Springerville arrays in 2004 is shown in Fig. 3. The annual reference yield for 2004 is 2175 sun-hours.

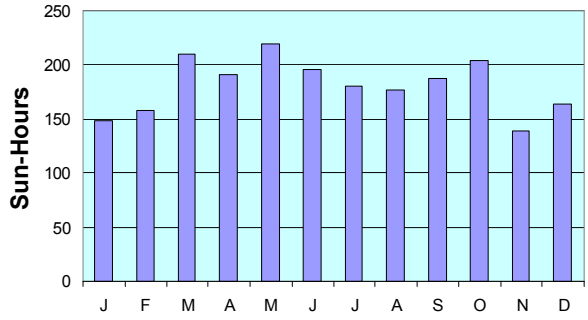


Fig. 3. Monthly Reference Yield (Sun-Hours) for 2004

The system monthly performance ratio is presented in Fig. 4. The performance ratio reflects the system losses going from aggregate nameplate dc power to annual average ac power of the system.

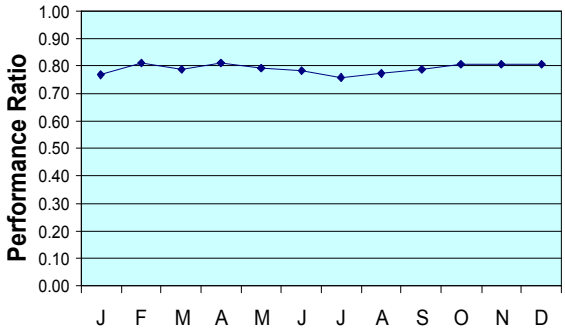


Fig. 4. Average Monthly Performance Ratio for All Systems in 2004

The average annual performance ratio for all systems in 2004 is 0.79.

3.2 Cost

Tucson Electric Power is realizing significant cost benefits by incorporating standardized products, volume purchasing and efficient array field design and installation. The Springerville experience has documented some of the lowest installed system costs ever reported thereby establishing a benchmark for state-of-the-art utility-scale systems. A cost breakdown for systems installed in 2004 is presented in Table 1.

Table 1. Cost Breakdown for Springerville Systems

| System Component | $/Wdc | $/Wac |
|---|---|---|
| **Modules** | **3.33** | **4.22** |
| **Array Field BOS** | **0.56** | **0.71** |
| **- Site Prep ($0.10/Wdc)** | | |
| **- Structure ($0.15/Wdc)** | | |
| **- Electrical ($0.30/Wdc)** | | |
| **- AC Intertie $0.01/Wdc)** | | |
| **Inverter/Transformers** | **0.40** | **0.51** |
| **Indirect/Overhead/Profit** | **1.11** | **1.40** |
| **Total** | **5.40** | **6.84** |

*3.3 Operation and Maintenance*

An unscheduled maintenance events results in a loss of generating capacity that affects one or more systems and requires human intervention to restore the system(s) to full operational capacity. Through January 1, 2005, the 26 crystalline silicon Springerville systems had provided 582 system-months of continuous operation since installation. Over that same period, a total of 94 unscheduled maintenance events were recorded which provides a mean time between unscheduled service per system of 6.2 months of operation.

Table 2 lists the annual maintenance cost, both scheduled and unscheduled, as a percentage of the cumulative capital investment by year. The average annual maintenance costs since the initial Springerville installations are 0.16% of initial capital cost.

Table 2. Maintenance Cost as a Percentage of Capital Investment

| Year | Scheduled % | Unscheduled % | Total % |
|---|---|---|---|
| **2002** | **0.08** | **0.01** | **0.09** |
| **2003** | **0.07** | **0.22** | **0.29** |
| **2004** | **0.06** | **0.05** | **0.11** |

**4. Conclusions**

The energy data, system cost, and maintenance experience with the Springerville crystalline silicon systems provide a treasury of information that establishes a benchmark for current utility-scale fixed flat-plate PV systems. This paper has identified a number of findings, including:

- Average annual ac system energy output in 2004 is 1720 kWhac per kWdc of array.
- Average annual ac system power in 2004 is 0.79 of the array dc nameplate rating.
- Innovative approaches including standardized array designs, low-cost array field BOS, and bulk hardware purchases have resulted in an installed system cost of $5.40/Wdc.
- Average annual O&M cost is 0.16% of initial system installed capital cost, not including rebuild/replacement cost of the inverter.
- The mean time between unscheduled maintenance service per system is 6.9 months of operation.

**ACKNOWLEDGEMENTS**

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**MAJOR FY 2005 PUBLICATIONS**

L. Moore and H. Post, Rolland Skinner, Randy Hauk, "O&M Field Experience with PV Water Pumping Systems", *Proceedings ISEC2005, August 2005*