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**PVUSA Construction and Safety:  
Experience, Lessons Learned and Costs**

**September 1994**

Prepared by:

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# **PVUSA CONSTRUCTION AND SAFETY: EXPERIENCE, LESSONS LEARNED AND COSTS**

September 1994

Dan Shipman, Bechtel Construction Company  
PVUSA Project Team

for

**Pacific Gas and Electric Company**  
Research and Development Department  
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## ABSTRACT

This report is the first of a series of PVUSA reports on PVUSA experiences and lessons learned at the demonstration sites in Davis and Kerman, California. During the course of approximately 6 years (1988-1993), nine PV systems have been installed ranging from 20 kW to 500 kW. Five 20-kW emerging module technology arrays were installed on universal project-provided structures, and four utility-scale systems (200 to 500 kW) were installed as turnkey (vendor designed and integrated) systems. The report emphasizes PVUSA construction and safety experience from the installation of these systems and is intended for use by utility personnel engaged in the construction of a photovoltaic (PV) power plant (e.g., engineers, construction supervisors, etc.). Subsequent PVUSA topical reports will address

- Validation of the benefits of the 500-kW Kerman PV plant
- Experience with the balance of system for PV installations
- Final assessment of data and experience with all the 20-kW EMT-1 systems at Davis
- PVUSA experience with power quality and power conditioning units
- PV system procurement, rating, and acceptance testing
- Data acquisition for PVUSA

## EXECUTIVE SUMMARY

The objective of this report is twofold: first, to relate PVUSA experience and lessons learned regarding the construction, safety, and costs of installing utility-scale (US) photovoltaic (PV) systems at Davis and Kerman, California, and second, to make recommendations to utilities that are potential developers of US PV systems.

Although the report emphasizes construction methods appropriate for PV system installation, general construction methods also are addressed. There are a number of construction implementation options available to system developers. These options range from hiring a system integrator or architect/engineer with full project responsibility, to conducting the entire project with utility staff. Information in this report should be used selectively after the scope of the PV system and the division of responsibilities for project implementation have been defined.

PVUSA site development began in 1987 at the Davis site. The eight systems installed to date at Davis consist of five emerging module technology (EMT) and three utility-scale (US) systems. They occupy 45 percent of the area available for PV development, leaving an unused area large enough to support several additional systems. In 1992, an additional US system was installed at a site near Kerman. This report focuses on the lessons learned about construction and safety during the installation, operation, and maintenance of these nine PV systems.

To fulfill PVUSA project objectives, much effort and coordination was required in advance of actual construction. System procurements and installations were planned, with specific assignments of organizational responsibilities within PG&E and Bechtel. PG&E provided overall project management and engineering, and Bechtel assisted with engineering, procurement, and construction management. These responsibilities ranged from acquiring leases and permits, developing labor relations agreements with local unions, drafting subcontract responsibilities, mobilizing subcontractors, and construction inspection and management to addressing safety issues and developing safety programs.

In this report the elements essential to a PV construction project are addressed from the perspective of PVUSA experience. These elements include

- Safety
- Quality
- Cost



- Planning and scheduling
- Labor relations
- Contract administration
- Site infrastructure development
- System start-up

Since its inception the PVUSA safety program has evolved from a company-standard program to a PV construction site-specific program. This process culminated in the PVUSA Safety and Health Action Plan, which specifies requirements and guides for job site safety. The plan was developed to formalize safety responsibilities and identify activities that present safety risks at PVUSA. Specific direction was incorporated into the plan to provide adequate PV guidelines and site-specific criteria. Additionally, individual safety training requirements, site safety enhancements, and a PVUSA Safety Committee have each contributed to overall safety awareness. The lost-time accident ratio for Davis is one-third the national average, and the PVUSA Kerman site has experienced no accidents or OSHA-reportable cases.

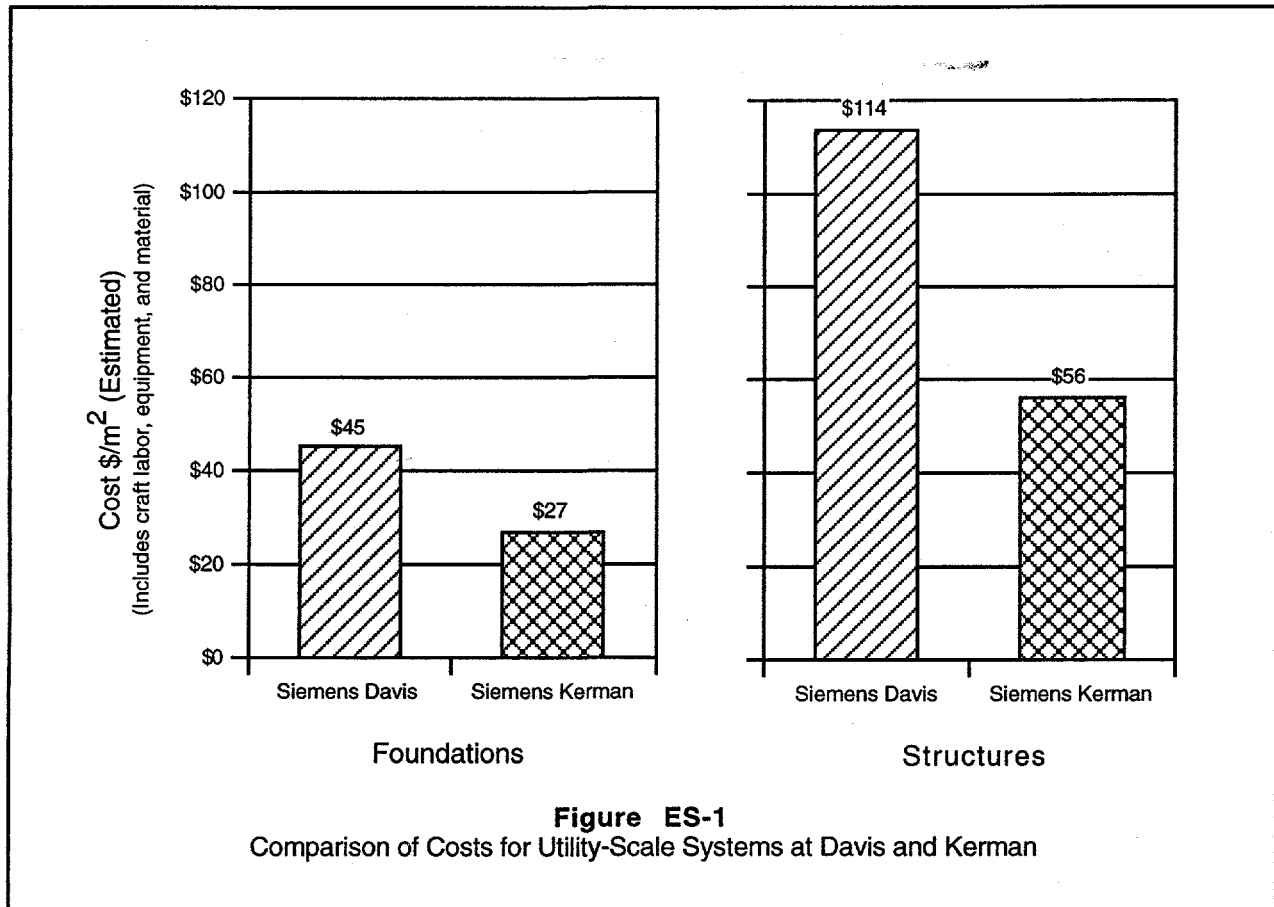
Because of the close relationships between various elements of a project, a failure to perform well in one area can have detrimental effects on other aspects of the project. For example, PVUSA experience indicates that

- Quality problems affect cost, schedules, and/or safety.
- Schedule problems affect cost and/or quality.
- Cost problems affect quality and/or schedule.

PV is a developing, rather than mature, technology. Some national standards for testing and manufacturing PV system components are still in the developmental stage. The developmental nature of PV is reflected in the installation schedules for most of the PV systems installed during the first phase of construction at Davis. Original schedules were delayed by 5 months up to 24 months or longer. However, the experience gained with the US contracts at Davis was valuable, and the lessons learned were applied with beneficial results during construction at Kerman.

Construction at Kerman provides a baseline experience for future US grid-support PV installations. The Kerman plan and schedule were implemented effectively, resulting in major improvements over the Davis systems' construction schedules, quality, and costs.

**Figure ES-1** shows construction material, labor, and equipment costs for similar foundations and support structures at Davis and Kerman.



A comparison of these costs reveals the effect of improved design, soils with higher load-bearing capacity, more attention to daily work plans, and selection of proven PV components. The cost reductions at Kerman are an encouraging sign for utilities; however, further cost reductions and additional installation experience are needed. Nonetheless, lessons learned at Kerman provide an opportunity to further reduce bottom-line PV costs. The developmental aspects of components for PVUSA and problems arising from field deployment of new PV materials continue to be sources of delay for PV construction efforts. Improved site selection criteria, more reliable components, and more innovative, cost-effective designs will encourage utility PV development. At present, gains in construction efficiency are overshadowed by the high cost of a dc PV generating system.

## **RECOMMENDATIONS**

Based on the construction experience at the PVUSA Davis and Kerman sites, the following PV-specific measures are recommended.

### **Site Infrastructure and PV System Construction (Section 2)**

- Consider site selection a critical cost factor.
- The level of PV plant commercialization must be considered and established before significant design effort is expended. Provisions for R&D activities have a significant impact on infrastructure layout and design.

### **Safety (Section 3)**

- Develop a PV-specific safety program tailored to the utility project.
- Certify modules to interim test standards.
- Install system in compliance with NEC/NESC and specifically NEC Article 690.
- Include the field wet resistance (wet megger) test in a detailed field test plan.
- Implement early PV safety training for utility personnel who will operate and maintain PV systems.
- Conduct on-site craft safety training with emphasis on energized dc circuits.

### **Planning and Scheduling (Section 4)**

- Allow sufficient lead time for delivery of materials in planning and scheduling.

### **Labor (Section 5)**

- Develop a project memorandum of understanding for union job sites to provide a means for resolving jurisdictional disputes.
- Identify and budget for specialized subcontractors with skills in the PV area and data acquisition/solar instrumentation.

### **Contractor Performance (Section 6)**

- Exercise tight control of PV suppliers during manufacturing and installation to offset developmental nature of the PV industry.

### Quality Control (Section 7)

- Develop a tailored QC program after reviewing PVUSA quality measures.
- Require demonstrations of components with unproven designs (e.g., PCUs, structures, or drives) to determine adequacy.

### Start-Up (Section 8)

#### Before start-up

- Maximize factory testing of PCUs.
- Witness and certify PCU factory tests.
- Request 2 days of training from PCU supplier.

#### During start-up

- Have PCU representative available.
- Have adequate spare parts on hand.
- Have adequate test equipment available.

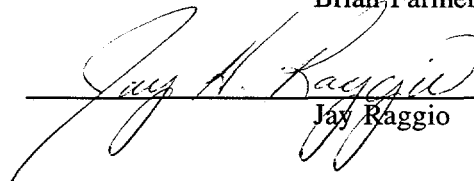
### Cost (Section 9)

- Use field-proven components or designs for the PCU to decrease overhead costs associated with extended system start-up periods.
- Evaluate potential PV sites in terms of base land costs, drainage characteristics, permit requirements, and soil conditions.
- Use standard materials and minimize material quantities for PV structure designs.

Project Manager

  
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Jay Raggio

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**ACTIVE PHOTOVOLTAIC CODES AND STANDARDS**

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## Section 1

# INTRODUCTION

This section provides background on PVUSA, describes construction and safety efforts at the Davis and Kerman sites, comments briefly on costs associated with site development, and outlines the format of this report.

## BACKGROUND

PVUSA is a national public-private partnership that is assessing and demonstrating the viability of utility-scale photovoltaic (PV) electric generating systems. PVUSA offers utilities the hands-on experience needed to evaluate and utilize maturing PV technology, provides manufacturers with a test bed for their products, and encourages technology improvement and cost reductions in PV modules and balance-of-system (BOS) components. The project also facilitates communication between utilities, government laboratories, and the PV industry that is necessary for successful development and commercialization of utility PV systems. PG&E leads the PVUSA Project Team, which manages daily activities and facilitates technology transfer. The specific objectives of PVUSA are

- To evaluate the performance, reliability, and cost of promising PV modules and BOS components side-by-side at a single location
- To assess PV system operation and maintenance (O&M) in a utility setting
- To compare PV technologies in diverse geographic areas
- To provide U.S. utilities with hands-on experience in designing, procuring, and operating PV systems
- To document and disseminate knowledge gained from the project

The project consists of emerging module technology (EMT) arrays and utility-scale (US) systems. EMTs are state-of-the-art PV module technologies that have not yet been field tested. The 20-kW size of the arrays was selected to demonstrate ease of manufacture and allow a statistically credible evaluation, while minimizing risks associated with a new technology.

PVUSA is fielding EMT arrays primarily to encourage promising PV technologies to move out of the laboratory and into pilot production. During this evolution EMT manufacturers can determine whether the manufacturing process merits further development or scale-up. The lessons learned by manufacturers are important input for PV technology commercialization decisions. EMTs also allow PVUSA to establish baseline information regarding various components of an array (e.g., junction boxes and inter-array wiring). This information is of interest regardless of the future

commercialization of the full array. In addition EMTs have provided PVUSA with the opportunity to create and establish procedures for performing O&M tasks and tracking O&M costs for PV systems, which were then used as a basis for developing corresponding procedures for US systems.

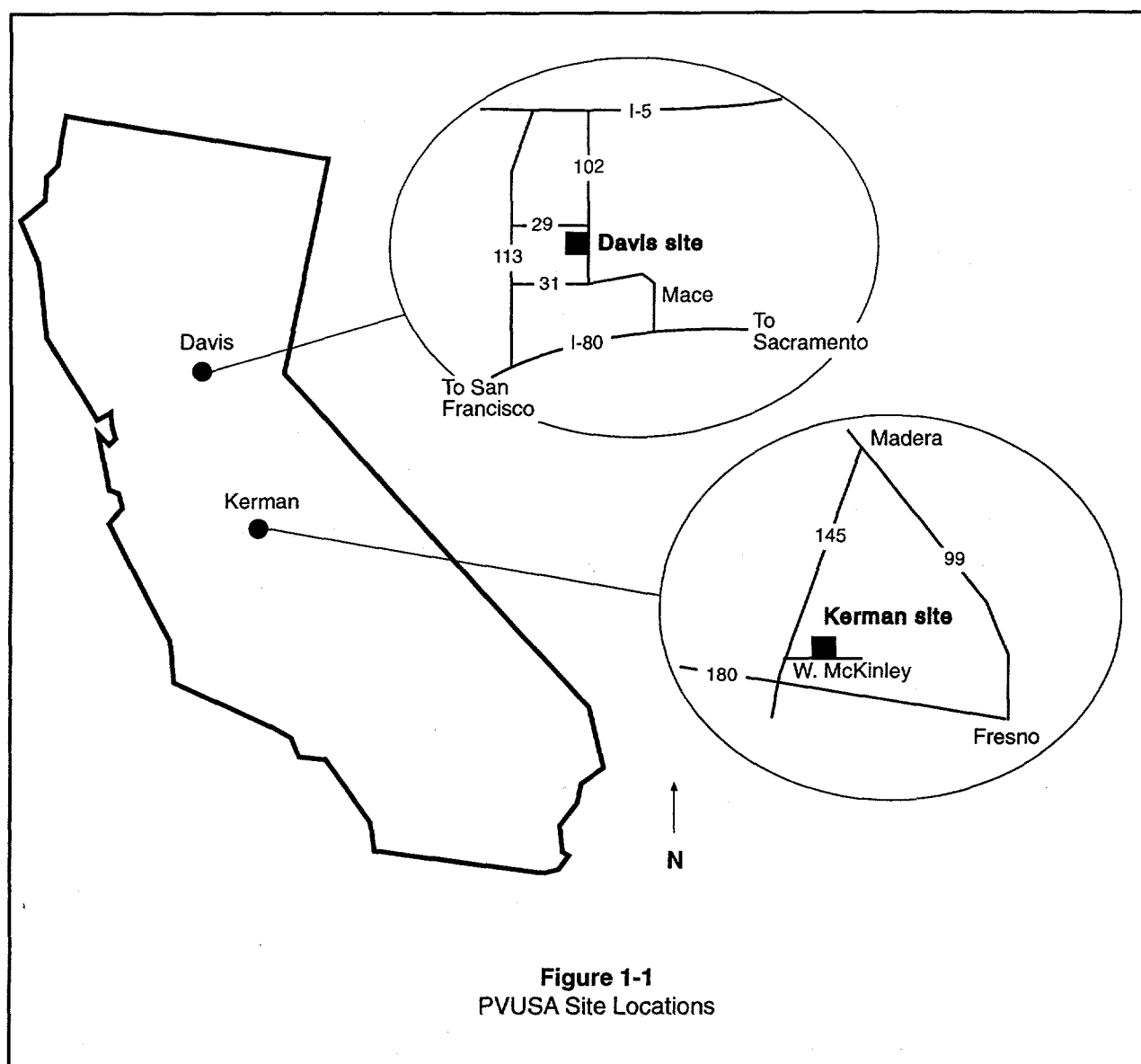
US systems offer valuable information for utilities. US systems are vendor-optimized turnkey PV systems that use mature module technologies and have the potential to produce low-cost energy and also meet O&M, power quality, reliability, and lifetime requirements necessary for utility applications. The US systems selected for demonstration are nominally 200 kW or larger; they are expected to capture much of the economies of scale of larger systems and provide realistic evidence of satisfactory system protection requirements, installation requirements and costs, system performance, O&M costs, and grid interaction. These systems incorporate innovative BOS designs that are expected to lead to cost-effective approaches for utility applications. They also provide both the project participants and the PV industry with experience in commercial procurement and construction practices.

One US system (US-2 Kerman) has been strategically sited within a utility's distribution system to allow detailed study of the impact of PV on the local grid. This grid-support system will allow verification of several potential benefits of distributed PV as well as information on the operational and power quality aspects of an unattended PV plant on a high-impedance distribution line.

PVUSA construction activities represent a critical step toward fulfilling the project's objectives. This report focuses on PVUSA PV construction and summarizes the experience gained and lessons learned at the PVUSA sites in Davis and Kerman, California. In addition, it discusses safety issues and experience and describes development and implementation of safety plans for both sites.

## **CONSTRUCTION**

PVUSA construction began with the mobilization of the Davis site development contractor in September 1987. During the next 6 years, PVUSA installed eight PV systems at the Davis site and a single 500-kW US system at the Kerman site. **Figure 1-1** shows the locations of the two PVUSA sites.



Two types of PV systems were installed. Small 20-kW emerging module technologies (EMT) systems were installed to provide a side-by-side comparison of production line quantities of PV modules. For these installations, identical “universal” support structures and power conditioning units (PCUs) were designed, purchased, and installed by PVUSA to provide the BOS for various EMT modules.

Utility-scale systems were the second type of PV system installed. These systems are much larger (174-500 kW) and were turnkey procurements (three were installed at Davis and one at Kerman). They represent more mature PV technologies that were presumed to be commercially viable.

Costs and quantities for construction labor and materials have been documented for all systems to provide a basis for evaluating cost-effective design features, PV modules, and construction costs associated with BOS components.

Traditional construction methods for placement of concrete, rebar, and steel were shown to be cost-effective tools for PV installation. System suppliers are currently addressing the need to reduce BOS costs, and progress is being demonstrated in this area at the Davis site. These cost savings are further discussed in Section 10.

The inability of PV suppliers to meet schedules for providing modules and PCUs hindered development of the Davis site. The timely delivery of modules and reliable PCUs is the key factor in meeting system construction schedules. When standard, commercially available equipment is used, PV system deployment proceeds quite rapidly. US-1 proposals accepted by PVUSA included components that had a lower level of commercial maturity than expected. Section 4 of this report addresses scheduling problems encountered by the PV subcontractors.

## **SAFETY**

Safety is the first priority for PVUSA construction and operations. For this reason, the PVUSA project team has exerted considerable effort to ensure safety at the sites. These efforts, which include developing the PVUSA Safety and Health Action Plan and individualized employee safety training schedules, constitute a developing model for excellence in PV safety.

## **REPORT FORMAT**

This report describes the construction and safety experience at PVUSA for the EMT and US systems, and is organized as follows:

This section (Section 1) provides background on PVUSA, describes construction and safety efforts at the Davis and Kerman sites, comments briefly on costs associated with site development, and outlines the format of this report.

Section 2 describes the permitting process for the Davis and Kerman sites, gives a historical account of infrastructure development at the two sites, and details infrastructure subcontracts at Davis and Kerman. It also discusses Kerman infrastructure costs and outlines potential areas for reducing infrastructure costs.

Section 3 describes PVUSA provisions for safety and their evolution, and discusses the PVUSA safety experience. It also advises on special safety provisions for PV and makes safety recommendations.

Section 4 reviews PVUSA scheduling activity, identifies milestones and schedule drivers for PV installations, presents a typical PV installation schedule, and makes recommendations relative to planning and scheduling.

Section 5 provides historical information regarding the use of construction labor at PVUSA and offers utilities some specific considerations for labor. Additionally, it provides insight into the need for specialized labor and extrapolates from PVUSA experience to make recommendations and present a typical labor breakdown.

Section 6 outlines PVUSA procedures for administering subcontracts, vendor engineering submittals, and field changes. It also discusses the monitoring of PVUSA subcontractor performance and presents some case histories. Recommendations are made in each area.

Section 7 describes steps taken by the PVUSA Project Team for quality assurance and quality control (QA/QC). Also, it discusses quality challenges encountered at Davis and Kerman and makes recommendations regarding quality.

Section 8 describes PVUSA start-up activities related to field acceptance tests, identifies the underlying causes of start-up problems, and recommends actions to be taken before and during start-up.

Section 9 provides Davis and Kerman cost comparisons, identifies BOS cost drivers, and discusses opportunities for cost improvements.

Section 10 lists references used in preparing this report.

Appendix A shows active photovoltaic codes and standards.

## Section 2

### SITE INFRASTRUCTURE AND OVERVIEW OF PV SYSTEM CONSTRUCTION

This section describes the permitting process for the Davis and Kerman sites, gives a historical account of infrastructure development at the two sites, and details infrastructure subcontracts at Davis and Kerman. It also discusses Kerman infrastructure costs and outlines potential areas for reducing infrastructure costs.

#### DAVIS SITE

A 20-year lease agreement between PG&E and the City of Davis for the 86-acre PVUSA site became effective in March 1987. An environmental study was performed that led to signing of the agreement in November 1986 and the subsequent negative-declaration environmental assessment. This made it possible to begin the process of securing 12 additional permits and a business license required by Yolo County to develop the site infrastructure and PV systems. The first permit—the conditional use permit—was issued in November 1986; the permit process concluded with the issuing of OSHA scaffold and trench permits in April 1991. The required permits and licenses for the Davis facility and the dates issued are shown in Table 2-1.

**Table 2-1**  
**Permits Required for the PVUSA Davis Site\***

Type	Date Issued
Conditional use permit	November 5, 1986
Encroachment permit	April 7, 1987
Business license	August 26, 1987
Left-turn lane and Road 102 widening	September 11, 1987
Sump pump permit	September 23, 1987
Instrument and control building foundation	November 23, 1987
Instrument and control building	March 10, 1988
Platform to roof permit	August 22, 1988
Water use permit	September 6, 1988
Well sewage disposal permit	April 14, 1989
Temporary storage shed permit	May 10, 1990
OSHA scaffold permit	April 24, 1991
OSHA excavation permit	April 24, 1991

\*No permits were required for Kerman.

The number of permits required to install a US PV system may range from none to a significant number that can affect the project schedule. Permit requirements are defined by the laws and regulations of state and local government, and vary according to the location, size, and complexity of the proposed facility. Utilities may enjoy a permitting exemption when PV installations are sited within the boundaries of an existing utility installation. Conversely, a PV installation in a rural or urban area may encounter opposition, and public hearings or environmental studies may be required. Early investigation of permit requirements is mandatory to avoid schedule delays and unanticipated costs.

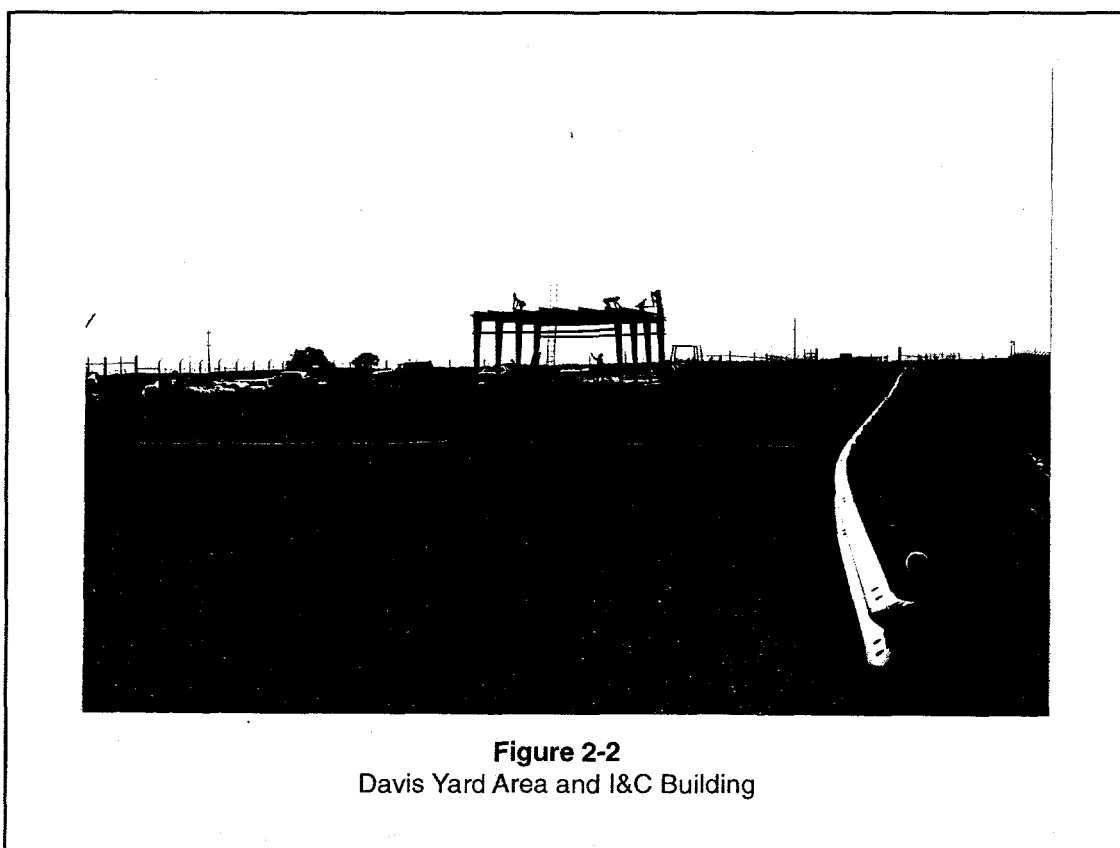
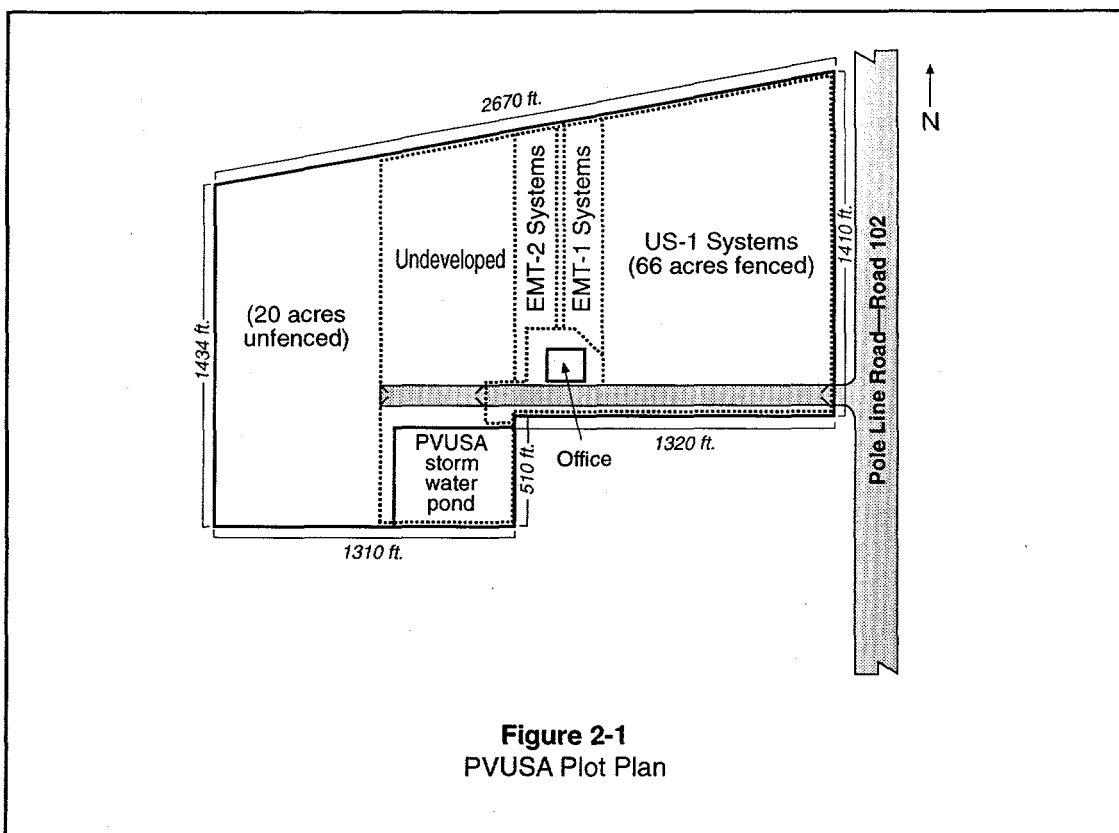
## **DAVIS INFRASTRUCTURE DEVELOPMENT**

To complement development of the Davis site, five technical studies were conducted. All studies were performed by PG&E or Bechtel except for the water quality study, which was conducted by Yolo County. Other than the geotechnical study, the studies were optional and were specific to the Davis site:

- **Geotechnical.** This report provided information on existing soil conditions that is required to establish design criteria for foundations.
- **Water quality.** This study determined that the site water supply was nonpotable and might produce a film when dried on glass modules.
- **Air monitoring.** A fire within an abandoned settlement pond prompted PVUSA to determine if combustible gases were being emitted from the soil. The results were inconclusive as the gases may have burnt off during the fire.
- **Vegetation and erosion control.** This study was performed to enhance PVUSA understanding of the adaptability of various types of ground cover at a PV installation.
- **Soil erosion.** The phenomenon of underground soil tunnels forming adjacent to drainage ditches is commonly referred to as "soil piping." Because of soil piping at the Davis site, PVUSA opted to perform a soil erosion study to provide technical advice for controlling and maintaining the problem. This information provided a basis for assessing future site maintenance costs.

Beginning in September 1987, contracts were awarded to develop the infrastructure for the Davis site, which consisted of abandoned settlement ponds that were used by a nearby canning plant. Dikes and underground piping divided the area and had to be removed to establish a drainage plan. To prepare the site, new ditches were excavated, a sump area was constructed, and a settlement pond was developed. Aggregate base roads were built throughout the site with additional aggregate base materials placed in the yard and what would later become the areas for EMT arrays. Additionally Yolo County required construction of a left-turn lane on Road 102 at the main entrance, which required several electric power poles to be relocated.





Because PVUSA project management had determined that only the easternmost 66 acres of the site would be prepared for PV arrays, all site contracts were limited to development of this space, rather than all 86 acres covered by the lease agreement. A subcontractor was mobilized to install utility-standard chain link fences and gates. The perimeter fence built to PG&E substation standards surrounds the 66 developed acres; two of these acres were sectioned off for the I&C building yard area. **Figure 2-1** shows the plot plan for the Davis site, and **Figure 2-2** shows the development of the Davis yard area and I&C building.

Operating from a mobile trailer, the site manager coordinated the subcontractor activities required to develop PVUSA Davis. The major activities involved constructing and/or installing the

- I&C building
- Site well
- Sump pump
- Visitor's Center trailer and deck
- 12-kV switchgear
- 480-V switchgear and related electrical underground
- PG&E interconnection
- 12-kV electrical underground
- Computers and data acquisition system (DAS) equipment
- Anemometer and rainfall station
- Solar reference instruments and platform
- Temporary power for construction and dewatering

The contracts required to develop the Davis infrastructure and BOS for the EMT-1 and EMT-2 procurements represent an investment of \$1.7 million. (See **Table 2-2.**) This cost does not include the value of the five EMT-1 PV subcontracts.

Several major contracts were awarded for construction of the first set of 20-kW emerging module technologies, known as EMT-1. A second and third EMT procurement was carried out, and these systems were designated EMT-2 and EMT-3.

**Table 2-2**  
**PVUSA Davis Infrastructure Subcontracts**

Subcontract Type	Award Date	Value of Contract	Scope of Work
<b>Research-Related Subcontracts<sup>1</sup></b>			
General building	1/21/88	\$127,796	I&C building, foundation, and utilities
Basic Data Acquisition System	5/24/88	291,623	Computers, data loggers, technical assistance, meteorological and solar instruments
Well driller	4/19/89	11,150	Well and septic systems
Visitor Center	5/4/89	27,614	Trailer, deck, A/V equipment
Specialty contract	12/11/90	9,018	Security system
Other research	1988-90	<u>23,266</u>	Miscellaneous research-related purchases
<b>Subtotal</b>		<b>\$490,467</b>	
<b>Site-Specific Subcontracts<sup>2</sup></b>			
Road widening/pole relocation	7/6/87	\$ 34,000	Left-turn lane on Road 102
Earthwork	9/1/87	531,337	Grubbing, grading, roads, drainage, road widening, etc.
Earthwork/mechanical	9/1/87	88,600	Sump pit and discharge piping
Storm water electrical	9/24/87	<u>58,659</u>	Sump pump and control installation
<b>Subtotal</b>		<b>\$712,596</b>	
<b>Infrastructure Subcontracts<sup>3</sup></b>			
Site fence	10/20/88	\$ 85,127	Site fences and gates (8114 linear ft)
Site survey	9/10/87	9,829	Site surveys, benchmarks
Site electrical	5/4/88	5,055	UPS installation, conduits
Site electrical	4/20/93	8,100	UPS upgrade, conduits
Site electrical	4/27/89	54,231	12-kV switchgear and grid protection
Site electrical	5/13/88	18,966	480-V equipment, terminations
Site electrical	6/10/88	282,564	BOS electrical
Testing lab	10/7/87	2,032	Soils testing
Equipment leasing	9/8/87	64,699	Construction overhead
Miscellaneous		<u>26,161</u>	Other
<b>Subtotal</b>		<b>\$556,764</b>	
<b>Total Value of Contracts<sup>4</sup></b>		<b>\$1,759,827</b>	

<sup>1</sup> Much of the costs incurred for these items were research-related.

<sup>2</sup> With optimal site selection, most of these costs could be eliminated.

<sup>3</sup> These contracts represent the typical infrastructure expenditures required to support a 66-acre utility-scale PV facility.

<sup>4</sup> This total does not include site management or engineering costs.

PVUSA chose to design and install identical BOS for the EMT-1 and EMT-2 arrays; this was done to eliminate BOS design characteristics from the comparison of EMT systems. The EMT-1 support structure consisted of a steel space frame attached to a reinforced concrete caisson foundation. This design satisfied the design criteria for all the EMT-1 systems. Installation of caissons for the first EMT-1 array began in July 1988; immediately thereafter the support steel and electrical underground were installed. Between 1988 and 1991, five EMT-1 systems were installed and became operational at the Davis facility.

In an attempt to reduce the BOS support structure costs, a treated wood structure and concrete caissons were procured and constructed for the EMT-2 arrays. Installation costs for the structures and caissons, which are located north of the Instrument and Control (I&C) building and adjacent to the EMT-1 arrays, provide a comparison with EMT-1 structure costs. Because of an unexpected 30 percent increase in the price of treated lumber and a high unit cost per caisson, there was no cost benefit associated with the EMT-2 wood structures. Initially it was estimated that the cost to install the wooden structures (with foundations) would be \$65/linear foot (lf), compared with the real cost of \$106.21/lf to install the EMT-1 foundations and supports. However, the combined cost of the EMT-2 foundations and structures was \$122.80/lf. Most of the increased cost was due to the higher labor costs associated with erecting the EMT-2 supports.

In 1989, PVUSA awarded the contracts for construction of three turnkey utility-scale (US-1) systems to be installed at Davis. These systems, ranging in design size from 174 kW to 400 kW, were built between January 1990 and June 1993; two of the systems were operationally acceptable by January 1994. The US-1 systems occupy approximately 10 acres on the east portion of the site. They are fixed-price turnkey systems with PVUSA providing only the interface junction box (IJB), 12-kV cable to the inverter location, solar instrumentation, and data signal cable and equipment.

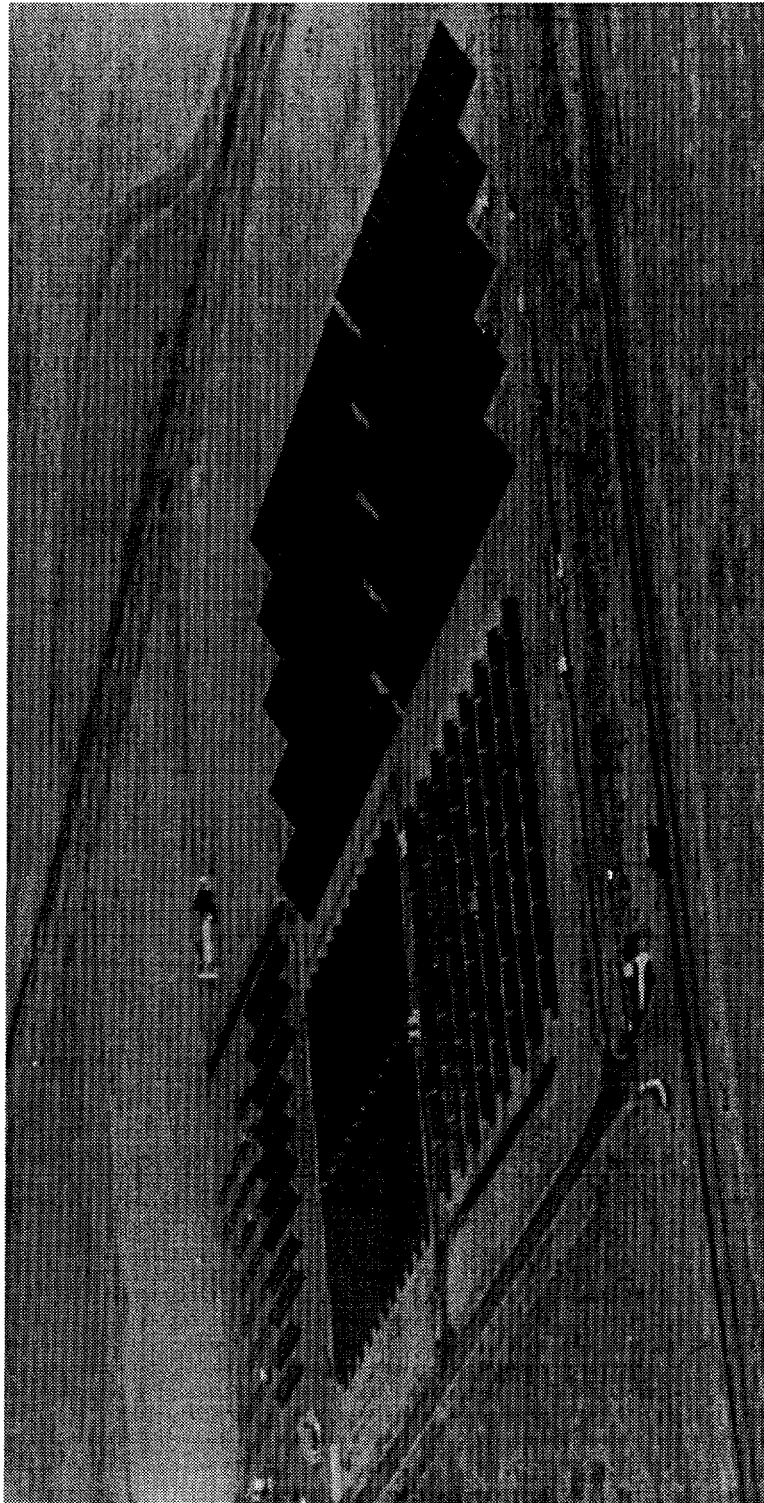
Concurrent with the installation of the EMT-1 and US-1 systems, two other noteworthy construction tasks were under way at the Davis site:

- The Electric Power Research Institute (EPRI), by agreement with PVUSA, installed the foundation and support structure for a high-concentration photovoltaic (HCPV) tracker.
- PG&E's general construction department installed a two-axis tracking array west of the site sump to study the tracker structure, bypass diodes, and source circuit configuration.

The EPRI HCPV is still under development; however, the PG&E tracker study has been completed, and the tracker is not currently operated. Construction of the two trackers was done with the approval of the PVUSA Steering Committee and the oversight of PVUSA site management.

A photo of the Davis site as it appeared in 1992 is shown in **Figure 2-3**.

The PVUSA Davis infrastructure can support 3 MW of PV. As of April 1994, 900 kW have been installed. This limited use of the facility is reflected in the cost/kW ratio. The overall cost of PV systems at Davis is distorted because of the ongoing research activities at the Davis facility, and analysis of costs is not particularly useful. However, the Kerman project does provide a baseline of typical infrastructure costs for future grid-support PV systems.



**Figure 2-3**  
PVUSA Davis, September 1992

## KERMAN SITE

In November 1991, PG&E purchased 10 acres of land in Fresno County, California. The initial May 1992 mobilization date was set based on the steady progress in land acquisitions, but it was later rescheduled for September 1992 due to delays in the permit process. These delays ended in August 1992, when Fresno County granted PG&E an exemption from land-use and building permit requirements. This exemption resulted from an agreement between the California Public Utility Commission, PG&E, and Fresno County, and is an important precedent for the permitting of future grid-support PV facilities in PG&E's service area. Additionally, municipal utilities may be exempt from most permitting requirements.

## KERMAN INFRASTRUCTURE DEVELOPMENT

Infrastructure development occurred from September to December 1992, with Bechtel's on-site management of all subcontractors. Table 2-3 shows the subcontracts issued for development of the Kerman infrastructure.

Table 2-3  
PVUSA Kerman Infrastructure Subcontracts

Subcontract Type	Award Date	Value of Contract	Scope of Work
Site development	5/8/92	\$132,720	Grading, aggregate base, roads, drainage
Site fence	10/8/92	\$38,269	Perimeter fence and gates (3300 linear ft)
Site well	10/27/92	\$6,793	Well, pump, pressure tank (120 ft deep)
Survey	6/1/92	\$1,305	Site survey
Electrical	9/25/92	\$149,000	Site electrical installation and underground electrical
Plumbing	10/19/92	\$13,693	Site septic, plumbing
Trailer manufacture	6/9/92	\$27,853	Construction trailer
Metal building	8/1/92	\$22,075	Control building (12' x 16')
Landscape	1/15/93	\$4,098	Landscaping, irrigation
<b>Total Value of Contracts*</b>		<b>\$395,806</b>	

\* Total does not include material value of UPS, 12-kV switchgear, battery charger, distribution panels, power cable, SCADA, storage van, or office furniture and supplies.



The value of the Kerman infrastructure subcontracts (\$395,806) includes costs specific to research and the site location. Kerman's infrastructure costs included expenditures for the extensive use of aggregate base, the construction office trailer, fencing off 10 acres (instead of only the seven acres used) septic, plumbing, well, landscaping, irrigation, and flood control structures. PVUSA estimates that this total cost could have been reduced by about 30 percent if Kerman had been a strictly commercial facility, requiring only the bare minimum in site infrastructure.

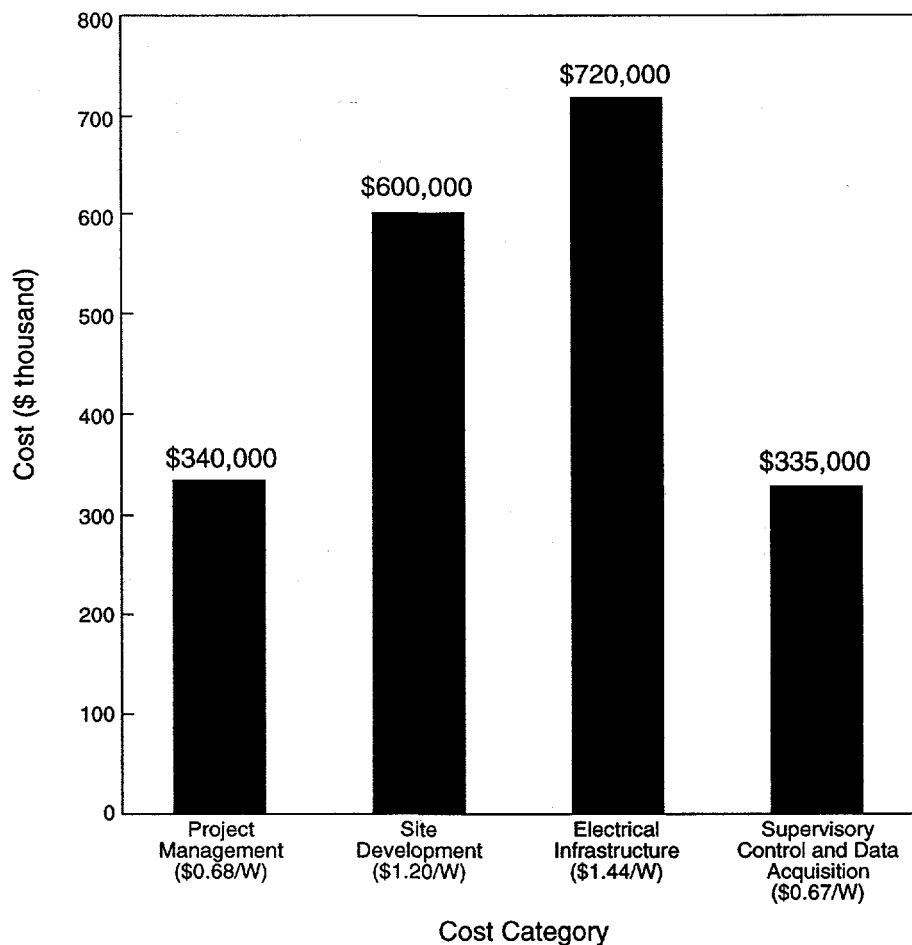
Kerman costs were initially summarized in a paper presented at the 23rd IEEE PV Specialist Conference in May 1993 (Jennings, et al., May 1993). The infrastructure costs presented in the IEEE paper provided the basis for a detailed cost estimate of the various Kerman infrastructure components.

Actual Kerman infrastructure costs will be presented in a report on BOS costs (Jennings, Reyes, et al., in progress). **Figure 2-4** indicates the actual infrastructure costs, which total \$3.99/W. This cost is in addition to the \$9.00/W attributed to the Siemens fixed-price contract for the PV turnkey system. It is important to note that the relationship between plant size and infrastructure costs is not linear; a plant twice the size of Kerman would have a minimum increase in site development costs.

Analysis of the Kerman infrastructure costs determined that a similar system with an optimized infrastructure and without research activities might be installed for \$2.35/W. This \$2.35/W cost assumes a hypothetical site that is similar to Kerman and has the same local code restrictions and design basis, but has a lower cost because the following elements and others have been eliminated:

- Construction/data trailer
- Septic system
- Water well
- Database computer
- Power quality monitoring equipment

Candidate sites that had adequate existing drainage provisions could further reduce infrastructure cost.



**Figure 2-4**  
**PVUSA Kerman Costs**  
(not including the \$9.00/W PV system price)

Development of PV power plants offers cost savings unavailable to many alternative power plants. The absence of process and service piping systems reduces development costs of a PV facility. Additionally, the absence of combustion byproducts eliminates costs associated with waste treatment, disposal, storage, transportation, and cleaning. These same features allow PV facilities to be sited more easily and should be emphasized in public relations efforts with neighbors and the community.

For the Kerman US-2 facility, PVUSA solicited competitive bids and selected Siemens Solar Inc. (SSI) to provide a 500-kW system with one-axis passive trackers. At the same time infrastructure development was started, Siemens mobilized to install the 500-kW PV array. The construction and start-up phases lasted 9 months, from September 1992 through May 1993, and the PV system was

rated in July 1993 at 498 kW ac based on PVUSA test conditions (PTC). PTC are defined as 1000 W/m<sup>2</sup> plane of array irradiance, 20°C ambient temperature, and 1 m/s wind speed. **Figure 2-5** shows the completed Kerman US-2 system.

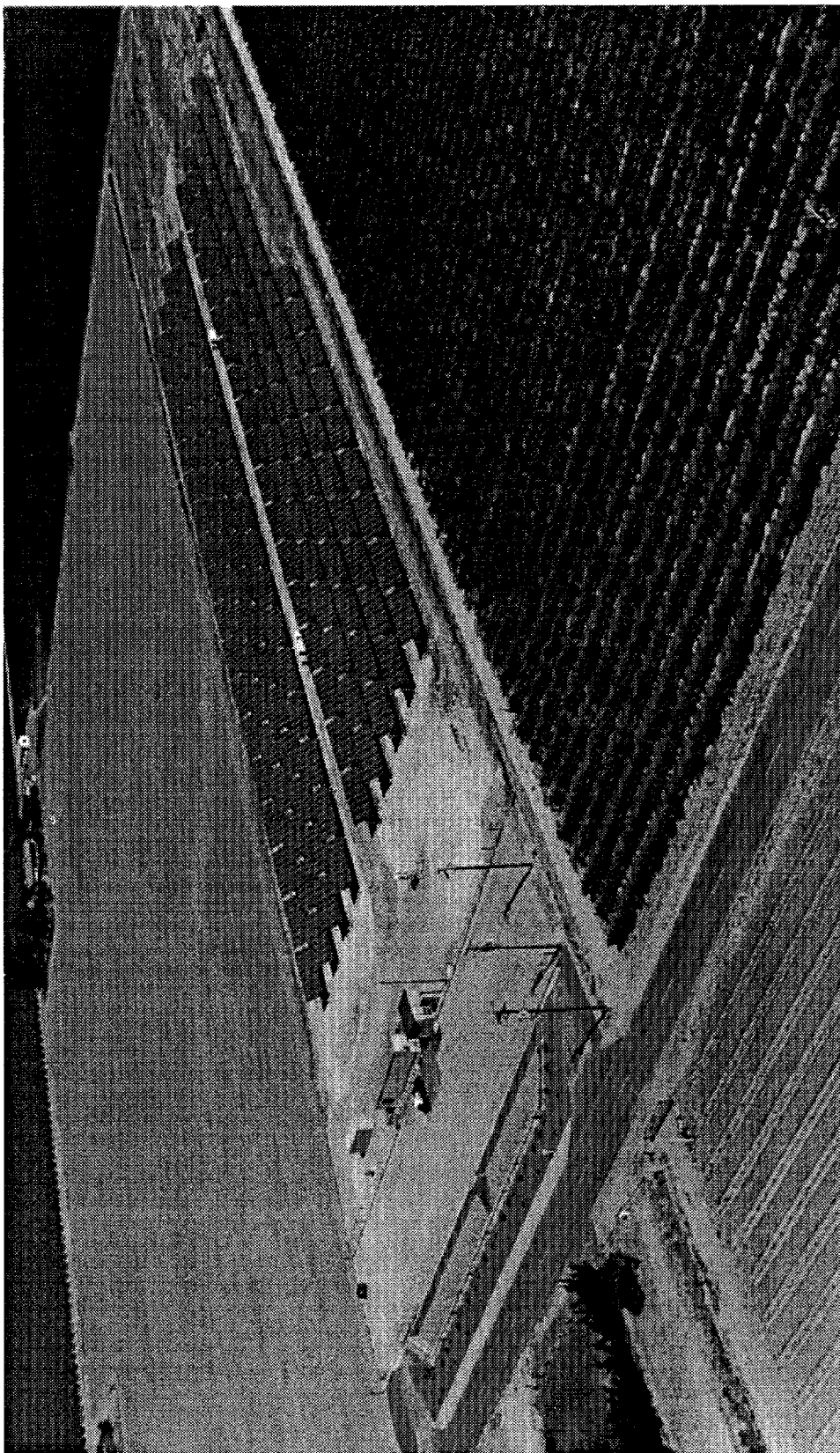
Developing the Kerman infrastructure in parallel with the PV system installation was a modification of the original plan made necessary because of permitting delays and contractual obligations with the PV supplier. The parallel construction sequence blocked the PV supplier's access to the array field and required

- Leasing an additional acre of land to provide access to the array field
- Installing an additional vehicle gate in the west perimeter fence
- Constructing a temporary aggregate base access road for the PV supplier
- Installing a temporary fence to secure the PV supplier's work area

These additional costs associated with parallel versus sequential construction were totally offset by a schedule improvement of 1 month, which resulted in decreased costs for site supervision and overhead.

The reduced scope of work associated with PV infrastructure also provides schedule improvements relative to other types of generation facilities. The Kerman infrastructure was completely developed in 3 months and included concessions specific to the location. For example, **Figure 2-6** shows a storm water holding pond required by local codes. This local code requirement was not applicable following a ruling on permits by the California Public Utility Commission; however, PG&E's engineering group conceded to this method for storm water runoff control.

Fortunately, the methods used for PV site development are similar to those used for other types of facilities. There is no lack of experienced, qualified subcontractors available to support infrastructure development. PVUSA experienced distinct cost advantages through competitive fixed-price subcontracts.



**Figure 2-5**  
PVUSA Kerman, January 1993



**Figure 2-6**  
Kerman Storm Water Holding Pond

### **MINIMUM INFRASTRUCTURE REQUIREMENTS**

The experience gained through the development of the Davis and Kerman sites has provided a basis for recommending a set of minimum site development requirements for a utility PV plant. These requirements are

- A secured area
- All-weather access to vital equipment
- Remote monitoring for an unstaffed facility
- Electrical switchgear, underground electrical, UPS, and protective relays to meet utility interface requirements
- Other utility-specific requirements (signs, control building, telephone, and meters)
- Drainage or flood control consideration

## RECOMMENDATIONS

- Consider site selection a critical cost factor.
- The level of PV plant commercialization must be considered and established before significant design effort is expended. Provisions for R&D activities (e.g., testing and data collection) have a significant impact on infrastructure layout and design.

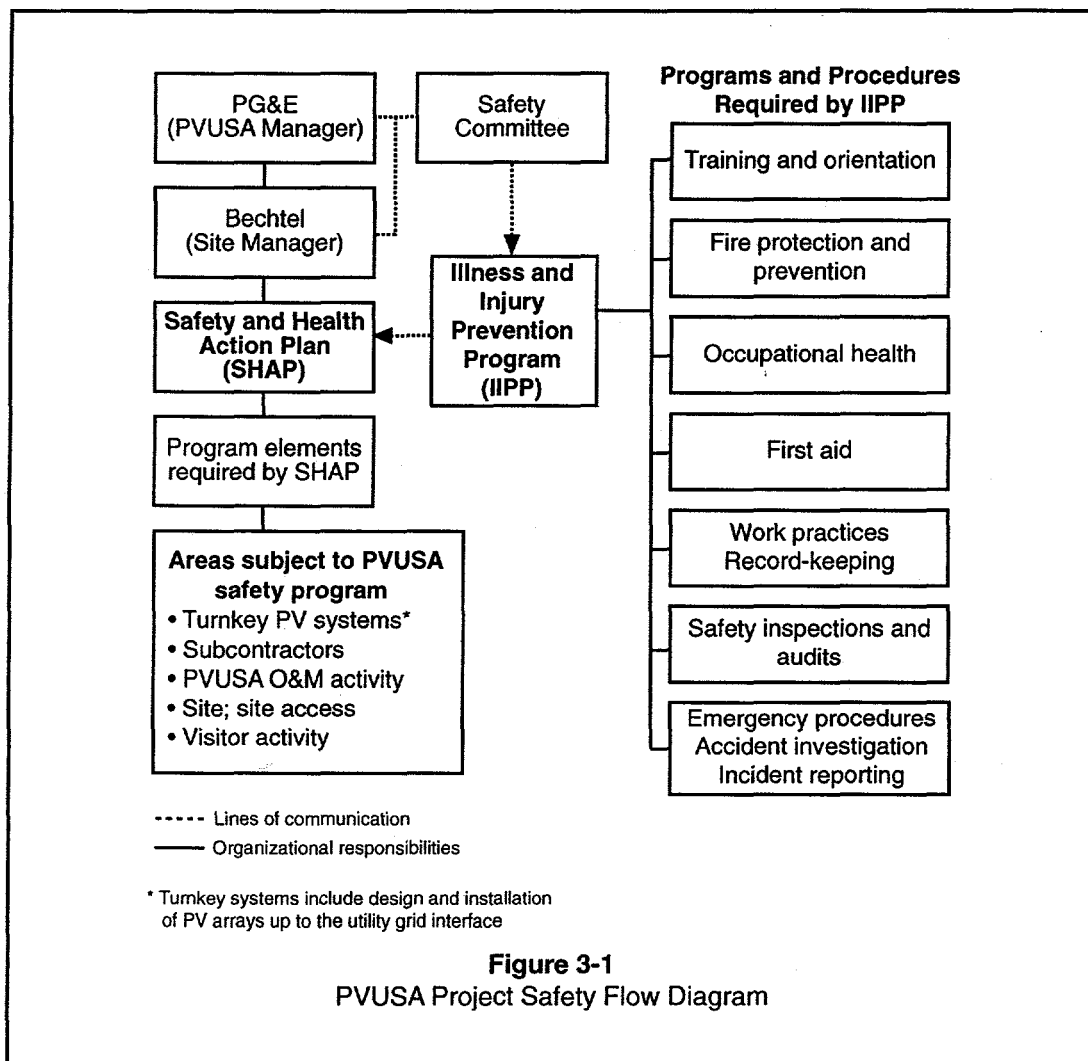
### Section 3

## SAFETY

This section describes PVUSA provisions for safety and their evolution, and discusses the PVUSA safety experience. It also advises on special safety provisions for PV and makes safety recommendations to utilities that are planning to construct, own, and operate a PV system.

### PVUSA SAFETY AND HEALTH ACTION PLAN

The PVUSA safety provisions are detailed in two documents. These provisions are illustrated in the flow diagram **Figure 3-1**. The first document is the Injury and Illness Prevention Program (IIPP) (PG&E/PVUSA, 1993), which is a statutory requirement of the California Occupational Safety and Health Act; the second is the PVUSA Safety and Health Action Plan (SHAP) (PVUSA, 1993).



The IIPP provides guidelines for implementing the SHAP on the PVUSA project. It incorporates provisions for achieving compliance with Cal-OSHA's, Bechtel's, and PG&E's safety requirements. Additionally, the IIPP is designed to create a safe, healthful work environment and to minimize employee accidents and damage to equipment and property.

The purpose of the SHAP is to establish guidelines for implementing and administrating the IIPP and to assign specific responsibilities for carrying out the plan. Additionally, the plan helps management, supervisory, and project personnel recognize, evaluate, and control hazardous activities and/or conditions within their respective areas of responsibility. The plan exceeds the safety requirements established by federal and state codes and provides additional guidelines to reaffirm the employees' basic responsibility for their actions.

### **SAFETY AND HEALTH ACTION PLAN**

#### **Program Elements**

- A. Project safety orientation
  - B. Toolbox safety meetings
  - C. Hazard communication program
  - D. Contractor/subcontractor safety programs
  - E. Confined space entry procedure
  - F. Equipment inspection program
  - G. Safe clearance procedure (tag-out)
  - H. Bomb threat procedure
    - I. Access control and security program
  - J. Supervisor safety and health orientation
  - K. Excavation and trenching program
  - L. Safety barricade procedure
  - M. PVUSA employee safety training
  - N. PG&E-specific procedures
  - O. Site tours and visitors
  
  - P. Ergonomics
  - Q. PV safety considerations
- } Under development

**Figure 3-2**  
PVUSA Safety and Health Action Plan



## **ELEMENTS OF THE PVUSA SAFETY AND HEALTH ACTION PLAN**

The elements contained in the PVUSA SHAP are listed in **Figure 3-2** and detailed below. It should be noted that this list of elements is not necessarily final nor definitive. Effective safety programs are "living" documents that undergo regular review; new elements may be added at any time.

### **A. Project Safety and Health Orientation Program**

This element ensures that sufficient time is allotted for the safety and health orientation of all newly hired or transferred employees. The orientation, though general in nature, is important because it provides employees with basic safety and health training; it also provides an opportunity for the employer to initiate training required by utility and government standards. When effectively conducted, the orientation also helps reduce the potential for accidents and minimizes exposure to future legal liabilities.

### **B. Toolbox Safety Meetings**

This element requires that construction workers attend weekly, 15-minute (maximum) meetings to discuss PVUSA and OSHA safety and health requirements. **Figure 3-3** is a PVUSA form for documenting subcontractor weekly toolbox meetings.

SUBCONTRACTOR PRE-JOB/TOOLBOX  
SAFETY MEETING

Date:	Subcontractor:
Time Began:	Meeting Leader Name (Print):
Time Ended:	Meeting Leader Signature:
Location:	Meeting Leader Social Security #:

Topics discussed and specific safety precautions for this task (attach or identify all documents, handouts or videos provided, viewed and/or discussed).


ATTENDEES

PRINT LAST NAME	SIGNATURE	SOCIAL SECURITY #

**Figure 3-3**  
Form for Prejob/Toolbox Meetings

### **C. Hazard Communication Program**

This element describes the requirements, procedures, training, and information regarding hazardous substances. The hazard communication (HAZCOM) program applies to all utility personnel, contractors, and subcontractors working at PVUSA. It does not relieve contractors and subcontractors of their responsibility to develop and implement effective, written HAZCOM programs.

### **D. Contractor/Subcontractor Safety Programs**

This element describes how each contractor or subcontractor shall prepare and submit for review a written safety and health program that fully describes a commitment to meet safety and health obligations, comply with government injury and illness prevention requirements, and generally contribute to project safety. These safety and health programs shall reference federal/state OSHA standards and any other rules, regulations, or standards applicable to construction activities in the state.

### **E. Confined-Space Entry Procedure**

The purpose of this element is to provide guidance for implementing an effective confined-space entry procedure for all personnel. A confined or enclosed space is any space with a limited means of egress, in which toxic or flammable contaminants may accumulate or which may have an oxygen-deficient atmosphere. Confined or enclosed spaces include caissons, storage tanks, process vessels, bins, boilers, ventilation or exhaust ducts, sewers, underground utility vaults, tunnels, pipelines, and open-top spaces that are more than 4 feet deep (such as pits, tubes, vessel vaults, and sumps).

### **F. Equipment Inspection Program**

This element describes inspection, O&M, and record-keeping requirements for all materials-handling equipment.

### **G. Safe Clearance Procedure (Tagout)**

This element defines specific requirements for providing protection to personnel that work on equipment and systems at PVUSA. It requires administrative control of protective tags and protective clearance for personnel, contractors, and vendors. **Figure 3-4** is a reproduction of a PVUSA switching log.

(1) SWITCHING LOG NUMBER 93-014	
(2) Sheet Number 1	(3) SWITCHING CENTER PVUSA
(4) Date 11/22/93	

(5) Purpose Clear 12KV to allow transformer tap change.

(6) Step No.	Location	Operation	Apparatus Number	Instructions	GIVEN FOR EXECUTION TO KOB		REPORTED EXECUTED BY KOB		TIME RPTD.
					TIME	PERSON	TIME	PERSON	
1	SSI	Stop	Inverter A	Shutdown Inverter A	06:55	KOB	6:55	KOB	8:30
2	SSI	Stop	Inverter B	Shutdown Inverter B	06:55	KOB	6:55	KOB	8:30
3	APS	Stop	Inverters	Shutdown Inverters 1, 2, 3, 4	06:59	KOB	6:59	KOB	8:30
4	IPC	Stop	Inverter	Shutdown inverter	06:59	KOB	6:59	KOB	8:30
5	I & C	Open	12489	OPEN SWITCH, LOCK, TAG MOL	07:01	KOB	7:01	KOB	8:30
6	SSI	Open	89-111	OPEN SWITCH, LOCK, TAG MOL	07:30	KOB	7:30	KOB	8:30
7	SSI	Open	TR-112	OPEN Fuse Door TAG MOL	07:30	KOB	7:30	KOB	8:30
8	SSI	Open	PT-111	Pull fuses, TAG MOL	07:35	KOB	7:35	KOB	8:30
9	SSI	Open	52-111	OPEN SWITCH, LOCK, TAG MOL	07:35	KOB	7:35	KOB	8:30
10	SSI	Open	52-112	OPEN SWITCH, LOCK, TAG MOL	07:35	KOB	7:35	KOB	8:30
11	SSI	Verify	TR-112 III	Verify that transformer has zero voltage.	07:40	KOB	7:40	KOB	8:30
12	SSI		TR-112 III	Change transformer taps.	07:50	KOB	7:50	KOB	8:30
13	SSI	Close	52-111	Remove tag and lock, close breaker.	07:51	KOB	7:51	KOB	8:30
14	SSI	Close	52-112	Remove tag and lock, close breaker.	07:52	KOB	7:52	KOB	8:30
15	SSI	Close	TR-112	Remove tag, close Fuse Door	07:53	KOB	7:53	KOB	8:30
16	SSI	Close	PT-111	Remove tag, install fuses	07:54	KOB	7:54	KOB	8:30
17	SSI	Close	89-111	Remove tag and lock, Close switch	07:55	KOB	7:55	KOB	8:30
18	I & C	Close	12489	Remove tag and lock, Close switch	08:05	KOB	8:05	KOB	8:30
19	SSI	Start	Inverter A	Start up Inverter A	08:14	KOB	8:14	KOB	8:30
20	SSI	Start	Inverter B	Start up Inverter B	08:15	KOB	8:15	KOB	8:30
21	APS	Start	Inverters	Start up Inverters 1, 2, 3, 4	08:10	KOB	8:10	KOB	8:30
22	IPC	Start	Inverter	Start up inverter	08:12	KOB	8:12	KOB	8:30

SWITCHING PREPARED BY

*[Signature]* DATE 11/22/93

SWITCHING CHECKED BY:

*[Signature]*

SWITCHING *KOB* DATE 11/23/93

DATE 11/27/91 DIRECTED BY: DATE

Figure 3-4  
PVUSA Switching Log

#### **H. Bomb Threat Procedure**

This element defines the course of action to be taken in the event that a bomb threat is received at a PVUSA facility.

#### **I. Access Control and Security Program**

This element describes a program for establishing access control and security requirements for project personnel, material, and equipment, incidental to the execution of the scope of work by the utility and its contractors and subcontractors.

#### **J. Supervisor Safety and Health Orientation**

This element describes the mandatory orientation given to utility personnel before their employment as supervisors on a PV installation.

#### **K. Excavation and Trenching Program**

This element establishes minimum requirements for project work involving excavations and trenches.

#### **L. Safety Barricade Procedure**

This element outlines procedures for controlling the use of barricade tape at PVUSA work sites.

#### **M. Employee Safety Training**

The purpose of this element is to provide a personalized safety training program for each employee aligned to his or her job description and level of responsibility. **Figure 3-5** shows a typical training record.

#### **N. PG&E-Specific Procedures**

This element defines existing PG&E procedures (e.g., clearances) that must be followed.

#### **O. Site Tours and Visitors**

This element describes a program designed to preserve the health and safety of the approximately 600 persons who visit PVUSA each year.

PVUSA SITE MANAGER SAFETY TRAINING SCHEDULE 1994

ACTIVITY	FREQ	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PVUSA clearance procedure refresher	annual												
Red Cross first aid training	maintain a.c.*												
Red Cross CPR training	annual								X				
Fire extinguisher training	annual											X	
Review CA Code of Regulations	8 hrs/yr.												
Offsite safety seminar	1/yr.												
PV specific safety training	4 hrs/yr.												
National Elec. code review	4 hrs/yr.												
Fed. code of regulations review	2 hrs/yr.												
PVUSA one-line diagram and electrical symbol review	4 hrs/yr.												
Emergency response training	4 hrs/yr.												
Hazardous material training	2 hrs/yr.												
Staff safety meetings	1 ea./mo.												
a.c. = active card													

INSTRUCTIONS: Please indicate the amount of time spent or the completion of the activity by initials in the appropriate column.

**Figure 3-5**  
Sample Safety Training Record

## DAVIS SITE EXPERIENCE

Since the project's inception in 1987, PVUSA has had a safety program that complied with all legal requirements and was in accordance with PG&E and Bechtel safety standards. The program included a requirement that all PVUSA subcontractors have safety programs and safety representatives to control their construction activities.

Since 1987, the Davis site has expended 95,000 man-hours, 50,000 of which were associated with construction, including the installation of approximately 1 MW of PV. Construction projects can be evaluated for safety performance in terms of lost-time accidents (LTA). The formula used to calculate LTAs is

$$\text{LTA ratio} = \frac{\text{Number of LTA cases} \times 200,000}{\text{Man - hours worked}} \quad (3-1)$$

With just one subcontractor-reportable LTA in more than 6 years, the LTA ratio for the Davis site is 2.11. The Bureau of Labor Standards has established an average LTA ratio of 6.0 for similar work. However, caution should be used in applying an LTA ratio to projects with labor hours significantly below 200,000, since a small number of accidents can distort the safety picture.

On August 7, 1991, a field superintendent employed by a Bechtel subcontractor sustained an electrical shock while performing electrical testing. This individual spent one night in a hospital for observation and was released the following day.

Immediately following the electrical shock incident, PG&E asked DOE, the project's major cofunder, for an independent evaluation of PVUSA's safety program. In December 1991, a team of safety specialists headed by the Biomedical and Environmental Assessment Group of Brookhaven National Laboratory (BNL) performed a site audit to evaluate PVUSA's safety program and recommend improvements to avoid a repeat of the incident. The results of this investigation, which were summarized in a formal report to PG&E, included five recommendations to reduce the possibility of future accidents. These recommendations are excerpted below.

### **BNL Recommendations**

Based on the review of the facts established in this investigation, the following recommendations are offered to reduce the possibility of future accidents at the PVUSA site. The funding agencies should require the prime contractor to

1. Establish a single entity to define, communicate, audit, and enforce safety rules and regulations at the site. We recommend that this authority be vested with PG&E because they are the prime contractor for this project. Because virtually all the work at the PVUSA site is conducted by contractors, special attention should focus on contractor safety programs and implementation.
2. Establish written rules and guidelines for safety programs. This should include, but not be limited to, electrical safety and "hot" work, general safety, emergency response, training, personal protective equipment, orientation for new employees, and operational readiness reviews.
3. Require review of the structural and electrical configuration of Bluepoint Associates inverter (and other new equipment) prior to purchase and installation to ensure that there are no inherent design defects producing increased risk of electrical shock.
4. Support PG&E and Bechtel efforts started after the accident to improve operational safety at the PVUSA site through funding and direct participation in development of safety procedures.
5. Request PG&E to develop and document safety policies and procedures that could be used at other utility photovoltaic sites.

Additionally, Bechtel's Safety Department conducted an extensive review of the incident and proposed recommendations for site safety improvements. PVUSA formed a safety committee, instituted the IIPP and SHAP, and implemented all BNL recommendations.

### **PVUSA ACTIONS IN RESPONSE TO BNL RECOMMENDATIONS**

Following is a summary of actions taken and documented in the IIPP and SHAP.

#### **Administration**

Section 1 of the SHAP defines the site manager as responsible for administering the plan with a direct and immediate reporting responsibility to the PG&E project manager. Duties and responsibilities for safety actions are clearly defined.

The PG&E and Bechtel project managers and Bechtel regional safety manager meet quarterly with the site manager in Davis to review and provide direction for the safety program. PG&E senior safety representatives participate on an as-needed basis. Site staff safety meetings are held and documented monthly.



Construction contractors are required to attend weekly safety meetings (toolbox meetings) to discuss safety aspects of the coming week's activities.

## **Training**

The adequacy of all safety training was reviewed, and the following measures were implemented:

- Site operations and clerical personnel have individualized training programs geared to their work assignments. These programs require 40 to 80 hours of training per year for each person.
- Emergency response training is mandatory for all site personnel and is included in their individualized programs. This training covers first aid, CPR, and fire prevention/fighting. Off-site personnel who may assume site responsibilities during vacations or at other times also receive emergency response training.
- As part of their 40 to 80 hours of scheduled training, site personnel also may attend 2-day safety seminars on OSHA electrical safety requirements or other industry programs.
- PVUSA has instituted a rotational "red hat" (safety supervisor) program for construction work in progress. This program broadens awareness of safety issues among all personnel and provides additional safety inspection of subcontractors.
- PVUSA has implemented training in applying the latest site procedures for ac grounding, circuit switching, and OSHA requirements.

## **Procedures**

The following procedures have been implemented or modified:

- To improve clearance and tagging procedures, the site electrical single-line diagram has been posted in a conspicuous location, and the site (circuit) clearance procedures have been upgraded. Clearance points are identified and flagged on the single-line diagram.
- Two-person teams ("buddy" system) are required while performing field work on all energized equipment.
- Site procedures for operating the scissor lift and for controlling hazardous materials have been established.
- The availability and readiness of all safety materials (e.g., first aid kits, rubber gloves, hot sticks, fire blankets and extinguishers, and safety goggles) are documented in safety logs.
- Procedures for conducting visitor tours have been refined. These procedures include initial safety instruction and surveillance during the tour. Visitors are restricted to a defined tour path that limits their exposure to hazards.
- A maintenance control log has been established for major items of construction equipment at Davis.

## **Equipment**

PVUSA has supplied the following safety equipment for job site use:

- A pair of 1000-V protective gloves has been issued to all site personnel.
- A portable cellular telephone (for emergency communication) is carried while performing field work on all energized equipment.
- Field safety boxes have been furnished at three strategic locations. These boxes contain safety goggles, a fire extinguisher and fire blanket, a first aid kit, an insulated cane (hook stick), and large and small cable cutters. The boxes have an audible alarm that can be activated in the event of a field emergency.
- Supplementary fire extinguishers have been installed in the I&C building, site trucks, and field safety boxes.
- Two flammable storage containers have been installed on site.
- Personnel grounding equipment (including cables, hot sticks, high-voltage testers, and protective suits) are furnished for personnel protection when clearing medium-voltage equipment.

## **PVUSA Technical Specifications and Supplier Prototype Equipment**

Since PVUSA is research-oriented, equipment that is less than fully commercially developed is accepted from suppliers. The safety aspects of new equipment are reviewed by independent safety consultants; an example is the Bluepoint (Dickerson) inverter furnished for the SSI 174-kW ac US-1 system at Davis. It should be noted that no national standards have been issued for inverters or PCUs; Appendix A lists documents under development and gives contacts for the latest information.

## **KERMAN SITE EXPERIENCE**

The turnkey, 500-kW PV installation at Kerman more closely resembles a traditional construction project. The Kerman project had a set duration, utilized proven and tested equipment and standard commodities, and had a comprehensive construction plan. There were 11,200 man-hours of on-site labor expended during construction and start-up; of this total, approximately 7000 man-hours were attributed to craft labor. Kerman has had no LTAs.

To further improve safety at the Kerman site, PG&E and Bechtel performed a safety audit and made recommendations for improvement. Additional warning signs, an eyewash station, and a storage locker for flammable material were among a few of the recommended improvements that were made.

## **RECOMMENDATIONS FOR UTILITY-OWNED PV SYSTEMS**

PVUSA Davis is a continuously staffed PV test and research facility. Therefore, the Davis safety program has a broader scope than would be required at an unattended utility PV installation. Nevertheless, the safety lessons learned at PVUSA apply to all PV systems, and the following considerations and recommendations apply to all PV construction and maintenance activities.

### **Special PV Safety Considerations**

PV arrays are unique in that potentially lethal dc voltages (up to several hundred volts pole-to-pole) are generated when light falls on the modules. While the generating source cannot be shut down, the systems can be short-circuited. Individual modules or panels are sometimes covered to test bypass diodes, but PV arrays are not installed with covers. For this reason, attention must be paid in designing the system grounding and in specifying requirements for module qualification, field testing, and O&M procedures.

The PV industry is still in the developmental stage. Industry standards for module qualification, PV system testing, and the design and manufacturing of PCUs continue to have an interim status. In the absence of UL or similar labels on components, PV installations intended to comply with the National Electric Code (NFPA 70) face difficulty in meeting the requirements set out in NEC Section 90-6 ("Examination of Equipment for Safety"). However, utilities may claim exemption to the NEC under NEC Section 90-2 (b) (5).

### **Recommendations**

The following recommendations pertain to the safe design, installation, operation, and maintenance of utility-owned, grid-support PV systems. Utilities should

- Establish a design basis early, and address compliance with utility standards, the NEC, and national safety standards (see Appendix A for industry standards under development).
- Specify PV modules to be certified as meeting the requirements of the latest industry standard released for use. Current interim standards are SERI/TR-213-3624 (SERI/NREL, January 1990) for flat plates or SAND 9-0958.UC-272 (Sandia National Laboratory, June 1992) for concentrators.
- Specify all equipment to meet the requirements of NEC Section 90-6 (in terms of labeling and/or safety certification) or subject the equipment to an independent design safety review.
- Require that suppliers of turnkey PV systems specify the installations to conform to the NEC, including module labeling and grounding. Exceptions should be defined in the design basis document.
- Require suppliers of turnkey PV systems to furnish a safety program in compliance with OSHA requirements and to provide a qualified safety representative.

- Establish field-testing procedures for accepting completed turnkey PV systems, including a requirement that systems pass a field wet resistance test.
- Establish a safety program for installing, operating, and maintaining PV systems. The program should include all applicable elements depicted in **Figure 3-2**. Utility clearance procedures may be used to support or replace Program Element G.
- Apply drawing control procedures to maintain and update single-line electrical drawings and vendor drawings used in conjunction with the clearance procedure (tagout).
- Initiate the training elements of the safety program early in the construction phase and involve utility O&M personnel in the construction activity.

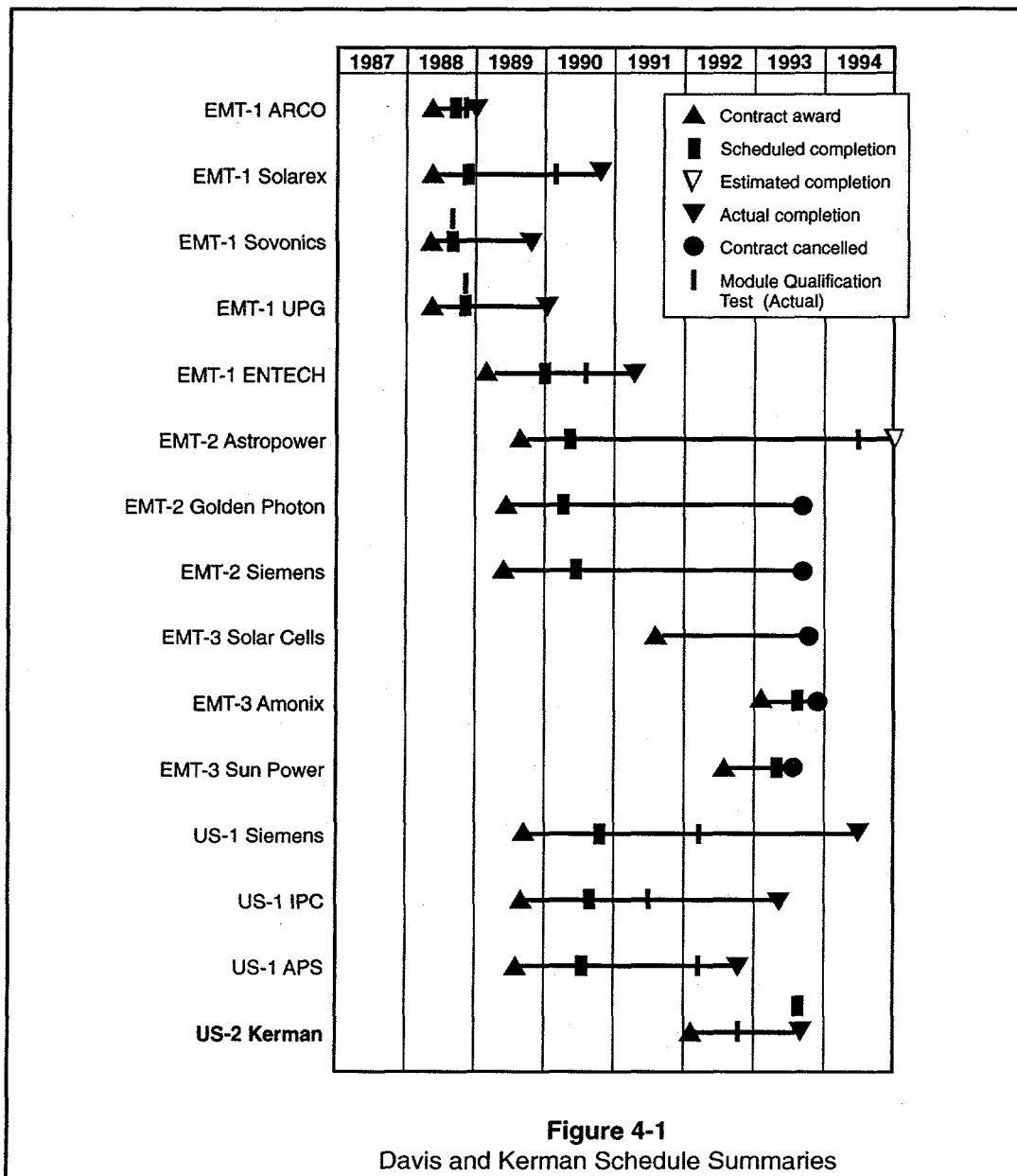
## Section 4

### PLANNING AND SCHEDULING

This section reviews PVUSA scheduling activity, identifies milestones and schedule drivers for PV installations, presents a typical PV installation schedule, and makes recommendations relative to planning and scheduling.

#### DAVIS EMT AND US-1 PV SYSTEM SCHEDULE PERFORMANCE

Figure 4-1 summarizes the Davis and Kerman construction schedules.



Davis PV system suppliers experienced difficulty in meeting their proposed contract schedules. Most EMT suppliers were unable to qualify their modules within the time allocated in the subcontracts. It is noteworthy that PVUSA did not emphasize PV supplier schedules when awarding and administering the EMT contracts because the EMTs were assumed to have the "growing pains" associated with emerging technologies. However, PVUSA anticipated that the later procurement of the US-1 systems would demonstrate noticeable improvements in schedule compliance.

One objective of the US-1 procurement effort was to demonstrate that PV suppliers could produce and install utility-grade, turnkey systems on a firm schedule. The PV components specified for the US-1 systems were believed to be "off-the-shelf"; however, in reality some components were the initial design or first-generation commercial products. Schedule delays associated with manufacturing, finance, planning deliveries, and start-up evidenced that the PV industry had not yet fully matured for the utility market.

Although construction of the US-1 systems at Davis was a scheduling disappointment, it did provide some valuable lessons to PVUSA and PV suppliers. These lessons are related to the quality problems described in Section 8 of this report. The subsequent PVUSA development at Kerman demonstrated improved planning and scheduling and on-time delivery for a PV system.

#### **KERMAN US-2 PV SYSTEM SCHEDULE PERFORMANCE**

The schedule performance of the Kerman US-2 construction can be used as a baseline for measuring the construction performance of future grid-support PV plants. The installation and start-up of a 500-kW grid-support PV system on schedule in 9 months was a significant improvement over the US-1 systems. A combination of factors contributed to this achievement, including

- A comprehensive plan and use of a Critical Path Method (CPM) schedule
- Selection of commercially proven components
- Improvements in manufacturing and delivery
- Monetary schedule incentives and liquidated damages
- Understanding of utility requirements
- Clearer design and performance expectations
- Use of substation design standards and practices
- Use of constructability reviews

- Previous experience at the Davis site
- More nuts-and-bolts descriptions of requirements in specification
- Allowance (60 days) for start-up delays in schedule

## MAJOR ACTIVITIES

Although the focus of this report is construction activities, schedule success depends on integrating engineering, procurement, and construction activities to form a total project schedule. Construction of a PV plant involves a multitude of activities related to field or site work; however, to form a comprehensive plan site-related activities need to be incorporated with off-site activities. The following is a list of major activities for deploying a PV plant from start to finish:

- Select site
- Obtain permit
- Perform geotechnical study
- Issue request for proposal (RFP) to PV supplier
- Select and award PV turnkey system contract
- Review and accept PV system drawings
- Perform civil and structural design/engineering for site infrastructure
- Perform electrical design and engineering for site infrastructure
- Procure necessary components and materials
- Prepare site and construct site infrastructure
- Construct PV turnkey system
- Conduct field acceptance testing
- Conduct preparallel testing
- Complete start-up testing
- Complete performance testing

These major activities are generally grouped into three classifications: engineering, design, and drafting; procurement; and construction. Activities within each classification can be broken down as follows:

### **Engineering, Design, and Drafting Activities (Site Infrastructure)**

- Civil/structural engineering
- Civil/structural drawings
- Electrical engineering
- Electrical drawings
- SCADA design
- Telecommunications design

### **Procurement Activities**

- PV turnkey contract administration
- Material requisitions preparation
- Miscellaneous purchase orders and subcontract administration

### **Construction Activities**

- Constructability reviews
- Site development
  - earthwork
  - roads
  - fences
  - buildings
  - electrical equipment (BOS)
  - electrical raceways and wiring (BOS)
  - well and septic system
- PV turnkey system
  - foundation installation
  - structures installation
  - PV array installation
  - electrical raceways and wiring
  - PCU substation



- Start-up
- Acceptance testing

## **CONSTRUCTABILITY REVIEWS**

Constructability reviews involve people sharing their construction knowledge. These reviews inject construction experience into the entire engineering, procurement, and construction process. This process involves team members agreeing on project strategy, looking for innovative work methods, reviewing drawings, attempting to eliminate activities that do not add value to the project, and trying to anticipate and resolve problems that could affect construction. Open communication between project management and engineering, procurement, and construction staff is essential.

The constructability review process guided early project decisions and has been a major tool in meeting project goals. PVUSA's site construction team performed constructability reviews of all drawings submitted for comments, utilizing similar construction experiences to flag items of concern. This process often streamlined subcontractors' tasks.

## **SITE DEVELOPMENT**

Engineering and procurement will be addressed in other PVUSA topical reports. Common construction activities required to develop infrastructure for the Davis and Kerman sites included

- Earthwork: grubbing, grading, establishing drainage
- Roads: compaction, road base, fine grading, testing
- Fences: install chain link gates, fence, and fence grounding
- Well installation: drilling, grouting, casing, pressure tank, etc.
- Septic system: tanks, leach lines, piping, distribution box
- Metal buildings: Davis office (I&C building) and Kerman control building
- Electrical: equipment installation, switchgear, conduits, direct burial, cable pulling, manholes, duct runs, terminations, etc.

These tasks are associated with any power plant development and are not unique to PV plants. Thus, a traditional approach to many of these construction activities has been developed and refined for efficient installation. The best methods for a particular site are often dictated by experience combined with design requirements. A well thought-out design that includes a constructability review is a basis for a successful field installation.

PVUSA project management applied its earlier experience in site development to prepare a critical path schedule for use with subcontractors that integrated engineering and procurement deliverables into the overall construction plan. There was a large pool of qualified local subcontractors to draw from for the necessary civil, electrical, and underground work associated with site preparation. The process of planning and scheduling the construction efforts was preceded by management planning that addressed

- Schedule drivers (objectives, permit process, PV supplier capability, PV supplier funding constraints, equipment lead-times and resources)
- Safety
- Quality control
- Construction and environmental permitting
- Temporary facilities, utilities, and services
- Medical facilities and emergency response
- Fire protection
- Environmental awareness and control
- Labor management
- Parking
- Constructability and site access

## **RECOMMENDATIONS**

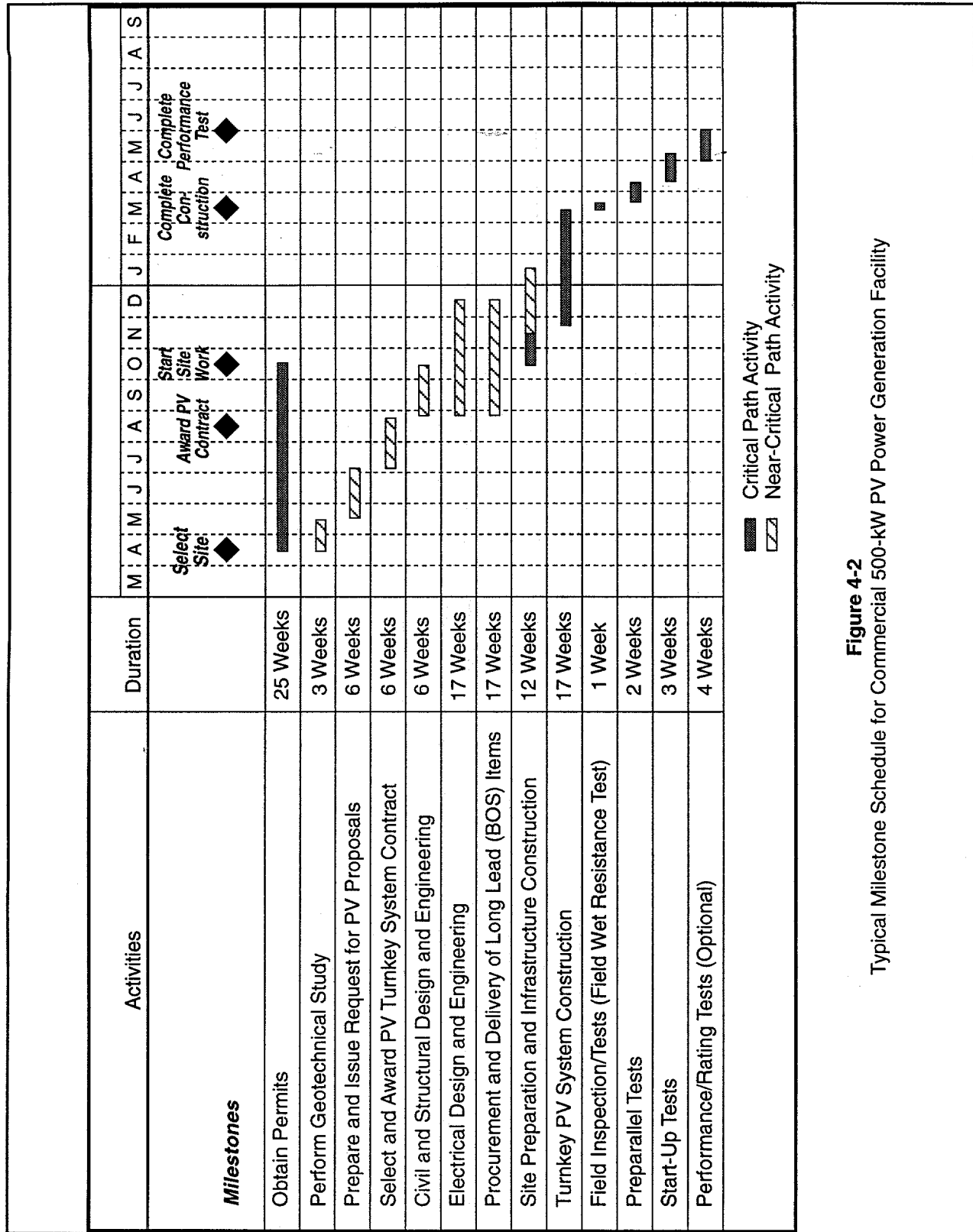
PVUSA believes schedule improvements can be realized in the following areas:

- Earlier identification of permitting requirements
- More timely issue of construction drawings
- Earlier purchasing of long lead-time items (for example, typical lead time for a PCU is 24-32 weeks; for switchgear, 16-24 weeks; and for modules, 4-32 weeks)
- Constructability reviews of PV drawings and utility BOS drawings
- Closer technology reviews of "standard" drawings to determine if materials specified are still being manufactured or used
- Use of field-proven components
- Use of CPM schedule for PV supplier and utility or owner activities
- Assignment of a project coordinator to be responsible for scheduling all activities, especially physical interfaces, and for updating and reviewing the schedule weekly

- Availability of packaged, replicable systems in mass production
- Pretesting of components when practical and reviews of previous start-up experience to anticipate problems and shorten start-up schedule

The 9-month Kerman construction period included more than 3 months of start-up time associated with various inverter problems. The start-up period ideally could have been reduced to 3 or 4 weeks, thus reducing the overall construction time by 2 months. A 7-month construction target is attainable and would make US systems more viable for the utility industry. **Figure 4-2** is a typical overall schedule for a commercial 500-kW PV power generation facility.

A benefit of PV is modular construction. For example, twice as many PV modules could be installed in the same time by doubling the installation work force. A PV plant such as Kerman could be doubled in size and still be installed on about the same schedule. In today's marketplace the delivery of PV components, i.e., modules and inverters, would likely control the schedule.



**Figure 4-2**  
Typical Milestone Schedule for Commercial 500-kW PV Power Generation Facility

## Section 5

### LABOR

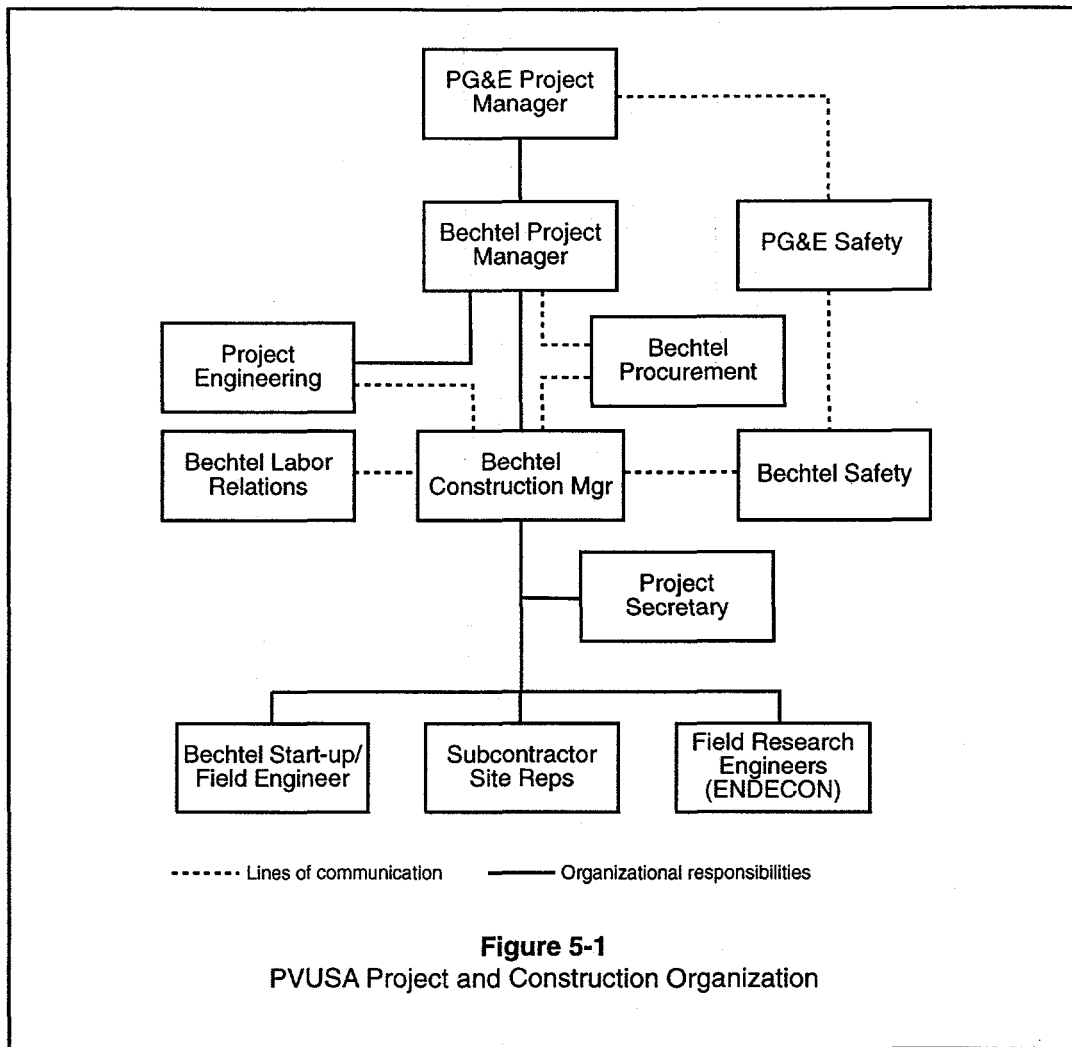
This section provides historical information regarding the use of construction labor at PVUSA and offers utilities some specific considerations for labor. Additionally, it provides insight into the need for specialized labor and extrapolates from PVUSA experience to make recommendations and present a typical labor breakdown.

#### NONMANUAL LABOR

PVUSA Davis employs more nonmanual staff than normally would be required for a typical utility PV installation. PVUSA site nonmanual staff are employed by either Bechtel Construction or ENDECON Engineering and receive project direction from PG&E. The PVUSA staff was expanded in April 1989 from three to four positions to support increased data analysis and O&M activities. The four positions are site construction manager, site secretary, and two research engineers. Because the research engineer position was held by three individuals between 1988 and 1990, on occasion there were five employees at the site during the transition from the previous engineer to the next one.

Each of these positions is required to fulfill the project's objectives. The activities associated with data accumulation, analysis, and PV system development are the most labor-intensive. In 1992, with the onset of Kerman construction and completion of additional Davis PV systems, it became necessary to assign an electrical field/start-up engineer to assist with start-up and O&M.

All PVUSA site staff are involved in the safety program. However, construction activity is coordinated by the site manager and electrical field engineer. Staffing requirements at PVUSA have been adjusted periodically to maintain the increased workload associated with additional PV development. The current PVUSA project and construction organization are depicted in **Figure 5-1**.



## MANUAL LABOR

Utilities have several options for assembling manual labor teams for PV system construction. PVUSA's experience is limited to union craft labor because Bechtel Construction Company is a union contractor. Some utility-specific considerations that may influence labor selection include the following:

- Does the utility have an internal construction organization with experience relevant to PV system construction?
- Does the utility prefer to use in-house resources to prepare a request for proposals and evaluate competitive fixed-price bids for the installation?
- Should the utility manage the work, hire craft labor directly, and independently procure the PV system components? If so, does the utility have a contractor's license to perform general building construction in the state?

- Should the utility hire a company with PV experience to provide engineering, procurement, and construction management services? Experience with recent installations indicates that good overall performance has been achieved by both small PV system designer/integrator companies and larger A&E firms.

In the case of PVUSA's Davis and Kerman installations, all Bechtel-hired subcontractors were affiliated with the Building and Construction Trades Department of the AFL-CIO. A memorandum of understanding (MOU) was established with the trade unions before the start of construction. The purpose of the MOU was to provide a process for resolving jurisdictional disputes and grievances arising out of the interpretation and use of the MOU agreement by project contractors and subcontractors. Compliance with the terms of the MOU was a prerequisite for subcontractors performing work at the Davis and Kerman sites. As a result of this agreement, no work stoppages were experienced at the job sites. The MOU provided consistent resolution procedures for minor jurisdictional disputes that resulted from craft assignments. Use of an MOU is commonplace in the construction industry; as an added value the signing of the MOU agreement brings both the contractor and trade unions into an open discussion before construction starts.

PV system development is relatively new to the trade unions, and jurisdictional assignments are continually challenged. The Carrisa Plains project established minor precedence for PV construction craft assignments; however, some current assignments do not follow previous logical experiences. This situation has created some challenges at PVUSA, especially in the area of craft assignments for steel erection and electrical interconnections. The Davis site crafts were from the Sacramento union locals, and the Kerman crafts were from the Fresno locals. The majority of the crafts were electricians; however, other crafts were represented, including

- Sheet metal workers
- Ironworkers
- Laborers
- Carpenters
- Operating engineers
- Teamsters
- Cement masons
- Pipe fitters

Using qualified craftsmen who have received training for the tasks they perform enhances craft productivity and quality.

All the crafts worked directly for subcontractors who were managed by Bechtel Construction. Payroll and daily craft supervision were the responsibility of the subcontractor. Additionally, Bechtel hired and coordinated specialty subcontractors required to start up and maintain the facilities.

### **SPECIALIZED SUBCONTRACTORS**

PVUSA PV subcontractors received assistance from second tier subcontractors to resolve system start-up problems. These subcontractors specialized in component manufacturing, field services, PCUs, transformers, tracker controllers, and wire rope tensioning. All specialty subcontractors were obligated to comply with the site safety plan and job site work rules.

Later, PVUSA identified a need to subcontract for specialty work to maintain the facility. The work performed by these specialized subcontractors includes

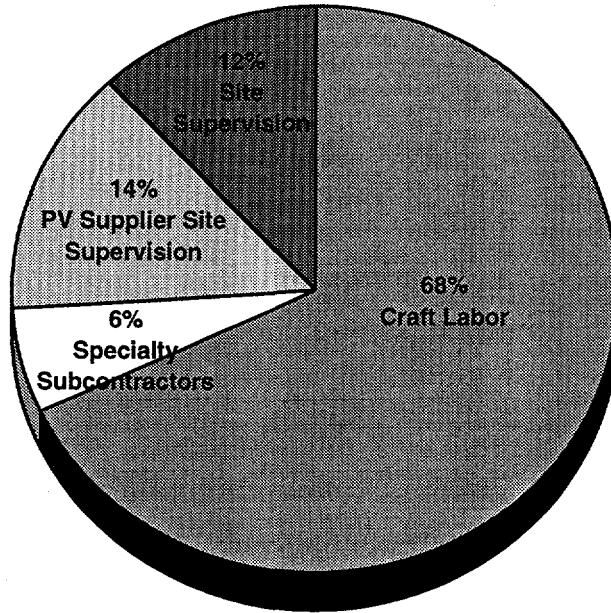
- Providing technical electronic field services
- Performing cable splicing
- Repairing the 12-kV fault interrupter
- Calibrating field instruments and test equipment
- Calibrating meteorological instruments
- Repairing test equipment
- Manufacturing and installing signs
- Calibrating and testing protective relays and performing preparallel inspections

These specialized subcontractors were often nonunion employees and were not required to comply with the provisions of the MOU. This provision was clearly outlined with the building and trade unions and produced no disputes in conducting work. Normally, these specialized trades receive greater compensation than the crafts affiliated with the local unions.



### TYPICAL LABOR HOURS BREAKDOWN

PVUSA construction experiences at Davis and Kerman have provided the information necessary to predict a typical labor breakdown for a utility-scale PV installation. **Figure 5-2** indicates the probable breakdown of labor hours for the installation of a 500-kW nonresearch PV facility. The actual costs associated with on-site labor will vary considerably by locale, depending on local labor rates.



**Figure 5-2**  
Estimated Breakdown of Labor Hours for Installing a 500-kW PV Facility

### RECOMMENDATIONS

- Develop a project memorandum of understanding for union job sites to provide a means for resolving jurisdictional disputes.
- Identify and budget for specialized subcontractors with skills in the PV area and data acquisition/solar instrumentation.

## Section 6

### **CONTRACT ADMINISTRATION AND CONTRACTOR PERFORMANCE**

This section outlines PVUSA procedures for administering subcontracts, vendor engineering submittals, and field changes. It also discusses the monitoring of PVUSA subcontractor performance and presents some case histories. Recommendations are made in each area.

#### **SUBCONTRACT ADMINISTRATION**

PV supplier subcontracts were administered by Bechtel site and San Francisco regional office personnel. Management of PVUSA subcontracts was a team effort, and the division of responsibility was shared for the duration of the subcontract, from subcontract formation to the final task, warranty repairs. Day-to-day subcontract activities were monitored and documented by site personnel. PVUSA construction management utilized conformed subcontracts to establish clear definition of the subcontractors' responsibilities and insisted upon compliance. Inspections were performed by site personnel and were normally less intensive than that required for other power plant installations.

#### **FIELD DRAWING CONTROL**

The drawings and technical specifications were the central and principal controlling elements of the contract. Control of the drawings was essential for ensuring that only the current approved revision of the drawing was used and that the design intent was satisfied. Receiving, logging, filing, and updating drawings, though menial tasks, are imperative for overall project success.

The PVUSA drawing control procedure has five steps:

1. Receipt of drawings from the San Francisco regional office via logged transmittals.
2. Review of new drawings by the site manager and placement of the drawings on stick files.
3. Filing of old drawings (outdated revisions).
4. Regular audit of vendor drawings against the Supplier Design Document Register (SDDR) provided by the San Francisco regional office.
5. Issuance of "released for construction" drawings to the subcontractors along with a drawing transmittal.

This process assured site personnel that they were always working from and inspecting to the latest drawing revisions.

## **DOCUMENTATION**

PVUSA project documentation creates an accessible history of the project that serves two roles; it helps with planning and managing the project, and with resolving claims and disputes.

The documentation is organized and maintained to support project management and prosecution or defense of claims. The following information is routinely maintained and organized in uniform files for each subcontract:

- Contract, change orders, amendments, and original bid documents (plans and specifications)
- All documents, worksheets, and forms associated with the original bid estimate and subsequent revisions
- Subcontractor or vendor files, including bids, subcontracts, purchase orders, together with changes and correspondence
- Project schedules, including the original schedule and all updates
- Insurance requirements and safety plan

Additionally, PVUSA maintains a photograph file showing the historical progress of each PV subcontractor. Construction progress photos are necessary to provide visual documentation in the case of any claims that might arise out of the subcontractor's performance of the work. PVUSA also made construction videos, although this activity was primarily for research.

## **FIELD CHANGES**

Field changes are inevitable simply because they have numerous sources. A few of the most common sources are drafting, design, or specification errors; "constructability" problems; unanticipated field conditions; redesign during construction; poor scope definition; schedule acceleration; and vendor manufacturing and installation errors. Whatever the cause of a change, it is virtually certain the change will have an adverse impact on work's progress.

Fortunately, PVUSA's field changes have been minimal compared with standard power plant construction, partially due to careful review of subcontractor drawings, but more important, because of the routine nature of PV installations. Through the construction of eight PV systems at Davis, there have been no significant monetary change orders granted to a subcontractor. Davis changes represent less than 0.005 percent of the total subcontract values.

The subcontractor for the Kerman electrical infrastructure, however, was granted 10 change orders for a total of \$50,801 over the original fixed-price contract. Of this amount, \$25,000 was anticipated

because the electrical subcontractor was used for the sake of convenience to install concrete foundations, additional spare conduits, SCADA interface equipment and conduits, and meter and relay panels, and to provide start-up assistance. This resulted in a \$25,801 overrun, or 26 percent over the original contract value of \$98,978.

Field changes will invariably increase the overall cost of a utility PV installation. PVUSA experience has indicated that a contingency of 2 percent should be adequate for budgeting the PV installation contract, and 10 percent should be added to the infrastructure subcontract amounts. These contingency amounts should provide a comfortable margin for the project budget. Utilities can further reduce the contingency budget by researching the track records of potential subcontractors before awarding the contracts.

### **SUBCONTRACTOR PERFORMANCE**

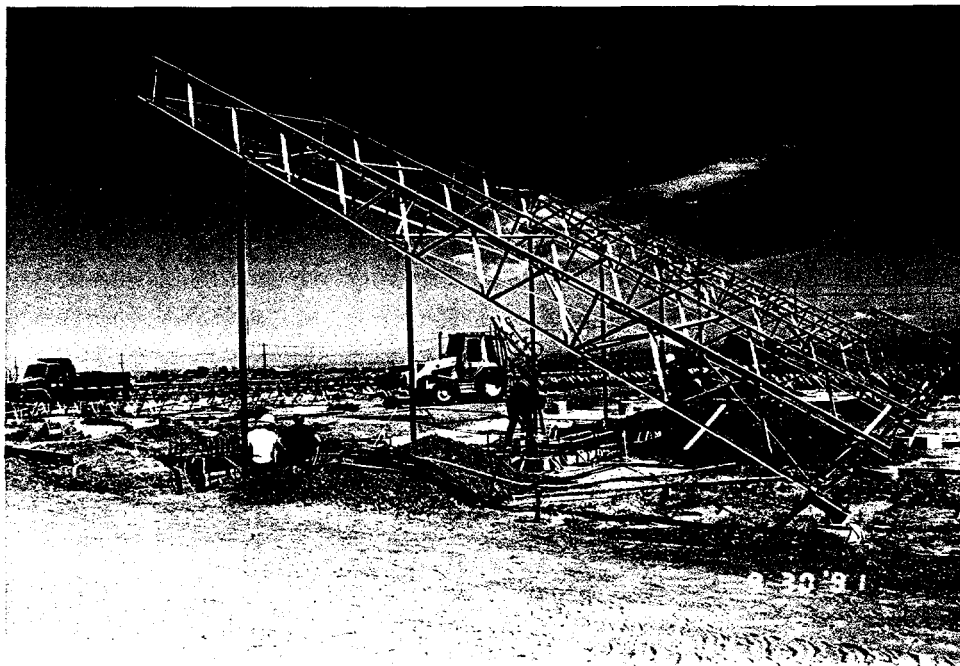
Subcontractor performance is measured by adherence to contract requirements, adherence to schedule, level of quality, and cost efficiency. The most important factor is the schedule, as it sets the stage for the latter two. Because two of the PVUSA Davis US system subcontractors failed to properly plan work during the installation phase, schedules suffered and cost overruns occurred for both suppliers with minimal impact on PVUSA costs. It should be noted that while many of the overall schedule delays were due to problems associated with start-up, material deliveries during installation impacted two of the Davis US system subcontractors. Inexperienced PV subcontractors found that high-quality installation was not synonymous with low-bid work. PVUSA construction management personnel quickly recognized that daily and nearly continuous inspections were required to attain a quality product. Also, an increased effort was needed to document PV subcontractors' daily work efforts and project planning deficiencies.

The significant schedule overruns for the PV systems at Davis resulted from overly optimistic planning, failure of manufacturers to deliver on time, reworking of components, financial failures, and PV installers' inexperience. The lack of PV-specific field experience became apparent as PV subcontract field supervisors attempted to execute the daily work plans. Fortunately, the PV installation was relatively simple, and construction on all systems was eventually completed.

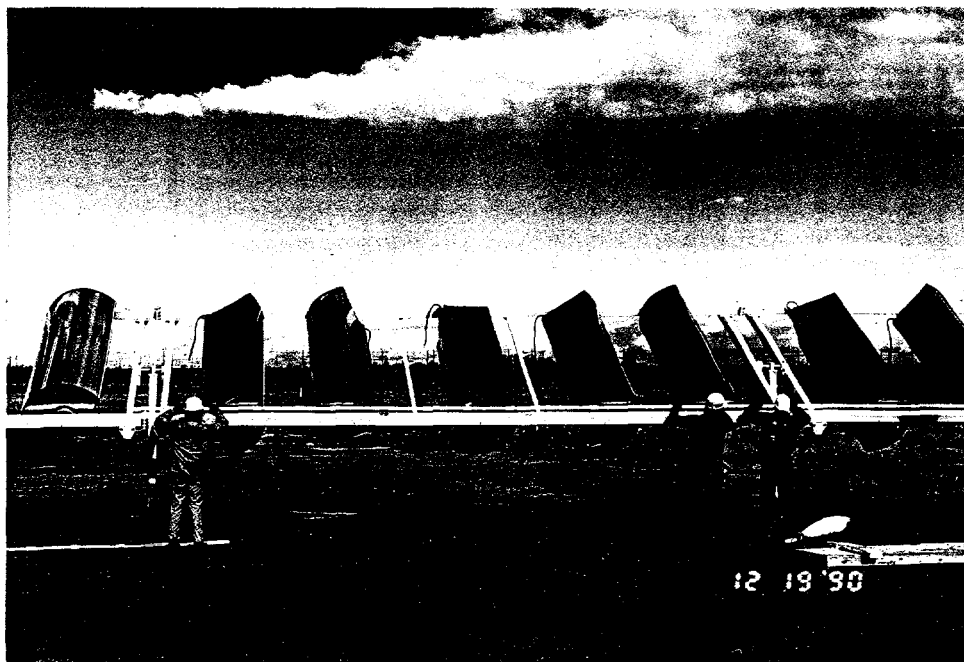
Figures 6-1, 6-2, 6-3, and 6-4 show examples of PV module support structures installed by PV subcontractors. Although the structures look different, they share common elements such as concrete, rebar, and structural steel. These common elements should provide for outstanding subcontractor performance, as the construction industry has refined these installation methods through decades of experience.

The APS support structure shown in **Figure 6-1** exemplified progress in innovative design characteristics and use of field construction aids. (Construction aids are devices generally designed in the field to improve labor performance by making it possible to complete specific tasks more quickly.) These advancements reduced overall installation and material costs. Specific examples of this included

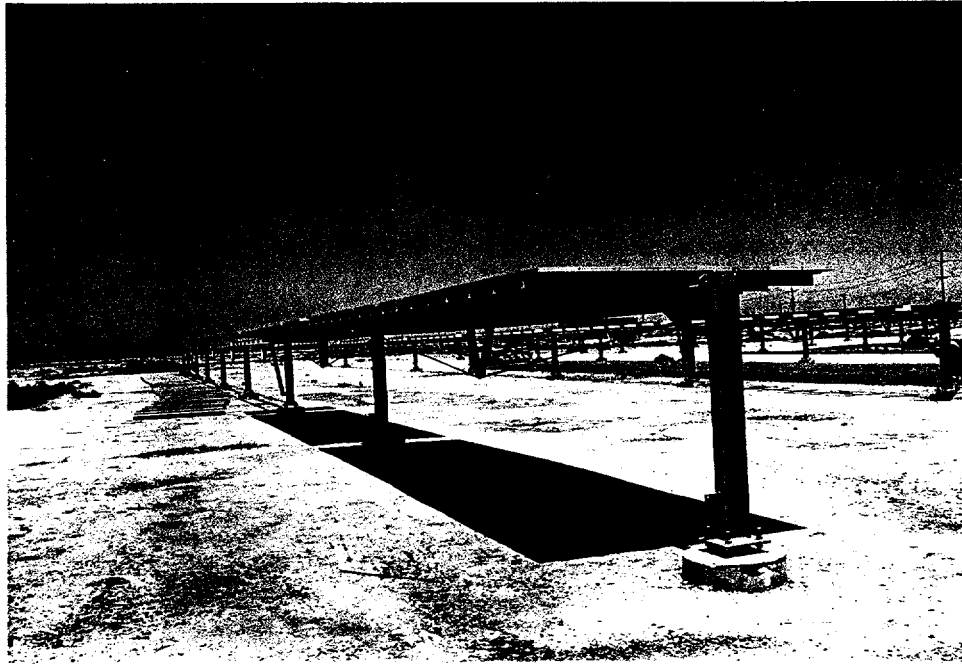
- The use of commercial steel trusses to support module panel assemblies. The trusses were manufactured and supplied by the largest domestic truss manufacturer.
- The use of Chance<sup>®</sup> screw anchors to support the rear posts of the structure. Due to highly alkaline soil conditions at the Davis site, the anchors had to be epoxy-coated instead of the standard galvanized product. Both the insufficient dry film thickness of the coating and damage to the epoxy coating during installation prompted engineering to require the installation of five cathodic test stations, thus the cost-effectiveness of this installation became questionable. However, rapid installation was achieved, and screw anchors could be considered for sites where galvanized coatings are adequate.
- A swivel design at the top of the rear pipes that allowed the entire section to be completed in the horizontal position, then lifted into the 30° tilt position. This design feature improved the construction schedule and provided enhanced labor efficiency.
- A construction aid that allowed each 10-module panel to be fully erected at ground level, then rolled into position on the support structure and permanently attached. This construction aid reduced labor hours required for module installation by an estimated 20 percent.



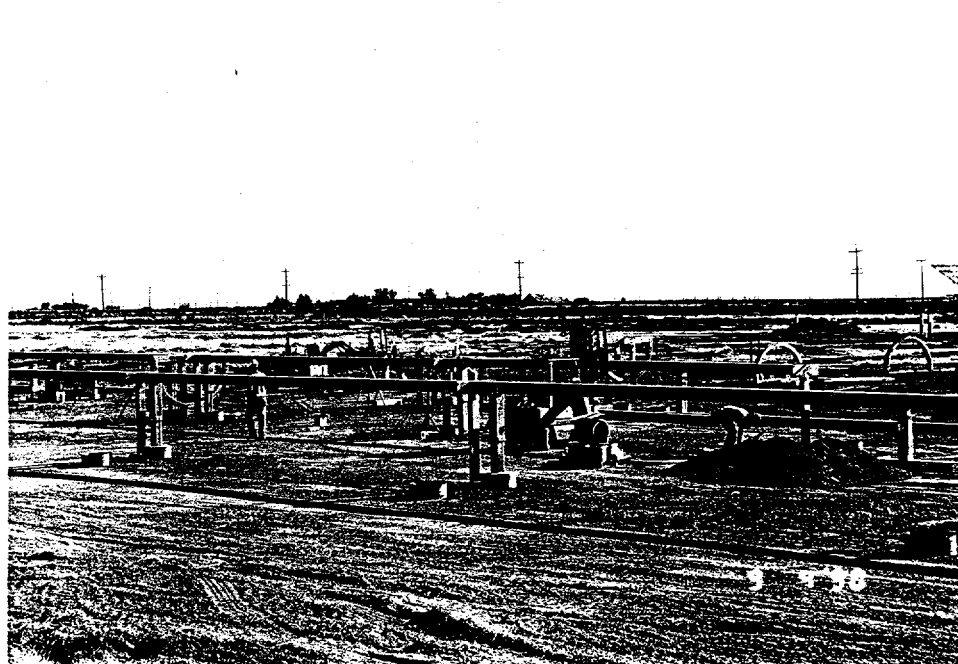
**Figure 6-1**  
APS Array Support Structure



**Figure 6-2**  
ENTECH Concentrator Array Support Structure

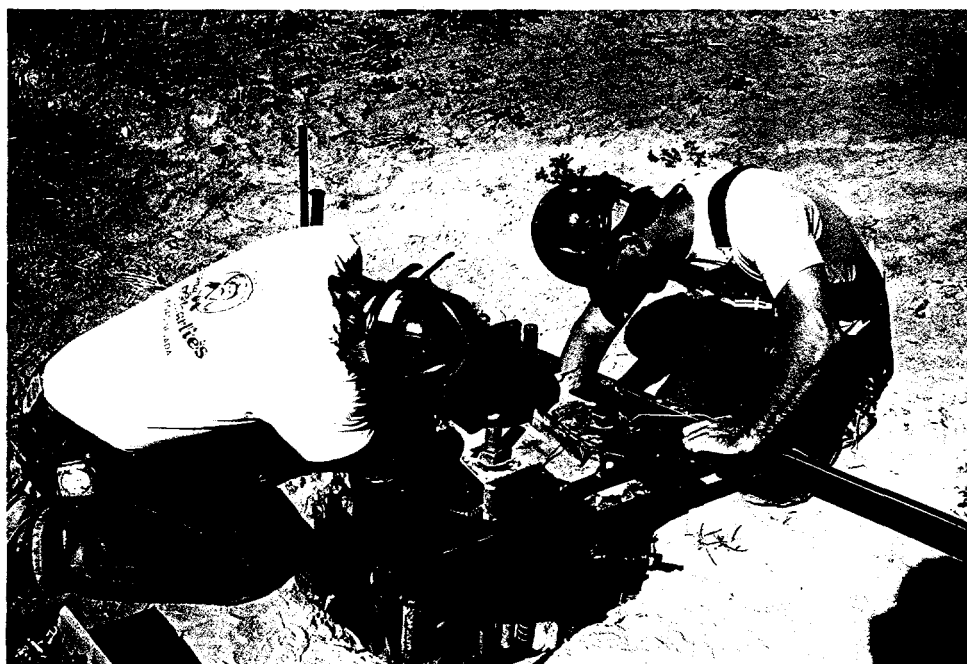


**Figure 6-3**  
SSI Array Support Structure



**Figure 6-4**  
IPC Array Support Structure

Construction of the Kerman US-2 system showed the performance advantages associated with good planning, scheduling, and most important, lessons learned from the Davis construction project. Having ascended this learning curve, the same PV installation subcontractors were better able to perform successfully during the installation phase. Use of proven components, early recognition of critical component delivery, execution of daily work plans, use of construction aids, and open communication all factored into the improved schedule performance. **Figure 6-5** depicts a steel form construction aid used as a bolt template, alignment tool, and concrete caisson form. This method saved time and money compared with common industry installation methods. Secondly, a contractual incentive for early completion also helped spur schedule improvements.



**Figure 6-5**  
Steel Form Construction Aid at Kerman



## **EMT BALANCE OF SYSTEM INSTALLATION AT DAVIS**

Different subcontractors were utilized for design and installation of the EMT-1 and EMT-2 modules and the EMT-1 and EMT-2 support structures and foundations. The support structures are shown in **Figures 6-6 and 6-7**. Both the EMT-1 and EMT-2 structures are fixed flat plate support systems; the major difference is that one uses cable-braced steel and the other treated wood. The structures were not optimized for specific PV module suppliers, but rather designed for multiple panel designs. Fixed-price contracts for various portions of both types of support systems were awarded to five subcontractors. All PVUSA BOS subcontractors performed within their schedules.



**Figure 6-6**  
Cable-Braced Steel Support Structure for EMT-1



**Figure 6-7**  
Treated Wood Support Structure for EMT-2

Additionally, identical power conditioning units and data acquisition systems were supplied and installed by PVUSA for the EMT-1 and EMT-2 arrays. A separate topical report will be issued describing PVUSA BOS in detail.

## RECOMMENDATIONS

- Exercise tight control on PV suppliers during manufacturing and installation to offset developmental nature of the PV industry.
- Require subcontractors to develop and apply a comprehensive QA/QC plan.
- Separate contract administration into
  - Commercial—the administration of prices, terms and conditions, invoicing, and warranty repairs is best performed in close collaboration with project management.
  - Performance—the job site administration of quality, safety, and compliance with technical requirements must be performed through routine inspections.
- Budget a contingency for field changes equal to 3 percent of the project's total value.
- Maintain construction records and retain for 5 years after system acceptance or until the system warranty expires. These records should include
  - Insurance certificates
  - Subcontractor safety program and training records
  - Accident reports
  - Site photos
  - Subcontractor correspondence
  - Progress reports
  - Labor (force) reports
  - Test and equipment reports
  - As-built drawings
- Monitor subcontract performance and apply performance yardsticks to measure adherence to schedules, level of quality, cost efficiency, and contract requirements.
- Institute weekly meetings with subcontractors to review safety concerns, schedules (including problems and field changes), performance (including a discussion of quality), and construction activity.
- As a minimum, provide weekly field inspections of the installation to assure subcontractor compliance to design requirements. The level of field inspections required should be based on the size of the facility, intensity of construction, and degree of difficulty associated with the tasks.

## QUALITY CONTROL

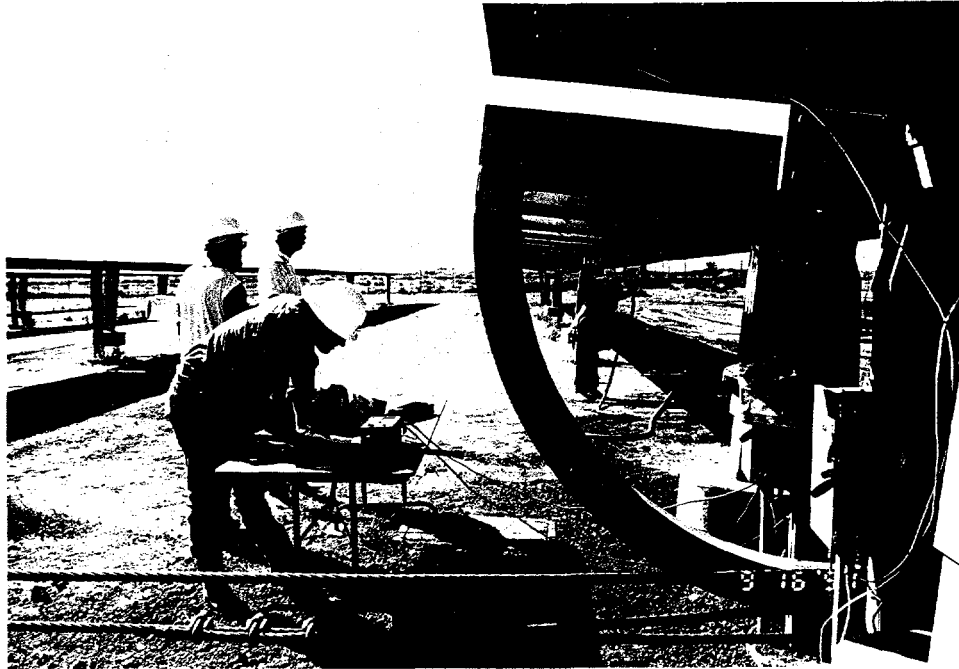
This section describes steps taken by the PVUSA Project Team for quality assurance and quality control (QA/QC). Also, it discusses quality challenges encountered at Davis and Kerman and makes recommendations regarding quality.

### QUALITY ASSURANCE

A discussion of PVUSA construction would be incomplete if quality was not addressed. The means to achieve an acceptable level of quality must be established early in a project.

Achieving quality is a team effort that begins with the selection of components and continues throughout start-up and contract closure. The old adage "It's cheaper to do it right than to do it over" is priceless advice because the cost of rework can far exceed the cost of quality control. PVUSA controlled quality by implementing the following series of activities, tests, and inspections:

- Oversight by a technical review committee (TRC)
- Screening of PV suppliers against defined selection criteria
- Review and acceptance of PV supplier documentation (including QA/QC plans, design drawings, calculations, and test results)
- Design review meetings with utility personnel and manufacturers
- Selection of proven components in some vital categories
- Constructability reviews
- Factory visits
- Factory inspections and testing of selected commodities (some modules and all PCUs)
- Visits by PVUSA quality inspectors to supplier shops as required
- Certification of successful module testing
- Certification of some components
- Design safety reviews of PCU
- Surveillance of construction activity by each subcontractor against its QA/QC plan (written notice of deficiencies)
- Operational testing to demonstrate system function and system output
- Field testing for construction completeness and acceptability (see **Figure 7-1**)



**Figure 7-1**  
PVUSA Field Wet Resistance Testing of Modules

Failure to perform any of these functions can result in a QC problem escaping detection. The nature of research contributes to component selection problems, and PVUSA was no exception.

### **QC CHALLENGES**

PV manufacturers and installers at Davis and Kerman experienced QC challenges. Both EMT and US systems had various quality control problems, most of which were unique to the PV industry. The most common ones are

- Cuts and "blisters" on module "environmental seal"
- Module termination disc failure
- Module junction box (JB)
  - cracks in the plastic
  - leaking seals
  - loose covers
- Module wire terminations not tightened
- Module/panel hardware failure in high-wind conditions (not tightened sufficiently)

- PCU
  - poor workmanship (soldering, connections)
  - inadequate cooling system (design flaw)
  - harmonics (design flaw)

### **Module Quality Control**

Although all module types installed at Davis were required to pass module qualification tests and be certified, QC in the module manufacturing process is not guaranteed by design testing. The following problems encountered in the field were traceable to factory quality control.

- Two EMT module types had excessive numbers of cuts or blisters on the modules' environmental seal; these defects required that the modules be returned to the factory either for rework or replacement.
- One innovative module termination disc passed factory testing, but failed after several months of field exposure. A costly retrofit using junction boxes was required.
- PV manufacturers frequently choose module junction boxes for module terminations. Typical box quality problems are cracks in the molded plastic, leaking seals, loose covers, and loose terminations that lead to arcing and melting of the plastic box. QC in both factory and field installation is needed to reduce these problems.

### **PCUs**

Of the 12 PCUs at Davis (made by four manufacturers), two showed evidence of workmanship problems, but PCU problems resulted primarily from design deficiencies, such as a lack of cooling or problems in the design of the firing or control circuitry. All PCUs received a design safety check that resulted in changes to equipment in the form of added barriers, grounding measures for stored energy components (capacitors), and rerouting of some internal wiring.

### **Balance of System**

QC challenges were found in these areas:

- Loose PV module and panel support hardware was encountered at PVUSA, but was not common. The large number of fasteners and connectors is an inherent characteristic of PV systems and requires special attention to ensure quality components are installed and properly tightened. Inspection of both the design and the field installation are necessary to control problems that may surface only during high-wind conditions.
- The corrosive interaction of dissimilar metals presented a minor problem that was forestalled in the design review stage by the introduction of insulating spacers.

- Array wiring: SSI wiring designations were difficult to interpret, and some wiring was terminated with polarity reversed. The dc collection boxes at the center of each row were designed without disconnects, which complicated fault tracing and maintenance.
- Trackers: ENTECH's tracker controller experienced quality problems with three failures due to loose connectors. Also, ENTECH had three failures due to wiring and limit switch problems.
- Mechanical: SSI experienced a schedule delay due to a late design change to the column anchor bolt spacing. The change required that all the column base plates be refabricated to accommodate a larger bolt spacing pattern.

The SSI torque tube bearings experienced cracking in the bearing housing because of differential tensioning of the bearing support bolts on uneven surfaces. This problem was resolved by adding 1/4 in. thick softener plates under the tensioning surfaces. Several bearing assemblies required replacement.

Originally, SSI designed a collar that fit over the torque tube rod ends and prevented longitudinal movement of the torque tube within each section. This design was later found inadequate, and each collar was removed using a cold chisel.

## RECOMMENDATIONS

Most of the QC-related items described in this section have been important lessons that vendors are actively addressing or incorporating. However, the following are still advisable:

- Tailor a project QA/QC program after a thorough review of PVUSA quality measures. Utilize off-site expert advice wherever utility experience is lacking.
- Require a demonstration of adequacy when unproven designs are offered in the proposals of PV suppliers. Require this demonstration for new PCUs, structures, and drive systems for one-axis trackers and concentrators.
- Use the PVUSA technical specification as a model for the project specification. Use the "Instructions to Bidders" section of the RFP to encourage use of proven components, the use of modular construction, and a trial or demonstration of innovative designs.

## Section 8

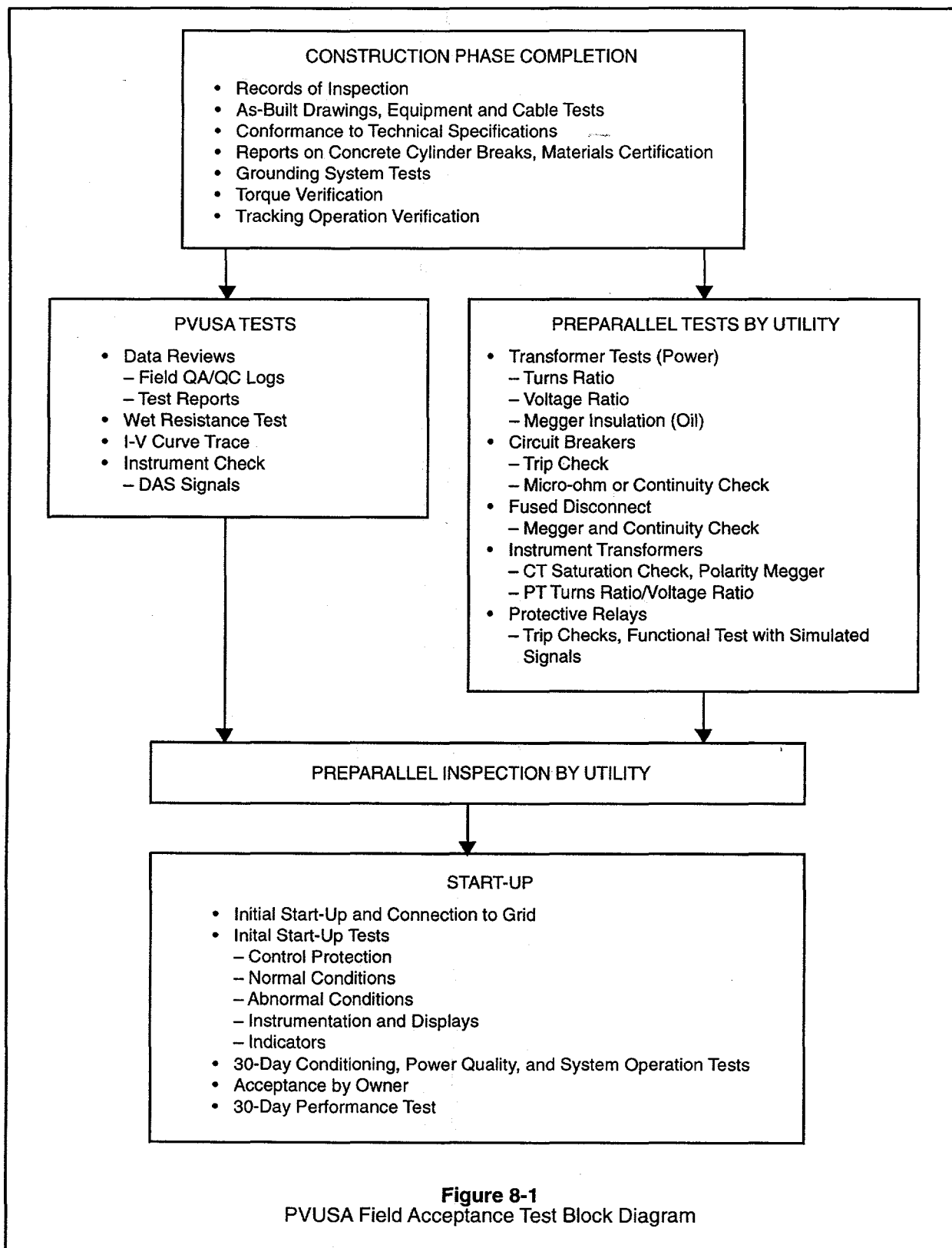
### **START-UP**

This section describes PVUSA start-up activities related to field acceptance tests. It also identifies the underlying causes of start-up problems and recommends actions to be taken both before and during start-up.

#### **START-UP PHASE**

The start-up phase is defined as the period between the completion of construction and release to operations (on-line or commercial operation). Completion of construction implies that all installation work is finished and has been subjected to insulation and other testing, and that the settings and function of the protective devices have been checked. Additionally, the system dc open circuit voltages have been checked, and the responsible utility entity has given permission to parallel to the grid at minimum power levels. **Figure 8-1** shows the sequence of checks and tests made to verify the completeness of the PV installation and the subsequent start-up of the system.





Testing in the construction phase is sufficiently broad to screen almost all PV system deficiencies with one important exception—the PCU (inverter). Start-up problems almost exclusively have been associated with the PCU.

Factory testing of PCUs is required by PVUSA technical specifications. However, since no factory test facilities currently exist for full-power testing of large PCUs, units that are approximately 50 kW or larger can be factory-tested only for the functionality of controls and limited power output. Similarly, parallel operation of PCUs cannot be demonstrated in the factory. Consequently, PCU problems dominate the start-up picture of PV systems.

Careful scheduling and coordination of the start-up phase is imperative because of the number of individuals involved, and the iterative process inherent in PV systems. During start-up all eyes, including those of the owner, primary contractor, equipment suppliers, and utility staff, are focused on and have particular interests in the overall system operation. PVUSA found the start-up process to be iterative in nature, in that control of the system passed from the contractor to the utility, then to the owner, back to the utility, and back again to the owner as the sequence progressed. If problems or failures occurred at any time, the contractor and supplier had to step back in.

#### **DAVIS EMT SYSTEMS**

All five Davis EMT systems and the Maui installation are equipped with DECC-Helionetics 25-kW Model 61635 PCUs. This PCU model was designed with a very wide operating voltage window of 240- to 540-V dc to allow flexibility for PV system designers.

As a condition for start-up testing, the utility required the addition of test jacks and banana plugs to each PCU; these additions allowed testing of the protective functions of the units (over/under voltage and over/under frequency) using external signal sources.

During start-up, adjustments to the PCU control printed circuit boards (PCBs) were required to trim each PCU to function effectively with its EMT PV system. Adjustments were somewhat trial and error in nature to establish definite, unique control set points that reflect individual PV array current and voltage characteristics.

The five Davis PCUs were found to have slightly different versions of the control PCBs. These PCBs controlled the peak-power tracking function, and the lack of uniformity presented problems when PCBs were swapped or when spares were inserted. Backfits were required to establish uniformity.

### **APS US-1 SYSTEM**

The 479-kW APS US-1 system was supplied with an APS PV-1 inverter that is made up of four identical 125-kVA inverter modules controlled by one central processing module.

A problem was experienced temporarily during the start-up testing of the utility-grade voltage control relays (51-C). Testing required removal of the relays from their permanent location. The length of the test leads placed the relays being tested too close to the control power transformer; as a result, an electromagnetic field (EMF) caused false tripping. After the 51-C relays were reinstalled on the designated control panel, the EMF noise and false tripping disappeared.

The PCUs also went into a shutdown mode (lockout) at the end of the daylight period instead of going into a standby mode. EMF was identified as a possible cause. A software modification that reset the PCU during the night cured the lockout problem.

### **IPC US-1 SYSTEM**

The 196-kW IPC US-1 system was supplied with a 200-kW Omnion Model 3200 PCU. During start-up, minor DAS signal interface and calibration work had to be performed to add pull-down resistors on the digital signals. Start-up was otherwise trouble-free.

The tracker controller experienced a clock error and a deficiency in the tracker software. These errors were corrected, and the tracker attained the aiming accuracy specified.

### **SSI US-1 SYSTEM**

Loose module terminations and a loose bypass diode termination surfaced when four modules burned. Apparently a loose connection heated and failed when the bypass diode was required to conduct (because of shading of the modules). The modules burned because the diode was no longer in the circuit.

The 174-kW (design) SSI US-1 system is equipped with two 100-kW Bluepoint Associates PCUs. This was the first utility-scale use of the newly developed Bluepoint PCUs. There were a number of nuisance trips during an extended period that proved difficult to diagnose and correct. Siemens retained a consultant to analyze the inverter problems and accepted the consultant's recommendation to reconfigure/repackage the PCU.

Start-up problems of the original PCUs included microprocessor faults, faulty contactors, dissimilar wire/terminal connections (copper/aluminum), commutation failures, and transient suppressor metal-

oxide varistor (MOV) failures. The commutation failures caused fuses to blow, and the MOV failures caused extensive fire damage on PCU "B."

Both PCUs were repackaged to replace faulty components and locate all PCU assemblies in one enclosure. Underrated components were replaced with adequately rated fuses and MOVs. However, the basic circuit topology was preserved.

The start-up experience on the reconfigured Bluepoint PCU included blown ac fuses attributable to utility transients and outages, microprocessor failures (lockout), and problems with the external ground-fault protective circuitry. A 28-day acceptance test was concluded in December 1993 with 95 percent availability. However, minor problems persist. In retrospect a program to develop the Bluepoint PCU design under noncommercial conditions would have been prudent.

### **SSI US-2 SYSTEM**

The 498-kW SSI US-2 system was equipped with two 275-kW Omnion Model 3200 PCUs. During start-up the following experiences were among the more significant:

- High-frequency (around 6 kHz) and resonant electrical noise (around 3 kHz) were experienced. The problem was corrected to an acceptable level by increasing the total capacitance of the inverter filter capacitors. Testing for current and voltage total harmonic distortion using standard power quality equipment had shown acceptable values, but had not detected this high-frequency noise.
- Paralleling inverters #1 and #2 resulted in a dc ground-fault trip of both inverters. The cause was identified as a high-frequency current on the ac side of the inverters that returned on the ground connection between the inverters. The problem was corrected by adding an isolation transformer to the output of inverter #2.
- At start-up a dc voltage imbalance was traced to a PV source circuit blown fuse. In a second incident, a dc voltage imbalance was caused by loose module connections that overheated and failed. Stripped threads on factory-installed terminals were the cause. Installation of replacement modules cleared the problem.
- During the initial inverter run period there was a problem associated with inverter trips due to cloud enhancement. The array would generate excess power to the PCU before the dc contactors could shed source circuits. This problem was resolved by programming the E-PROM chip to decrease the time between enhanced irradiance and the shedding of source circuits.

The start-up experience gained from the PVUSA Davis and Kerman installations provides valuable information to the utility, subcontractor, and manufacturers that should contribute to the success of future PV installations.

## **RECOMMENDATIONS FOR THE PERIOD PRIOR TO START-UP**

- During factory testing of PCUs, test the units as close to the PCU rated power as practical.
- For factory testing of PCUs, prepare the test set-up to simulate the final field configuration, as closely as possible.
- Update and make available a set of mark-up drawings. These drawings should reflect the final field wiring configurations and as-built condition of the PCUs.
- As soon as practical, perform preparallel testing on utility-required equipment, including switchgear, SCADA equipment, relays, transformers, and breakers.
- Familiarize utility start-up personnel with PCU operations and the maintenance manual. Utility personnel also should attend a 2-day training course conducted by the PCU manufacturer.
- Witness factory testing of the PCU and require that the manufacturer submit certified factory test results for review and approval.

## **RECOMMENDATIONS FOR THE PERIOD DURING START-UP**

- Require the PCU technical representative to be available for advice during the field inspection and initial power-up of the PCU.
- Identify and have on hand an adequate number of critical spare parts during start-up.
- Require the availability of proper diagnostic tools and equipment, such as an oscilloscope and a spectrum analyzer.
- Perform all necessary tests, especially power quality tests, and determine specific levels of electrical noise.

## Section 9

### CONSTRUCTION COST

This section provides Davis and Kerman cost comparisons, identifies BOS cost drivers, and discusses opportunities for cost improvements.

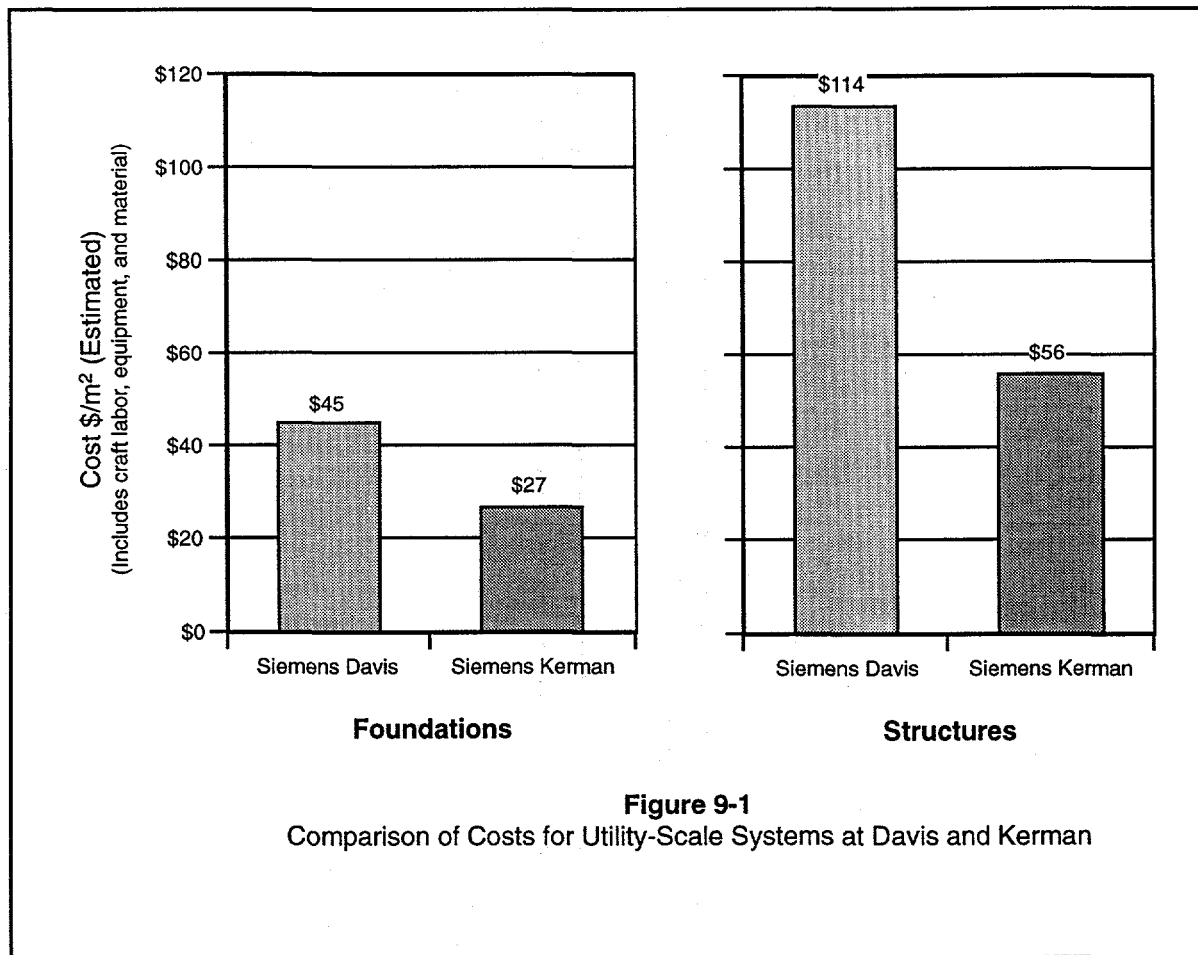
#### PV CONSTRUCTION COSTS

The utility-scale PV systems installed at Davis and Kerman were contracted on a fixed-price basis. PVUSA provided all infrastructure installations at both locations. A separate topical report to be published on BOS will include comprehensive cost data. This section provides some preliminary conclusions about costs associated with the construction of the BOS.

#### DAVIS US-1 COSTS

Total PV construction cost is the sum of on-site labor plus materials. Cost can be reported as total cost, cost per unit, cost per square meter of array (cost/m<sup>2</sup>), or cost per watt (cost/W).

**Figure 9-1** compares costs for US structures and foundations at Davis and Kerman. The SSI (Siemens) foundations and structures at Davis and Kerman are a good case for comparison because both systems are one-axis trackers.



PVUSA cost estimates are based on estimated material values and actual labor hours at \$40 per hour (except when noted otherwise). The quantities are estimated based upon takeoffs from the design drawings. **Tables 9-1** and **9-2** detail the estimated costs ( $\pm 5\%$ ) for US-1 foundations and structures.

**Table 9-1**  
**Estimated Quantity and Cost Comparison for US-1 Foundations**

Item	Siemens 7.9% eff* 174-kW ac 1-axis	IPC 8.0% eff* 180-kW ac 1-axis	Chronar (APS) 4.2% eff* 400-kW ac flat plate
Concrete (excludes equipment pads)	176 cu yd 72 caissons 30 in. diam x 13 ft 6 in. deep	107 cu yd 110-18 in. diam x 9 ft 6 in. deep 2-30 in. diam x 20 ft 6 in. deep 1-36 in. diam x 20 ft 6 in. deep	154 cu yd 176-18 in. diam x 9 ft deep 56-18 in. diam x 12 ft deep 8-18 in. diam x 13 ft deep
Rebar (excludes equipment pads)	16,128 lb #8 verticals #4 ties	none in design	21,187 lb #7 verticals (perimeter) #5 verticals (interior) #3 ties (all)
Embeds	11,980 lb 4 $\frac{1}{4}$ in. diam x 6 ft 6 in. long bolts each caisson	21,888 lb embed + pedestal wide flange sections	5040 lb 7 $\frac{7}{8}$ in. diam x 12 in. long =960 1 $\frac{1}{2}$ in. diam x 12 in. long =240
m <sup>2</sup> array (out to out)	1822.3 m <sup>2</sup> 8 rows 282 ft 9.7 x 104 in. 8 x 282.81 x 8.67 ft = 19,615.68 ft <sup>2</sup>	2529.4 m <sup>2</sup> 11 rows 308 ft 7 $\frac{1}{2}$ in. x 96 $\frac{3}{8}$ in. 11 x 308.63 x 8.02 = 27,227.34 ft <sup>2</sup>	13,389.66 m <sup>2</sup> 5 rows 681 ft 7 $\frac{1}{4}$ in. x 42 ft 3 $\frac{1}{2}$ in. 5 x 681.6 x 42.2916 = 144,129.77 ft <sup>2</sup>
m <sup>2</sup> total module area	1,690 m <sup>2</sup>	2,443 m <sup>2</sup>	11,520 m <sup>2</sup>
Concrete/m <sup>2</sup> module area	0.104 cu yd/m <sup>2</sup>	0.0438 cu yd/m <sup>2</sup>	0.0134 cu yd/m <sup>2</sup>
Rebar lb/m <sup>2</sup>	9.54 lb/m <sup>2</sup>	not applicable	1.84 lb/m <sup>2</sup>
Embed lb/m <sup>2</sup>	7.09 lb/m <sup>2</sup>	8.96 lb/m <sup>2</sup>	0.438 lb/m <sup>2</sup>
Caissons #/m <sup>2</sup>	0.043 caisson/m <sup>2</sup>	0.0463 caisson/m <sup>2</sup>	0.0208 caisson/m <sup>2</sup>
Total cost	Material = \$40,162 Labor = \$36,040 <sup>‡</sup> Total = \$76,202	Material = \$50,196 Labor = \$29,120 <sup>‡</sup> Total = \$79,316	Material = \$ 79,535 <sup>†</sup> Labor = \$ 78,800 <sup>‡</sup> Total = \$158,335
Cost/m <sup>2</sup> module area	\$45.09/m <sup>2</sup>	\$32.47/m <sup>2</sup>	\$13.74/m <sup>2</sup>
Cost/W (Rated power)	(134) \$0.569/W	(196) \$0.405/W	(479) \$0.331/W

\* eff = rated ac efficiency at PVUSA test conditions (PTC).

† Includes \$52,800 for earth anchors.

‡ Craft labor is calculated using \$40/hr. Technical representatives' time is calculated at \$60/hr.



**Table 9-2**  
**Estimated Quantity And Cost Comparison for US-1 Support Structures**

Item	Siemens 7.9% eff* 174-kW 1-axis tracker	IPC 8.0% eff* 180-kW 1-axis tracker	Chronar (APS) 4.2% eff* 400-kW flat plate
Support steel quantity	89,611 lb excluding sag cables and tracker actuators	119,784 lb excluding winch and drive cables	291,377 lb joists/angles = 137,242 lb c-studs = 105,937 lb rear posts (pipe) = 28,198 lb misc. hardware = 20,000 lb
Total cost	Material = \$179,222 Labor = \$ 15,440 <sup>†</sup> Total = \$194,662	Material = \$239,568 Labor = \$ 14,840 <sup>†</sup> Total = \$254,408	Material = \$180,975 (includes: hardware \$20,000, joists \$87,637, c-studs \$53,600, and rear posts \$19,738) Labor = \$ 46,800 <sup>‡</sup> Total = \$227,775
Support steel lb/m <sup>2</sup>	53.02 lb/m <sup>2</sup>	49.03 lb/m <sup>2</sup>	25.29 lb/m <sup>2</sup>
Cost/m <sup>2</sup> module area	\$194,662/1690 m <sup>2</sup> = \$115.81/m <sup>2</sup>	\$254,408/2,443 m <sup>2</sup> = \$104.14/m <sup>2</sup>	\$227,775/11,520 m <sup>2</sup> = \$19.77/m <sup>2</sup>
Cost/W (Rated power)	(134) \$1.453/W	(196) \$1.298/W	(479) \$0.476/W

\* eff = rated ac efficiency at PVUSA test conditions (PTC). Efficiency of Siemens system based on supplier's estimate (system yet to be accepted by PVUSA).

<sup>†</sup> Includes estimated \$24,000 labor to install c-studs and rear posts.

<sup>‡</sup> Craft labor is calculated from actual man-hours observed. \$40/hr is used for craft labor and \$60/hr is used for technical representatives.

NOTE: Estimated values are used to ascertain material costs based on actual calculated material weights. The following material estimates are used:

- |   |           |
|---|-----------|
| 1. Prefabricated galvanized misc. steel | \$2.00/lb |
| 2. Joists, studs, and galvanized pipe   | \$0.70/lb |
| 3. Misc. hardware (plates, nuts, bolts) | \$1.00/lb |

## KERMAN US-2 COSTS

This report addresses only costs associated with infrastructure (Section 2) and PV BOS development and does not attempt to break down PV subcontractor costs. More complete Kerman costs are summarized in a paper, "PVUSA Kerman Costs," presented in May 1993 at the 23rd IEEE Photovoltaic Specialist Conference in Louisville, Kentucky.

Using information provided by Siemens Solar Industries, Inc., **Table 9-3** estimates Kerman foundation and structure costs. The Kerman combined costs indicate a 52 percent savings compared with a similar system installed at Davis. These savings can be attributed to smaller caissons, less rebar/m<sup>2</sup> of array, fewer embeds/m<sup>2</sup> of array, and less support steel/m<sup>2</sup> array. These combined quantity savings and improved construction methods resulted in a \$0.73/W (or \$58.33/m<sup>2</sup>) savings at rated power. Additionally, improved soil conditions at the Kerman site provided an opportunity to improve the design of the caissons. Suppliers can improve costs with repeated designs.

**Table 9-3**  
**Estimated Costs for Kerman US-2 Foundation and Structure**

<b>Foundation Costs</b>		
<b>Item</b>	<b>Quantity</b>	<b>Cost</b>
162 caissons 24 in. diam x 11 ft deep	238 cu yd	\$11,900
Rebar	21,809 lb	\$7,700
Steel concrete forms		\$4,751
Embeds	26,955 lb	\$60,000
<b>Total material cost</b>		<b>\$84,351</b>
Labor cost (equipment included)		\$53,193
<b>Total foundation cost</b>		<b>\$137,544</b>
<b>Cost/m<sup>2</sup> module area</b>		<b>\$26.40/m<sup>2</sup></b>
<b>Cost/W</b>		
Rated power (498-kW)		\$0.28/W
<b>Structure Costs</b>		
<b>Item</b>	<b>Quantity</b>	<b>Cost</b>
Material (excludes tracking actuators)		\$242,642
Labor		\$40,000
Equipment		\$2,000
<b>Total structure cost</b>		<b>\$284,642</b>
<b>Cost/m<sup>2</sup> module area</b>		<b>\$54.63/m<sup>2</sup></b>
<b>Cost/W</b>		
Rated power (498-kW)		\$0.57/W

Davis and Kerman site infrastructure costs are addressed in Section 2 of this report. Additional significant cost savings arising from improved construction methods may not be possible. However, improvements in designs and site selection and shorter start-up periods could improve bottom-line costs. These cost improvements will result specifically from designs that reduce the quantities of materials and promote the use of standard materials and construction installation methods. Site selection is also a cost driver for PV facilities because of drainage requirements, land costs, soil conditions, and permit requirements.

## RECOMMENDATIONS

- Potential PV sites should be evaluated for base land costs, drainage characteristics, permit requirements, and soil conditions.
- Use field-proven components or designs to decrease overhead costs associated with extended system start-up periods.
- PV structure designs should emphasize the use of standard materials and minimize material quantities.

Section 10  
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Appendix A

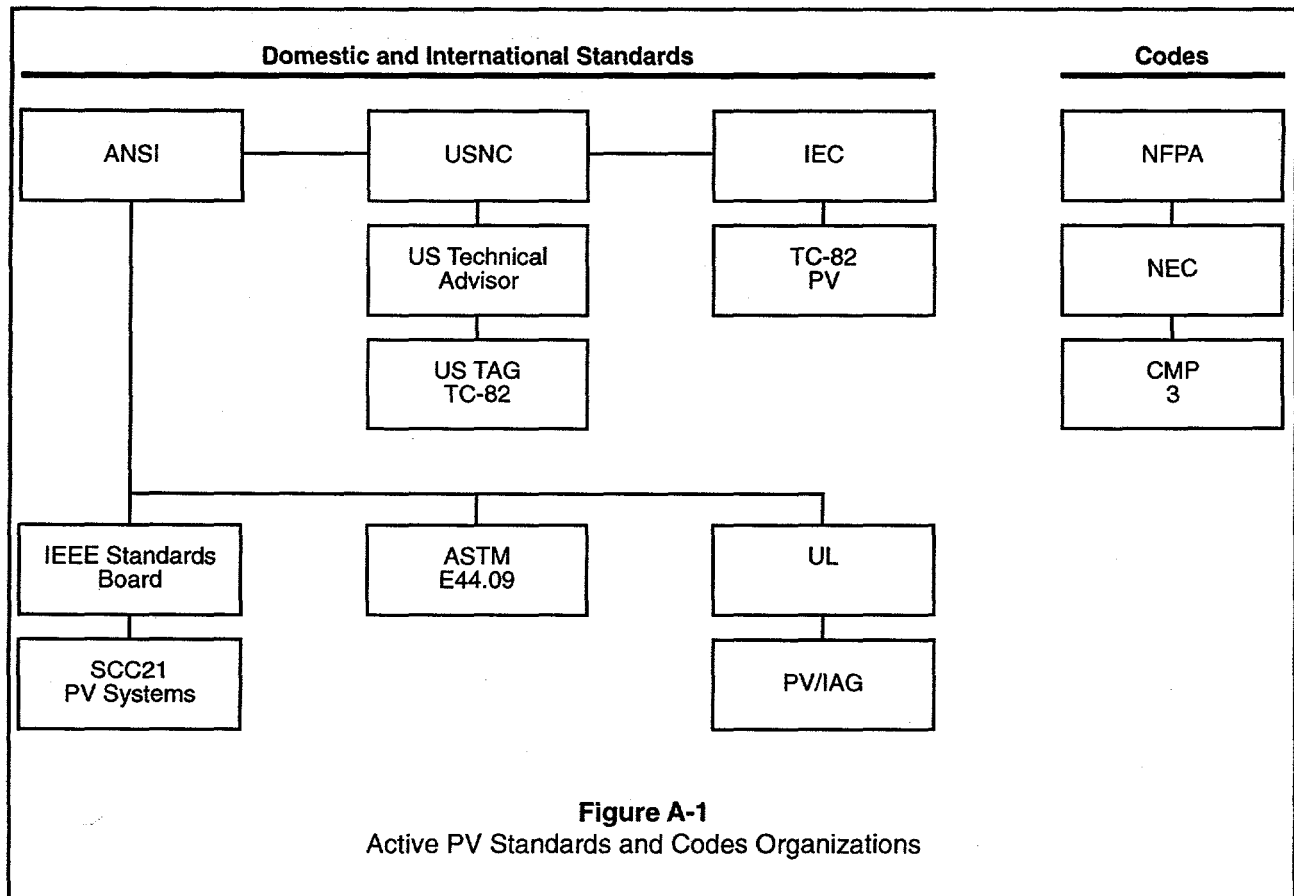
**ACTIVE PHOTOVOLTAIC CODES AND STANDARDS**

## Active Photovoltaic Codes and Standards

February 1994

PVUSA has demonstrated a need to develop and issue standards for the design, procurement, and evaluation of photovoltaic components and systems. The experience obtained has allowed PVUSA to be an active participant in the development and review of numerous standards. Information and expertise offered by PVUSA has helped accelerate this work.

The detail (status/other) contained in this Appendix (courtesy of the IEEE/SCC 21 Chairman, Dr. Dick DeBlasio) is believed to be correct as of February 1994. For more up-to-date information on any specific code or standard, inquiries should be directed to the responsible organization or contact person.



### IEEE SCC 21 Standards and Status

Number	Title	Status
P926	PV Energy Performance Ratings	PAR* approval 1981, supporting work in progress
P927	PV Energy Calculations	PAR approval 1981, supporting work in progress
928	IEEE Recommended Criteria for Terrestrial Photovoltaic Power Systems	Printed 1986 Reaff. 1991
929	IEEE Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic Systems	Printed 1988 Reaff. 1991
937	IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic Systems	Printed 1987 Reaff. 1993
1013	IEEE Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic Systems	Printed 1990
1144	Sizing of Industrial Nickel-Cadmium Batteries for Photovoltaic Systems	Printed 1987
1145	IEEE Recommended Practice for Installation and Maintenance of Nickel-Cadmium Batteries for Photovoltaic Systems	Printed 1991
1146	Grounding of Battery Subsystems in Photovoltaic Systems-Recommended Practice	PAR approval 1987, work in progress
P1262	Recommended Practice for Qualification of Photovoltaic Modules	PAR approval 1991, D5 (1994)
P1361	Recommended Practice for Determining Performance Characteristics and Suitability of Batteries in Photovoltaic Systems	PAR approval 1993, work in progress
P1373	Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems	PAR approval 1993, work in progress
P1374	Guide for Terrestrial Photovoltaic Power System Safety	PAR approval 1993, work in progress

\* PAR indicates a project authorization request was granted on the date shown.



# ASTM E44.09 Standards and Status

Number	Title	Status
E 927-91	Specification for Solar Simulation for Terrestrial Photovoltaic Testing	Printed
E-948-83	Test Methods for Electrical Performance of Nonconcentrating Terrestrial Photovoltaic Cells Using Reference Cells	Printed, being revised
E 973-91	Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell	Printed
E 0121-91	Methods for Measuring the Spectral Response of Photovoltaic Cells	Printed, being revised
E 1036-85	Methods of Testing Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells	Printed, being revised
E 1038-93	Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact With Propelled Ice Balls	Printed
E 1039-85	Method for Calibration and Characterization of Nonconcentrator Terrestrial Photovoltaic Reference Cells Under Global Irradiation	Printed, being revised
E 1040-93	Specification for Physical Characterization of Nonconcentrator Terrestrial Photovoltaic Reference Cells	Printed
E 1125-86	Test Method for Calibration of Primary Nonconcentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum	Printed, being revised
E 1143-87	Test Method for Determining the Linearity of a Photovoltaic Device With Respect to a Test Parameter	Printed
E 1171-93	Test Method for Photovoltaic Modules in Cyclic Temperature and Humidity Environments	Printed
E 1328-90	Terminology Relating to Photovoltaic Solar Energy Conversion	Printed
E 1362-90	Test Method for the Calibration of Nonconcentrator Terrestrial Photovoltaic Secondary Reference Cells	Printed
E 1462-92	Test Method for Insulation Integrity and Ground Path Continuity of PV Modules	Printed, being revised
E 1524-93	Test Method for Saltwater Immersion and Corrosion Testing of Photovoltaic Modules for Marine Environment	Printed
131	Test Method for Concentrator Devices	Work in progress
192	Test Method for Solar Radiation Weathering of Photovoltaic Modules	Work in progress
198	Test Method for Saltwater Pressure, Immersion, and Temperature Testing of Photovoltaic Modules for Marine Environments	Work in progress
199	Test Method for Wet Insulation Integrity Testing of Photovoltaic Modules	Work in progress
200	Test Method for Electrical Performance and Spectral Response of Multi-Junction Photovoltaic Cells and Modules	Work in progress
201	Test Method for Mechanical Integrity of Photovoltaic Modules	Work in progress

### IEC TC-82 Standards and Status

Number	Title	Status
IEC-891	Procedures for Temperature and Irradiance Corrections to Measured I-V Characteristics of Crystalline Silicon PV Devices	Printed
IEC-904-1	Measurement of PV I-V Characteristics	Printed
IEC-904-2	Requirements for Reference Solar Cells	Printed
IEC-904-3	Measurement Principles for Terrestrial PV Solar Devices With Reference Spectral Irradiance Data	Printed
IEC-1173	Overvoltage Protection for PV Power Generating Systems	Printed
IEC-1194	Characteristic Parameters of Stand-Alone PV Systems	Printed
IEC-1215	Design and Type Approval of Crystalline Silicon Terrestrial PV Modules	Printed

### Underwriters Laboratories Inc.

Number	Title	Status
UL-1703	Flat-Plate Photovoltaic Modules and Panels	Printed, first edition 1986. Proposed rev. in process.
Subject- UL-1741	Proposed Draft of the Standard for Power Conditioner Units for Use in Residential Photovoltaic Power Systems	Plans for initial review by IEEE SCC21, revise and conduct industry review through UL Industry Advisory Group

### National Electric Code (Article 690)

Number	Title	Status
ANSI/ NFPA 70-1993	National Electric Code, Article 690, Solar Photovoltaic Systems	Current printing 1993. Proposed 1996 revisions submitted 11/93. PV TRC of CMP-3 organized in 1993 to address changes to the Code in 1999.

## **Publication Availability**

### **IEEE Standards**

IEEE  
Customer Services  
445 Hoes Lane  
P.O. Box 1331  
Piscataway, NJ 08855-1331  
Telephone: 908/981-0060

### **ASTM Standards**

ASTM  
1916 Race Street  
Philadelphia, PA 19103-1187  
Telephone: 215/299-5400

### **IEC Standards**

American National Standards Institute  
11 West 42nd Street  
13th Floor  
New York, NY 10036  
Telephone: 212/642-0023

### **UL Standards**

Underwriters Laboratories Inc.  
333 Pfingsten Road  
Northbrook, IL 60062-2096  
Telephone: 708/272-8800

### **NEC Code**

National Fire Protection Association  
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### Other References

**NREL (SERI/TR-213-3624)** Interim Qualification Tests and Procedures for Terrestrial Photovoltaic Thin-Film Flat-Plate Modules, January 1990.

**IEEE 519** Guide for Harmonic Control and Reactive Compensation of Static Inverters, 1981.

Recommended Practice for Harmonic Control in Electric Power Systems, 1992.

**IEEE 1001** IEEE Guide for Interfacing Dispersed Storage & Generation Facilities With Electric Utility Systems, 1988.

**IEEE 1035** IEEE Recommended Practice: Test procedure for Utility-Interconnected Static Power Converters, 1989.

### Other Activities

**NREL/ASU** Development of PV module certification and laboratory accreditation criteria. NREL/DOE-funded subcontract with ASU, Initiated November 1993.

Over 30 members of Criteria Development Committee with representation from testing laboratories, manufacturers, utilities, etc.

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