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Photovoltaic Balance-of-System Designs and Costs at PVUSA

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ABSTRACT

This report is one in a series of 1994-1995 PVUSA reports that document PVUSA lessons learned at demonstration sites in California and Texas. During the last 7 years (1988 to 1994), 16 PV systems ranging from 20 kW to 500 kW have been installed. Six 20-kW emerging module technology (EMT) arrays and three turnkey (i.e., vendor designed and integrated) utility-scale systems were procured and installed at PVUSA's main test site in Davis, California. PVUSA host utilities have installed a total of seven EMT arrays and utility-scale systems in their service areas. Additional systems at Davis and host utility sites are planned.

One of PVUSA's key objectives is to evaluate the performance, reliability, and cost of PV balance-of-system (BOS). In the procurement stage PVUSA encouraged innovative design to improve upon present practice by reducing maintenance, improving reliability, or lowering manufacturing or construction costs. The project team worked closely with suppliers during the design stage not only to ensure designs met functional and safety specifications, but to provide suggestions for improvement.

This report, intended for the photovoltaic (PV) industry and for utility project managers and engineers considering PV plant construction and ownership, documents PVUSA utility-scale system design and cost lessons learned. Complementary PVUSA topical reports document

- Construction and safety experience
- Five-year assessment of EMTs
- Validation of the Kerman 500-kW grid-support PV plant benefits
- PVUSA instrumentation and data analysis techniques
- Procurement, acceptance, and rating practices for PV power plants
- Experience with power conditioning units and power quality

EXECUTIVE SUMMARY

Photovoltaics for Utility Scale Applications (PVUSA) is a national cooperative research and development project that has a mission to acquire information through field installation and testing of photovoltaic (PV) technologies in utility-scale applications and to provide the information to utilities and other participants. This report evaluates and documents the designs and costs of utility-scale balance-of-system (BOS) components at PVUSA sites in California and Texas.

In this report, BOS accounts for all labor, materials, equipment, and overheads associated with an electric utility planning, siting, engineering, procuring, managing, and constructing a grid-connected, utility-grade PV plant, except for the purchase price of the PV modules. BOS is comprehensive in that it covers PV system BOS as well as owner-provided BOS, although the two are kept distinct to permit comparison with studies based on different definitions for BOS.

PVUSA utility-scale (US) systems are vendor-optimized turnkey PV systems that use mature module technologies and have the potential, by incorporating innovative BOS designs, to produce low-cost energy while meeting the operation and maintenance (O&M), power quality, reliability, safety, and life expectancy necessary for utility applications. Advanced Photovoltaic Systems (APS), Integrated Power Corporation (IPC), and Siemens Solar Industries (SSI) supplied the US systems at PVUSA's main test site in Davis, California **(Figure ES-1)**. SSI, Utility Power Group (UPG), and ENTECH installed US systems at PVUSA host utility sites owned by Pacific Gas and Electric Company (PG&E), Sacramento Municipal Utility District (SMUD), and Central and South West Services (CSW). The three Davis systems experienced multi-year schedule delays due to technical problems or supplier transitions. The PG&E, SMUD, and CSW host utility systems were completed in a more timely, representative manner. **Table ES-1** lists the US systems, completion dates, system ratings, contract prices, and actual system costs (if available from the PV system supplier).

Various PV system designs are represented. The systems employ single-crystal, polycrystalline, or amorphous silicon PV modules; metal or wood/metal support structures; fixed, passive one-axis tracking, active one-axis tracking, or two-axis tracking orientations; and a selection of module sizes and PCU models. Single-crystal silicon modules, one-axis trackers, and Omnion PCUs are predominant. The innovative features, areas for optimization, system costs, utility-provided BOS costs, and PVUSA lessons learned are reported.

Figure ES-1. PVUSA Davis, September 1992.

Table ES-1
PVUSA Utility-Scale Systems

Owner	System Supplier, Location	Technology	Date Completed	Rating (kWac)[a]	Contract Price ($/W)	Actual Cost ($/W)
PVUSA	APS, Davis, CA	Amorphous silicon, fixed tilt, APS PCU	10/92	479[b]	4.18	not available
PVUSA	IPC, Davis, CA	Polycrystalline silicon, one-axis active tracking, Omnion PCU	7/93	196	9.37	10.40
PVUSA	SSI, Davis, CA	Single-crystal silicon, one-axis passive tracking, Bluepoint PCU	6/94	67[c]	26.94[c]	33.62[c]
PG&E	SSI, Kerman, CA	Single-crystal silicon, one-axis passive tracking, Omnion PCU	6/93	498	9.58	10.19
SMUD	UPG, Sacramento, CA	Single-crystal silicon, one-axis active tracking, Omnion PCU	4/94	213[d]	7.20	not available
CSW	UPG, Ft. Davis, TX	Single-crystal silicon, one-axis active tracking, Omnion PCU	11/94	100[e]	10	not available
CSW	ENTECH, Ft. Davis, TX	Single-crystal silicon 21x concentrator, Omnion PCU	1/95	88[f]	13	not available

[a] Rating based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1,000 W/m^2 plane-of-array irradiance for flat plates and 850 W/m^2 for concentrators, 20 $^{\circ}$C ambient temperature, and 1 m/s wind speed.

[b] Performance when system was accepted; the rating would be about 400 kW if based on 1994 data.

[c] Based on 50% of the installed array; one of the two PCUs is not operational.

[d] Interim rating by PVUSA.

[e] Based on supplier's estimate (system yet to be rated).

[f] Rating by CSW.

SYSTEM INNOVATION

BOS innovation was evident in all of the systems. APS Davis has a lightweight and inexpensive support structure that also facilitated module installation. APS Davis uses the array to shade the PCU, avoiding the need to use air conditioning units. IPC Davis uses the largest modules available to minimize module-to-module wiring and module installation labor. The modules initially used an innovative disk and wiring harness design that required significantly less time for module-to-module wiring than if conventional module junction boxes were used. The IPC Davis one-axis tracking design includes a backtracking algorithm to reduce row-to-row shading in the early mornings and late afternoons and a nonhorizontal stow position to enhance array cleaning at night by condensation or rain. SSI Davis uses a PCU design that, with further development, promises to be a highly efficient, low-cost option. SSI Kerman benefited from the lessons learned at Davis, and features a dramatic reduction in foundation and structural materials per unit area of module, and a next-generation passive tracker refrigerant. SMUD UPG and CSW UPG support structures use wooden utility poles and other off-the-shelf hardware and components such as motors, programmable controllers, and screw jacks to reduce costs. CSW ENTECH uses galvanized, instead of painted, steel structures to minimize maintenance costs associated with painting.

SYSTEM OPTIMIZATION

Design and operational improvements have been identified for all of the systems. The APS Davis system is the only one evaluated that uses amorphous silicon modules. The fixed-voltage APS PCU requires semiannual manual adjustments to decrease the energy losses due to seasonally changing array maximum power voltage. The APS Davis annual energy output can no longer be maximized because the amorphous silicon degradation has shifted the peak power voltage during the summer months beyond the PCU voltage window of operation. PCUs associated with amorphous silicon arrays should ideally be designed to operate in a wider voltage window than those for nondegrading arrays. Unfortunately, PCU design optimization for amorphous silicon arrays is a challenge since little data are available on long-term amorphous silicon performance degradation.

The IPC Davis support structure was far from optimized. The one-axis tracking system uses concrete counterweights that increased material and labor requirements, and could be eliminated by modifying the support structure design to collocate the center of gravity and the rotational axis. The design also required tight construction tolerances, increasing construction costs. IPC's proposal to PVUSA in response to a subsequent request for US system proposals indicated major advances in their one-axis tracking design, at least partially based on lessons learned at Davis. The PV system was also oversized for the PCU, which has contributed to several shutdowns of the PCU when high-power conditions exist.

None of the Davis PCUs are commercially available in 1995, including the 1990 Omnion unit. Several have unresolved problems. The SSI Bluepoint PCU-A is not operating; the IPC Omnion PCU tripped routinely during the 12 months starting April 1993. As stated earlier, the APS PCU cannot be adjusted to the peak power output because the operating voltage has dropped below the adjustment point. The more recently installed SMUD and CSW systems employ a new generation of Omnion PCUs, which will hopefully demonstrate improved reliability and significantly reduced failure-related maintenance costs.

SYSTEM COSTS

The PV system price paid by PVUSA does not necessarily reflect true PV system cost. For highly visible and research-oriented projects like PVUSA, contract prices may be less than actual costs if suppliers underestimate or intentionally underbid the cost. Conversely, a premium may be added for research or first-off design and manufacturing costs not attributable to the *n*th plant of similar design. Available data from the Davis and Kerman system suppliers indicate that, although exceeding contract prices, actual capital costs to the system suppliers were as low as $10/W. Actual PV system costs were $2,043,000 ($10.40/W) for IPC Davis, $2,252,800 ($33.62/W based on the 67-kW rating for 50% of the installed array) for SSI Davis, and $5,072,293 ($10.19/W) for SSI Kerman. About half of the actual capital cost for each system is attributable to the BOS. Although the data are not available, the actual costs to the PV system supplier of some of the more recent installations for SMUD and CSW are believed by PVUSA to be less than $10/W. SMUD and CSW had less stringent interconnection requirements than PG&E.

All of the Davis and Kerman systems can be improved to lower costs with minor design changes that are not expected to diminish system performance or reliability. PVUSA estimated PV system cost reduction potentials of $169,750 ($0.35/W) for APS Davis, $355,350 ($1.81/W) for IPC Davis, $307,000 ($4.58/W) for SSI Davis, and $462,500 ($0.93/W) for SSI Kerman. These PV system cost reductions may have been realized by eliminating PVUSA's research-related BOS requirements and having the PV system suppliers modify their procedures (e.g., quality control) and system designs based on lessons learned. Cost reductions associated with PV technology breakthroughs, volume purchases of US systems, and supplier-initiated efforts (e.g., production scaleup and automation) are not included but would be significant.

UTILITY-PROVIDED BOS COSTS

To an electric utility, the purchase price for an installed turnkey PV system is not a complete representation of PV system costs; utilities should also account for owner-provided BOS, which includes site preparation, interconnection, project management, engineering, and procurement. PG&E-provided BOS for the SSI Kerman system cost $4.04/W, for a total system cost to PG&E of $13.62/W. SMUD-provided BOS for the UPG system cost $4.79/W, for a total system cost to SMUD of $11.99/W, but did not involve land siting and acquisition, permitting, fencing, or a grounding grid. CSW-provided BOS for the UPG and ENTECH systems cost $3.60/W, for a total system cost to CSW of $13.60/W and $16.60/W, respectively.

PVUSA, SMUD, and CSW agree that utility-provided BOS costs could be significantly reduced for subsequent, non-research installations. In their independent evaluations, utility-provided BOS costs might be as low as $2.30/W for a 500-kW system like PVUSA Kerman, $1.07/W for the three additional SMUD systems totaling 317 kW to be installed at Hedge substation in 1995, and $0.75/W at the CSW Solar Park after the third 100-kW system is installed. The utility-provided BOS cost estimates are notably less for SMUD and CSW than for PVUSA, attributable at least in part to PVUSA's higher estimates for owner home-office ($1.26/W) and owner construction ($0.51/W) costs. As PV systems become standardized and familiar to owners, the costs of owner-provided BOS will tend to decrease and PV system BOS costs will reflect system design standardization, efficiency, kW rating, and supplier and owner experience.

LESSONS LEARNED

There are no BOS technical issues precluding grid-connected PV market growth, although PCU reliability is the most outstanding area for BOS improvement. PVUSA believes that the PCU reliabilities currently being demonstrated are unsatisfactory for widespread utility acceptance. Start-up durations for the majority of PVUSA systems were unexpectedly extended due to PCU problems. Convergence by PV system suppliers in the use of the most commercial PCU (Omnion) does not appear to be sufficiently increasing reliability or decreasing capital or maintenance costs. These PCU suppliers, including Omnion, do not have a sufficient market demand to freeze their designs, which would allow full optimization and debugging. Failure-related maintenance costs from system acceptance through 1994 have been about 1¢/kWh for the innovative fixed and tracking systems at Davis and 0.6¢/kWh for the second-generation tracking system at Kerman. PCU problems are a key driver for failure-related maintenance costs; non-PCU failure-related maintenance costs are 0.3¢/kWh or less for the Davis systems and 0.4¢/kWh for the Kerman system.

Based on PVUSA experience, an optimized utility-scale system would use high-efficiency, stable, large, and inexpensive PV modules. High-efficiency modules minimize support structure costs,[1] stable modules minimize energy production losses due to mismatch between system components, large modules minimize wiring and handling costs, and inexpensive modules improve system economics. Module connection approaches such as Mobil Solar's module disks and wiring harnesses have demonstrated promise in reducing material and installation costs compared to conventional module junction boxes. The optimum support structure (i.e., fixed vs. tracking) varies depending on the application and owner requirements. Continued problems with CSW ENTECH tracking suggest that additional two-axis tracking development is needed to ensure high reliability. Passive one-axis tracker performance and associated environmentally compatible refrigerant options need to be improved. PVUSA believes that additional PCU development is required to increase reliability and reduce failure-related maintenance costs to acceptable levels significantly below 1¢/kWh.

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Brian K. Farmer

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[1] Note, however, that module efficiency and cost are not equal tradeoffs. Assuming BOS is 50% of system cost, and area-related BOS is 50% of that (i.e., area-related BOS is 25% of system cost), a module that is twice as efficient as another module can only cost 25% more to have comparable system costs.

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Section 1
INTRODUCTION

This section states the report objective, provides background on the Photovoltaics for Utility Scale Applications (PVUSA) project, briefly describes the utility-scale (US) systems and PVUSA-provided balance-of-system (BOS), and summarizes the report organization.

REPORT OBJECTIVE

Photovoltaic (PV) system experience and cost projections are of great interest to utilities evaluating the proper timing of PV implementation. While cost trends for PV modules are tracked and regularly documented by PV industry researchers, minimal experience and cost data for US BOS are available on which to base cost trends. The objective of this report is to evaluate the design and cost of US BOS components at PVUSA sites in California and Texas.

In this report BOS accounts for all labor, materials, equipment, and overheads associated with an electric utility planning, siting, engineering, procuring, managing, and constructing a grid-connected, utility-grade PV plant, except for the purchase price of the PV modules. A PV plant consists of a competitively procured PV system and the owner-provided BOS, which includes owner engineering, procurement, and project management; land acquisition; permitting; site preparation and improvements; electrical equipment to interface between the PV system and the utility grid; and instrumentation and control (see **Table 1-1**). PV system BOS also includes on-site activities associated with module-to-module wiring. PV plant BOS as defined by this report is comprehensive in that it covers PV system BOS as well as owner-provided BOS, although the two are kept distinct throughout the report to permit comparison with studies based on different definitions for BOS.

A PV BOS report can address many different aspects, including design, cost, performance, reliability, operation and maintenance (O&M), and construction. The report's focus and level of detail depend on the targeted audience, data availability, and the content of other available complementary reports.

For this BOS design and cost report, the targeted audience includes utility project managers and engineers considering PV plant construction and ownership and, to a lesser extent, the PV industry. The report is focused on evaluating PVUSA US system designs and owner-provided PV plant BOS design, O&M experience, and cost. Data are available on the PVUSA owner-provided BOS, but PV supplier-provided BOS data are available *only* as suppliers elected to provide data. The information provided in this report

Table 1-1
Major PV Plant Elements

BOS Provided by PV System Supplier (typical)	BOS Provided by PV Plant Owner (typical)
PV system engineering	Plant civil/structural/electrical engineering
PV materials procurement	Plant procurement
PV system project management	Plant project management
PV system construction	Plant construction management
PV panelization	Land acquisition
PV system foundations	Permitting
PV system support structures	Site preparation and improvements
Power conditioning unit(s) (PCUs)	Switchgear
dc wiring from PV to PCU(s)	ac wiring from transformer(s) to utility
Transformer(s)	Plant instrumentation and control
PV system warranty	PV system acceptance testing
PV system spare parts	

promotes the development of commercial PV plants and can be used to

- Consider adopting successful BOS innovations
- Avoid unresolved PV system BOS problems
- Target cost-reduction efforts on cost drivers
- Schedule PV plant construction
- Budget for owner-provided BOS and O&M
- Track costs
- Exploit economies of scale

PVUSA BACKGROUND

PVUSA is a national cooperative research and development project that has a mission to acquire information through field installation and testing of PV technologies in utility-scale applications and to provide the information to utilities and other participants, facilitating informed decisions. To achieve its mission, PVUSA has the following five objectives:

1. Evaluate the performance, reliability, and cost of promising PV modules and BOS components side-by-side at a single location.
2. Assess PV system O&M in a utility setting.
3. Compare PV technologies in diverse geographic areas.

4. Provide utilities in the United States with hands-on experience in designing, procuring, and operating PV systems.

5. Document and disseminate knowledge gained from the project.

As noted above, this report is focused on PVUSA's first and fifth objectives.

UTILITY-SCALE SYSTEMS

PVUSA US systems are vendor-optimized turnkey PV systems that use mature module technologies and have the potential, by incorporating innovative BOS designs, to reduce the cost of energy for utility applications. The US systems, ranging from 70 to 500 kW, capture some economies of scale and provide important data on constructability, costs, system protection requirements, performance, reliability, O&M, grid interaction, safety, and lifetime. PVUSA's specifications required that each PV system be designed for a 20-year life and that the design and installation comply with the National Electric Code (NEC), state of California regulations, and local codes. However, PVUSA did not mandate Underwriters Laboratories' (UL) certification for PV modules, PCUs, and other PV system components, although a safety design review was required for all PCUs to meet NEC requirements for examination of equipment for safety.

PVUSA US systems at Davis and Kerman are listed in **Table 1-2**. Other installed US systems procured by PVUSA host utilities (PVUSA Project Team 1994) are not evaluated in this report due to confidential cost information and general limited data availability, although the more recent US system installations by the Sacramento Municipal Utility District (SMUD) and Central and South West Services (CSW) are briefly discussed in **Section 6**.

Table 1-2
PVUSA US Systems at Davis and Kerman

PV System Supplier and Location	Technology	Date System Accepted	Rating (kWac)[a]	Efficiency (% ac)[a]
Advanced PV Systems (APS), Davis	Amorphous silicon, fixed tilt, APS PCU	October 1992	479	4.2
Integrated Power Corp (IPC), Davis	Polycrystalline silicon, one-axis active tracking, Omnion PCU	July 1993	196	8.0
Siemens Solar Industries (SSI), Davis	Single-crystal silicon, one-axis passive tracking, Bluepoint PCU	June 1994	67[b]	7.9
SSI, Kerman	Single-crystal silicon, one-axis passive tracking, Omnion PCU	June 1993	498	9.8

[a] Based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1,000 W/m^2 plane-of-array irradiance, 20° C ambient temperature, and 1 m/s wind speed.

[b] Represents 50% of the installed array; one of the two PCUs is not operational.

For highly visible and research-oriented projects like PVUSA, the contract price may be less than the actual cost if the PV system supplier elects to contract for a price lower than the cost or underestimates the cost; however, continuing this practice does not reflect real cost improvement and is unsustainable by the supplier. Conversely, a premium may be added for research or first-off design and manufacturing costs not attributable to the *n*th plant of similar design. The price-cost difference is highly sensitive to the supplier's business strategy and unanticipated problems. Therefore, price may not be the most appropriate data point on which to base cost trends; however, actual PV system cost data availability is at the discretion of the PV system suppliers.

Cost data are available for three of the four PVUSA US systems. Published SSI Davis and Kerman (Cunow 1994) and IPC-provided IPC Davis costs are reported. The PV system sales tax and spare parts cost are identified whenever possible, since these costs differ depending on geographic location and owner preferences. The PV system suppliers reviewed and provided input to this report prior to publication. Quantity and cost estimates of material, construction labor, and equipment for PV system foundations and structures at Davis and Kerman have been documented (Shipman 1994).

PVUSA's research nature significantly elevates PV system and PVUSA-provided BOS costs. PVUSA encourages and procures innovative, unproven PV system BOS to demonstrate promising low-cost designs; unanticipated problems during system start-up extend the schedule and increase costs. To better represent commercial PV systems, the research-related components of PVUSA are extracted from PVUSA designs and costs in this report.

Improvements are proposed for each system. These improvements extract research-related BOS and incorporate lessons learned with neutral or improved impact on system performance, O&M requirements, or cost. Each improved, hypothetical US system has a minimum 20-year life expectancy, low O&M requirements, no research-related costs, and no problems with siting, schedule, or infrastructure. The estimated cost reduction potential associated with each of the proposed improvements is quantified.

PVUSA-PROVIDED BOS

Designed for at least 20 years of operation, the PVUSA-provided Davis and Kerman BOSs were designed, installed, and tested in accordance with local and state of California codes, standards, and regulations in force at the time of contract signing, including California Occupational Safety and Health Administration (Cal/OSHA), PG&E Power Producers' Interconnection Handbook, American National Standards Institute, Institute of Electrical and Electronic Engineers, National Electrical Manufacturers Association, Insulated Cable Engineers Association, Uniform Building Code, and Underwriters Laboratories. In addition, the Kerman infrastructure is based on PG&E engineering standards applicable to substation design.

PVUSA Davis, PVUSA Kerman, and a commercial PV plant are compared in **Table 1-3**. All three of the Davis US systems experienced multiyear schedule delays due to technical, financial, and/or component delivery problems, increasing PVUSA engineering, project management, and on-site labor costs. PVUSA-provided Davis BOS is not evaluated in this report (although infrastructure subcontract costs are documented in *PVUSA Construction and Safety* [Shipman 1994]) due to the significant research nature of the site.) Some core BOS (e.g., switchgear, roads, fencing, PVUSA construction management) is shared disproportionately between the Davis US systems. In addition, the PVUSA Davis design is distorted by the research nature of the facility, with BOS to allow future system installations, facilitate special tests, tour visitors safely, and accommodate the full-time on-site PVUSA staff.

The Kerman PV plant was completed in a timely manner and has fewer research-related components than PVUSA Davis. **Section 5** of this report cites the actual PVUSA-provided Kerman BOS design and cost, and estimates the cost reduction potential by eliminating the Kerman PV plant's research nature and incorporating lessons learned. The resulting "improved" Kerman PV plant indicates the anticipated owner-provided BOS cost if PVUSA had constructed the Kerman PV plant without research-related components but with the knowledge gained from the Kerman project.

Table 1-3
Key Differences Between PVUSA Davis, PVUSA Kerman, and a Commercial Utility-Scale PV Plant

	PVUSA Davis	PVUSA Kerman	Commercial Plant
PV system	Various technologies, first generation, not optimized	One technology, second generation, semi-optimized	One technology, at least second generation, fully optimized
PV system award-to-completion time	3-5 years	15 months	13-24 months[a]
Siting criteria	Solar resource, proximity, availability	Grid-support value	Grid-support value
Land	66 of 86 leased acres fenced (15 acres developed)	7 of 10 purchased acres developed	All procured acres developed
On-site staff	Five	None	None
Research-related on-site BOS	Includes visitor center, office building, office furniture, septic system, water well, data acquisition system that collects data from all PVUSA sites, tour path, and research components of roads, parking area, and meteorological equipment	Includes purchased construction trailer, office equipment, septic system, water well, and research components of roads, parking area, meteorological equipment, and SCADA	None
Owner project team	Three-agency, four-site team	Three-agency, four-site team	One agency, two-site team

[a] Duration depends on plant size. Range given for 100-kW to 5-MW plants. See **Section 5** and **Figure B-3.**

Increasing numbers of utilities are considering commercial PV plants as a generation resource option, but many are unfamiliar with their cost; minimal data are available. Based on PVUSA experience, owner-provided BOS costs for various sizes of hypothetical "commercial" PV plants are estimated in **Section 5** to quantify what the minimum owner-provided utility-grade PV plant BOS might cost today and to indicate the economies of scale.

Cost reductions associated with PV technology breakthroughs, volume purchases of owner-provided BOS, and supplier-initiated efforts (e.g., production scaleup and automation) are not reflected in this report but would be significant.

REPORT ORGANIZATION

This report evaluates the design and cost of PVUSA US systems and is divided into the following sections:

This section (**Section 1**) states the report objective, provides background on the PVUSA project, briefly describes the US systems and PVUSA-provided BOS, and summarizes the report organization.

Sections 2, 3, and **4** describe the Davis US systems supplied by APS, IPC, and SSI, respectively. System design, chronology, and costs are discussed. PV system BOS lessons learned and the estimated impact on design and cost are provided.

Section 5 focuses on the Kerman PV plant owned by PG&E. It describes the US system supplied by SSI and the PVUSA-provided BOS, outlines the chronology in plant construction, provides a breakdown of the work of the construction labor force, and itemizes the costs for the PV system and PVUSA-provided BOS. The section also discusses lessons learned, and in light of these lessons, describes the design, schedule, and costs of the owner-provided BOS for commercial plants of varying sizes with requirements similar to the Kerman PV plant. Recommendations for PV plant installation based on PVUSA experience are also made.

Section 6 briefly describes the US systems owned by SMUD and CSW.

Section 7 summarizes PVUSA's lessons learned with module and array wiring, foundations and structures, PCUs, and interconnection and utility distribution requirements. Available capital and failure-related maintenance cost data for the US systems at PVUSA and host utility sites are also discussed.

Section 8 lists referenced publications.

Appendix A contains referenced drawings.

Appendix B contains the schedule used to manage the PVUSA Kerman project.

Appendix C outlines the work breakdown structure used by PVUSA, describes an improved structure, and provides recommendations to those considering cost tracking of utility-scale PV plants.

Appendix D contains cost tables.

Section 2

ADVANCED PHOTOVOLTAIC SYSTEMS

This section describes the Davis US system supplied by Advanced Photovoltaic Systems (APS). System design, chronology, and costs are discussed. PV system BOS lessons learned and the estimated impact on design and cost are provided.

PV SYSTEM DESCRIPTION

The 479-kW APS PV system consists of five PV array rows, four inverters (Advanced Photovoltaic Power Logic Engineering model APPLE-500-256-1), a power step-up transformer, and a 15-kV fused disconnect switch. The array field consists of four source circuits, each source circuit supplying the dc power input to one of the four inverters. The array field is the largest of the three US systems at PVUSA Davis (**Figure 2-1**). All APS drawings referenced are located in **Appendix A.**

Drawing 256216 is the single-line diagram. The array source circuit operating voltage is 343 Vdc (315-350 Vdc) pole-to-pole, with a maximum open circuit voltage of 570 Vdc pole-to-pole. A source circuit consists of 2,400 Eureka modules, or 240 panels connected in parallel. A source circuit is composed of one row plus one-quarter of the back (northernmost) row. Physically supporting each source circuit are 30 identical structural sections. Each of the five rows in the array field has 24 sections, and each section supports eight panels or 80 modules. Each panel consists of 10 modules connected in series.

The four dc source circuits are routed underground through PVC conduit up to the dc collection box at the PCU container (enclosure), (see Drawing 801065). From the dc collection box, the four source circuits are individually terminated in their respective 400-Adc fused disconnect switches. The fused disconnect switch is also used to short circuit the source circuit, if needed, such as during maintenance work.

A refurbished sea container (**Figure 2-2**) houses four inverters, a central processor unit, a switch module containing three circuit breakers and protective relays, a dc collection box, and four source circuit fused-disconnect switches. The sea container, referred to as the PCU container, is a cost-effective enclosure for the inverters. However, although meeting NEC code requirements, the container's width does not provide adequate room for maintenance work. Two roll-up doors were added by PVUSA for safety egress. In retrospect, rearranging the equipment inside the sea container would have eliminated the need for roll-up doors. The container is located beneath the array structure, which shades the container and avoids the need for air conditioning. In addition, a roof vent and a fan keep the interior temperature within the range required for the equipment. APS constructed a gravel road to access the PCU container.

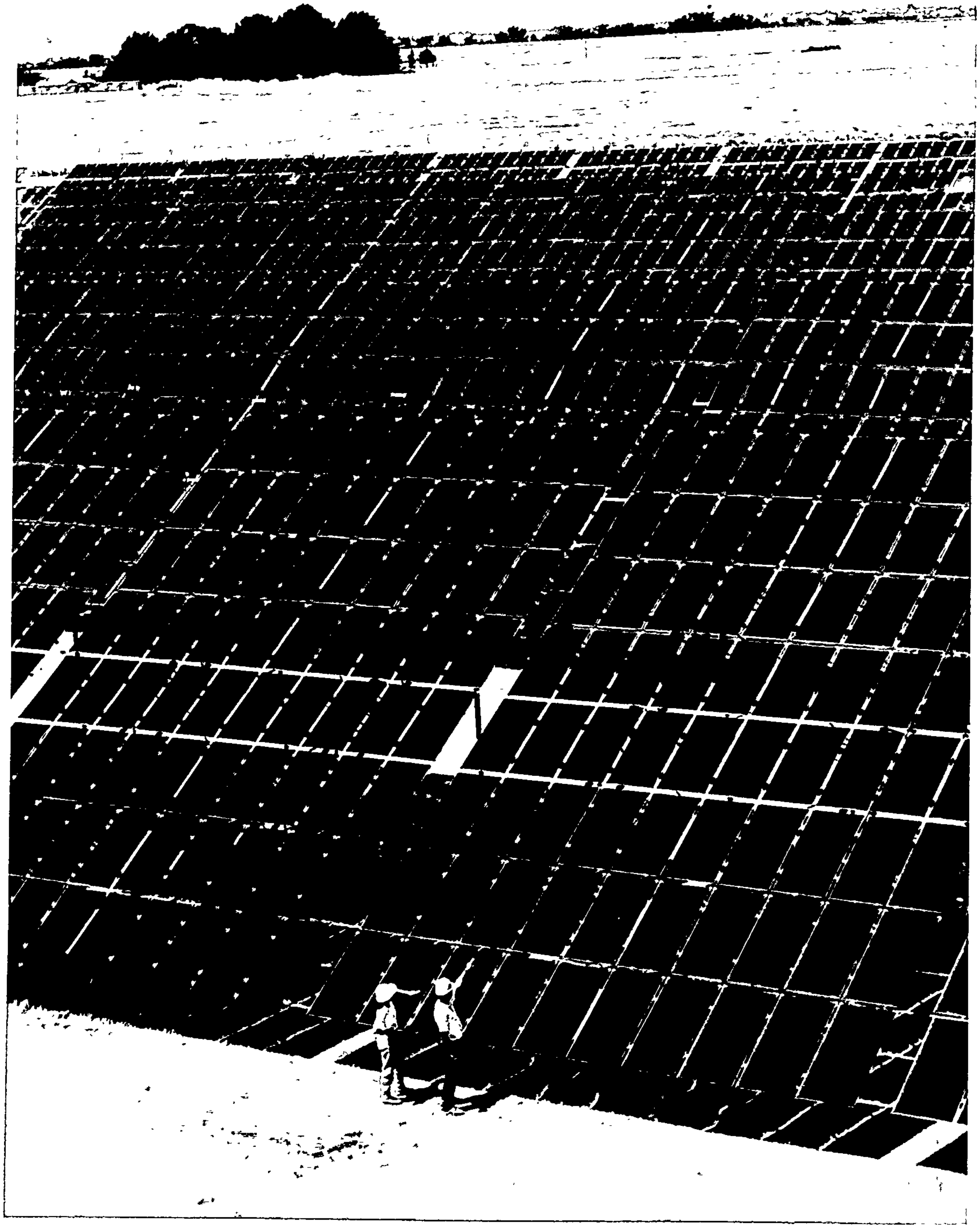

Figure 2-1. APS Davis array.

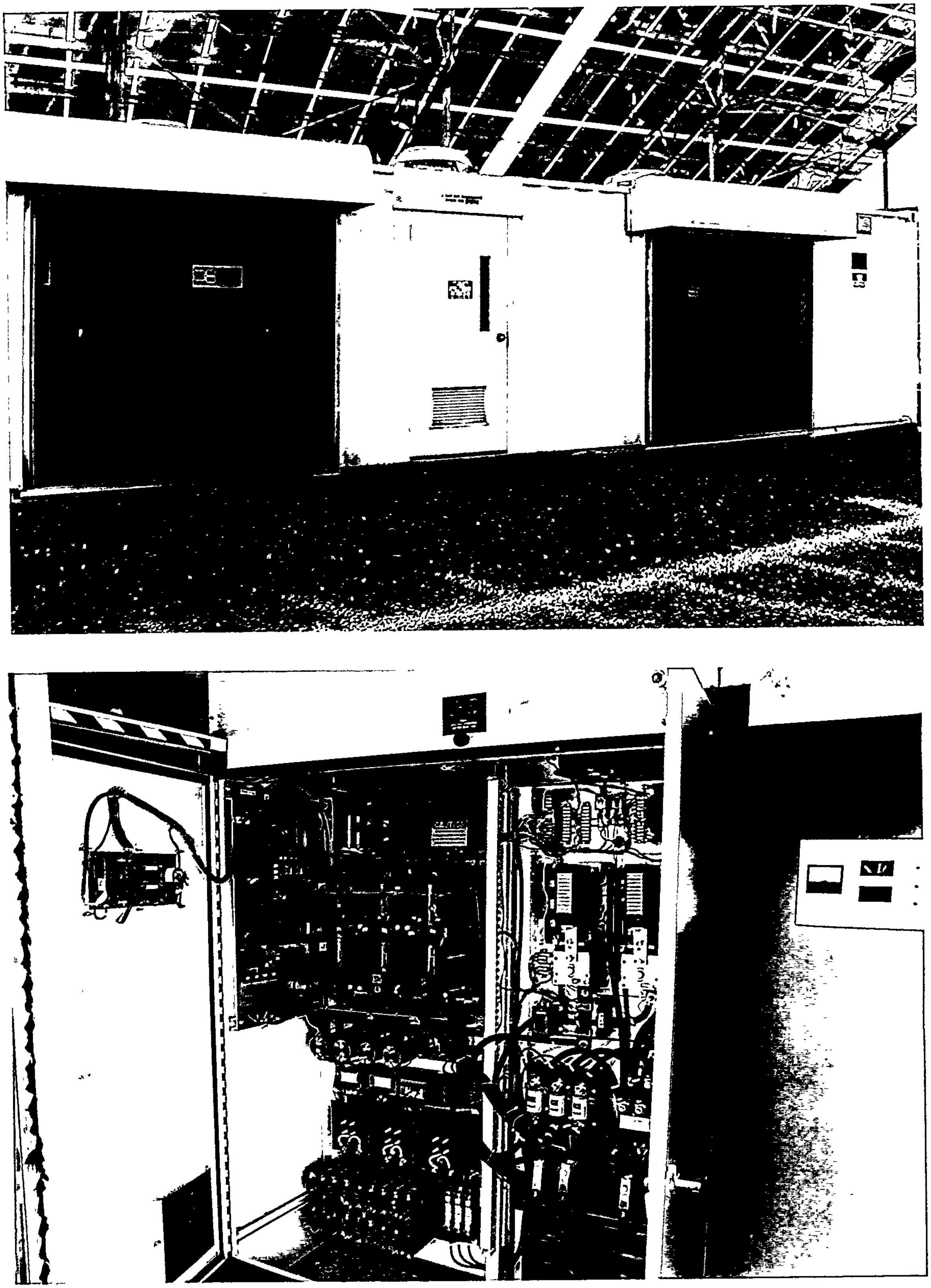

Figure 2-2. APS Davis PCU.

The input power for each inverter comes from the source circuit disconnect switch. Each inverter has a set of dc and ac contactors that are sequentially operated during start-up and shutdown. The four inverters are controlled by a central processing unit. The output of each inverter is 396 Vac, three phase. Two inverter outputs are paralleled at a 500-A circuit breaker. The 500-A circuit breaker feeds the ac power to the step-up transformer. There are two three-phase 396-Vac outputs from the two circuit breakers (two inverters per circuit breaker, and two circuit breakers for the four inverters). The circuit breakers are equipped with stored-energy trip devices (capacitors). If parameters are outside the set points, three utility-grade overcurrent with voltage control relays trip the circuit breakers.

The 530-kVA step-up transformer is configured as a forked-wye transformer, with two three-phase 396-V windings and one three-phase 480-V winding on the low-voltage side. At the high-voltage side, the transformer winding is connected in delta, with 12,470 V line-to-line. Power factor correction capacitors and harmonic filter capacitors are connected on the 480-V winding of the step-up transformer. The high side of the step-up transformer is connected to the 15-kV fused disconnect switch.

All of the instrumentation signals from the PV system are brought into and terminated in the PVUSA-provided interface junction box (IJB). PVUSA collects all information through the IJB. The IJB contains the PVUSA-provided utility-type revenue meter (JEM®[1]), DAS data logger, and UPS circuit.

For the PV system grounding, the rebar of each array concrete foundation is used as ground rods. A #2 AWG bare copper ground wire connects all the concrete foundations in each row, and is then connected to a #2/0 AWG bare copper ground wire that is run along with the electrical underground conduits. At the PCU container area, a ground grid was installed by APS. The ground grid consists of a #2/0 AWG bare copper ground wire that loops around the PCU sea container, transformer pad, and the 15-kV fused-disconnect switch pad. All the equipment in this area are bonded to this ground loop. The APS-provided ground system is connected to the PVUSA-provided ground system at the step-up transformer.

The APS array section foundations consist of two soil anchors at the north end and two concrete caissons at the south end. The soil anchors are made of steel with fusion-bonded epoxy coatings. The epoxy coating on some soil anchor shafts was not uniformly applied at the fabrication shop. Field measurements showed that the specified thickness was not met; in the worst case, the thickness was 9 mils instead of the 15 mils specified. Thus, given the very corrosive nature of the Davis site soils, seven test stations were installed at strategic locations around the array field to evaluate the corrosion rates of the soil anchors. Test readings taken annually for the last three years indicate acceptable corrosion rates.

The APS array section structure (**Figure 2-3**) consists of commercially available steel trusses with standard sheet metal "C"-studs used as module supports. The steel trusses are an innovative and economical design for supporting eight panels with 80 modules total. The array section is a modular building block that is easily adaptable to large array fields.

The Eureka modules are the largest (5 ft x 2.5 ft) unframed glass-on-glass a-Si thin film modules manufactured to date. The modules are designed with pigtail connectors (one positive and one negative) instead of traditional junction boxes. These connectors simplify wiring and minimize installation and maintenance labor. Module bypass diodes are integral with the module positive connector. Blocking diodes for the high-voltage, low-current circuit design are integral with the negative wiring harness assembly that connects the panels in parallel. Module mounting is accomplished by four factory adhesive-bonded aluminum mounting channels at the back of the module.

The modules were mounted onto the sheet metal panel assemblies at a nearby shop. The 10-module panels were shipped to the Davis site using a flatbed truck equipped with steel racks that enabled it to carry 10 panels at a time. Module-to-module wiring was done indoors at the shop, minimizing the need for

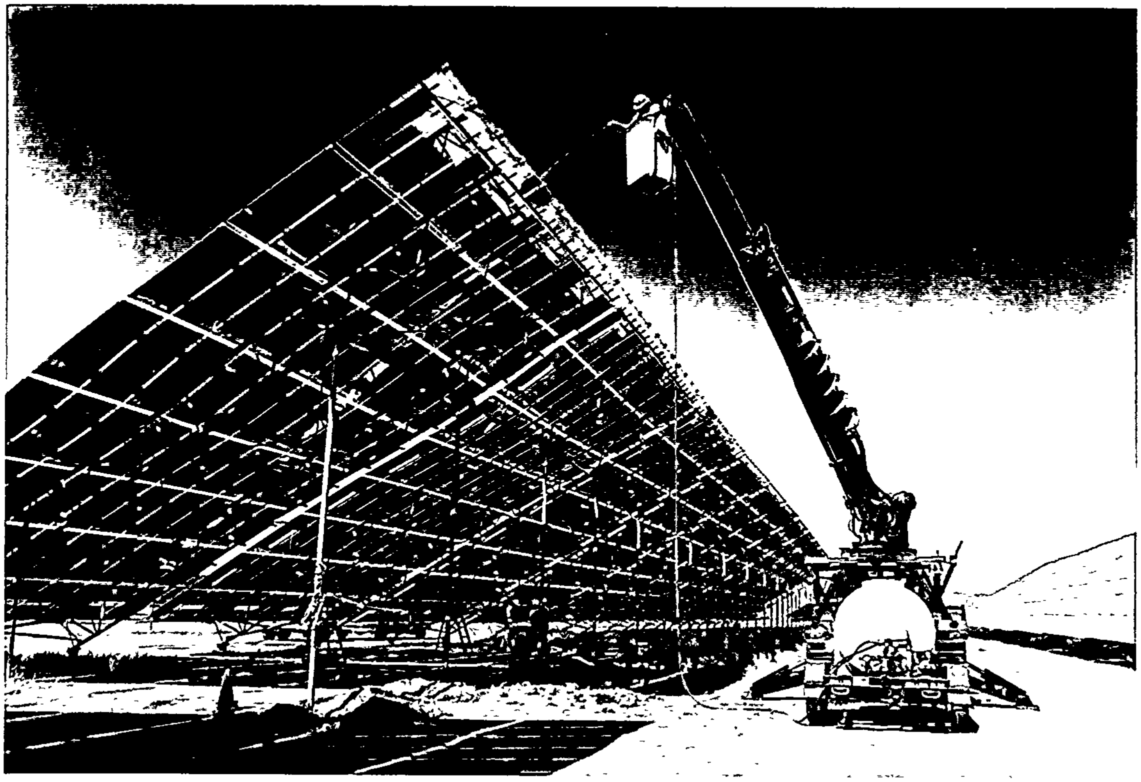

Figure 2-3. APS Davis support structure (back of array).

electrical rubber gloves during handling and installation. Parallel connection of panels within a section was done in the field using wire harness assemblies. The wiring harness assemblies were factory prefabricated and used epoxy-filled piercing connectors. The piercing connectors were intended to simplify installation; however, the vendor fabricating the harnesses did not properly fill the connector with epoxy, causing 242 out of 960 connectors to fail the Field Wet Resistance Test (FWRT). APS field-retrofitted the piercing connectors with boots, after which they all passed the FWRT.

CHRONOLOGY

Major milestones are shown chronologically in **Figure 2-4**. The contract for the APS PV system was originally awarded to Chronar Corporation in June 1989. Engineering documents were submitted by Chronar for review and acceptance immediately following the contract award. On July 20, 1989, Chronar and PVUSA project team members conducted a design review meeting. Questions were raised concerning the effect of the corrosive nature of the Davis site soil on the soil anchors and the effectiveness of the electrical wiring connectors. The soil anchors were subsequently coated with fusion-bonded epoxy in place of the standard galvanized coating. Epoxy coating greatly increases the soil anchors' resistance to corrosion. Electrical connectors similar to those proposed in July 1989 were used in Davis for the first three test sections in December 1991, and none failed the FWRT.

In December 1990, Chronar completed installing the foundations and structures for the array field. Also in December 1990, Chronar Corporation filed for Chapter 11 protection under the bankruptcy code. APS, a new company, acquired the most advanced Chronar technology and its facilities, and retained one-third of the Chronar employees. The retained Chronar employees included most of the scientists and engineers engaged in thin-film development and the PVUSA project. APS then initiated negotiations for a contract from PVUSA to complete the work unfinished by Chronar.

With court approval, APS signed a new contract with PVUSA in September 1991 to complete the project that was only partially completed by Chronar. In December 1991, APS installed modules/panels on three (of 120) sections to perform a time-and-motion study. They took video recordings of the process and timed each process, including the delivery of panels to the site from the nearby shop. The study gave APS an insight into their installation schedule and cost, which proved beneficial. Module qualification tests were successfully completed in March 1992. A PCU safety design review was conducted at the APS factory in November 1991. Factory witness testing of the PCU was completed in March 1992. The 9,600 modules for PVUSA were fabricated and shipped to a nearby (Vacaville, CA) panel-assembly facility in June 1992.

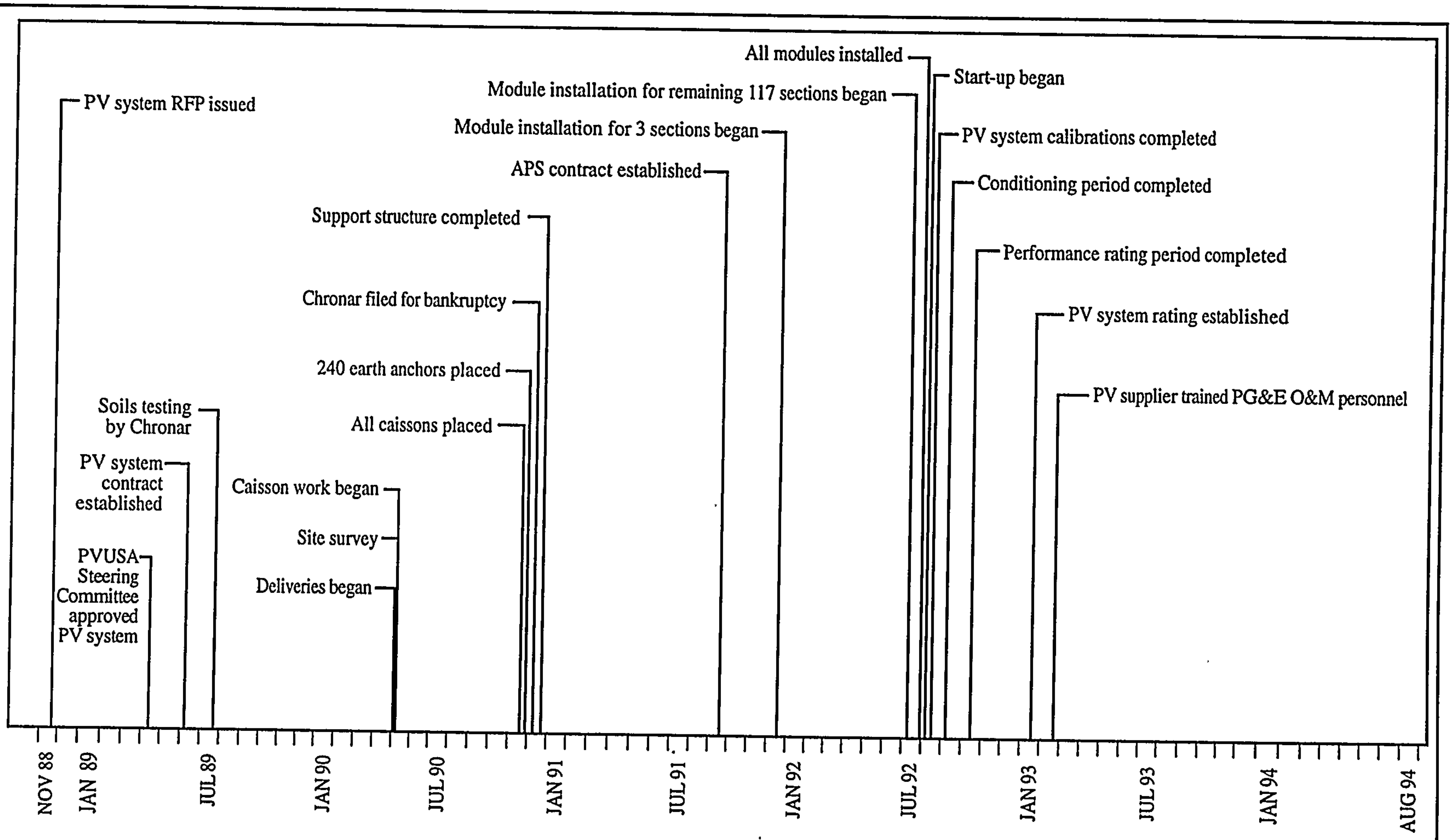

Figure 2-4. APS Davis chronology.

Module installation consisted of two phases. APS mobilized in December 1991 to install three test sections consisting of 240 modules and began collecting data prior to installation of the remaining sections. The installation of the three test sections also provided a time-and-motion data base. At APS's request, PVUSA collected current-voltage (I-V) curve data at least once per month on the test sections and provided the data to APS. In mid-1992, APS re-mobilized to install PV modules for the remaining 117 sections in about two months.

The APS construction was completed in August 1992. Initial parallel connection to the utility distribution circuit took place in August 1992. Final acceptance by PVUSA occurred in December 1992. The APS system is PVUSA's first accepted US system and, of the three systems now in place at the site, required the least time to complete despite the financial difficulties of the original supplier.

PV SYSTEM COSTS

PVUSA paid a total of $2,000,081 for the combined Chronar and APS contracts, which includes California sales tax for the 479-kW PV system. APS declined PVUSA's request for actual cost data. However, PVUSA believes that the actual PV system costs exceeded the $4.18/W price, the overrun attributable primarily to Chronar's bidding strategy. Except for APS Davis, no installed US system has been priced anywhere near $4.18/W, including subsequent APS bids through 1994. In mid-1994, SMUD awarded a $6.68/W contract for a 108-kW APS system; a 200-kW Utility Power Group system was procured by SMUD in 1993 for $7.70/W.

PV SYSTEM LESSONS LEARNED

Successful Innovations

APS satisfied all contract requirements, providing a robust PV system that is expected to meet its 20-year design life (amorphous silicon degradation issues not withstanding). The experience gained by PVUSA and APS with earlier PV installations and APS's innovative foundation and structure design helped minimize costs.

Cost reduction was encouraged from the beginning, starting with the PV system RFP. The PV system was competitively bid and responses were evaluated with equal weights on the following criteria:

- System price
- System design's adequacy for low O&M cost and high reliability
- System's suitability for long-term cost goals, or as a promising intermediate step
- Bidder's capability

APS conducted a time-and-motion study on three test sections in December 1991, which aided APS in creating a good installation specification and ultimately minimized the cost of installing panels and erecting the entire array field.

APS shipped 10-module panels from a nearby assembly shop to reduce field installation work. The modules were panelized, which reduced field wiring to panel-to-panel interconnections. The panels arrived onsite with the positive and negative panel wiring shorted to reduce light-induced degradation and also minimize the need to use electrical rubber gloves (personnel safety protection equipment) during panel handling and mounting. After all the panels were installed on the array structure, the panel-to-panel parallel interconnecting wires were installed. Modules were supplied with "snap-on" pin connectors, which facilitated connection to inter-panel wiring harnesses.

APS used a dc bus concept for the array field wiring, which minimized labor and material costs. Each section of the APS source circuit was tapped onto a cable bus using piercing connectors. The cable bus ran inside the structural channel, which eliminated the need for a raceway.

BOS Problems and Resolutions

The APS dc wiring included innovations, such as the use of piercing connectors in parallel panel connections. These connectors had the potential to save field labor in wiring installation. The connectors were initially identified by APS as suitable for outdoor installation; however, field testing showed that the connectors allowed water intrusion. The piercing connectors were filled with epoxy during installation, but still failed the field wet resistance tests. APS determined that the most effective way to fix the deficiency was to install environmental seals (boots) to the connectors.

During panel assembly by an APS subcontractor, an improperly calibrated pneumatic tool was used to tighten the module mounting bolts and nuts. Some improperly torqued module mounting bolts and nuts on eight modules in one panel failed in high winds. Subsequently, all fastenings in the entire field were retightened and secured with "locktite." PV suppliers should exercise vigilance when checking the QA/QC program of each subcontractor.

Potential for Improvements

Several BOS components have significant PV system cost reduction potential with either positive or no effect on system performance (**Table 2-1**).[1]

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[1] These would not necessarily lower the system's $4.18/W price since this price is probably not indicative of actual cost.

Table 2-1
Cost Reduction Potential of APS Davis BOS

BOS Component	Component Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PV Supplier's Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
Piercing connectors	Field retrofit to add boots	APS initially identified the piercing connector component as suitable for marine engine room installation.	Procedural change. Application of components that are tested and certified for an application differing from the intended service should be scrutinized.	15,000	4,000
PCU inspection	Factory inspection by owner	Not required for mature equipment.	Procedural change. Eliminate 3 trips to APS if mature equipment.	0	6,000
Soils report	Duplicated by APS	Owner did not guarantee its own soils report.	Procedural change. Eliminate if owner guarantees soils report.	5,000	0
PCU protective circuit	Separate 51C relays	Controls that include all protection requirements.	Procedural change. Include all control and protection in PCU circuitry such as the overcurrent with voltage control relay (51C). Utility to eliminate the requirement for utility-grade relays.	12,000	4,000
Soil anchor tests	Used soil anchors	APS needed to prove the stress and strain forces, basis for design.	Procedural change. Innovation is good, but first obtain adequate data on the components or materials.	25,000	5,000
PCU safety design review	Does not meet NEC	Does not meet NEC, required by PVUSA to ensure safety features are incorporated in design.	Procedural change. With mature PCU technology and as the equipment is listed, this requirement can be eliminated.	8,000	2,000
Module mounting hardware	Module bolts re-torqued	Improperly calibrated pneumatic tool used in factory fabrication of panels.	Quality control issue. Use properly calibrated tool and properly rated tool.	12,000	0
15 additional modules	Delivered to National Labs	Research-related.	Research item. Eliminate.	1,000	0
15-kV fused switch	Installed	Research-related.	Research item. Eliminate.	20,000	5,000
dc instrumentation	Installed	Research-related.	Research item. Eliminate.	5,000	0
PCU display meters	Installed	Visual aid to visitors only.	Research item. Eliminate.	5,000	0
UPS circuit	Installed	UPS circuit for research data logger.	Research item. Eliminate.	0	1,000
Module thermocouples	Installed	Research-related.	Research item. Eliminate all 3 thermocouples.	3,000	0
O&M manual	Submitted	Customized document. APS had to create the O&M manual from scratch.	Supplier efficiency issue. With standardized installations, only minor custom PV system features and printing cost will accrue.	30,000	2,000
			Subtotal Cost Reduction Potential	141,000	29,000
			Total Cost Reduction Potential	170,000	(35¢/W)

To meet the utility requirements, PVUSA provided three overcurrent relays with voltage control (51C) and an uninterruptible power supply (UPS) circuit for the relays. The relays trip the two APS inverter ac output circuit breakers. Unlike rotating generators, the PV system cannot supply large fault currents. The 51C relays are therefore set to trip on undervoltage with load current rather than on overcurrent, and with zero time delay. Utility protection engineers need to become familiar with PV generating systems and tailor protection requirements accordingly for these generating systems with limited fault capacity.

Another requirement in the PVUSA specification was submittal of a system O&M manual. This was the first time APS was required to submit a system O&M document. PV system suppliers should have standard O&M manuals which can be tailored to specific PV systems they build. All PV systems should include an O&M manual as one of the deliverables.

Requirements related to the research purposes of the PVUSA project could be eliminated. These include PCU display meters, PCU factory witness testing, the 15-kV fused switch, 15 additional modules, three back-of-module thermocouples, and dc instrumentation.

The PCU display meters serve as a visual aid to visitors but provide little or no value for normal O&M tasks. For a non-research project, the 15-kV fused switch can be eliminated. A research project requires testing, and the 15-kV switch provides a convenient isolation and maintenance point. Similarly, the 15 total additional modules delivered to PG&E and the national laboratories are not necessary for mature commercial modules in a non-research project.

PVUSA required a safety design review of PCUs which lacked UL labeling (or similar) to meet NEC 90-6, Examination of Equipment for Safety. As PV system technology matures, UL listing may become standard practice for component manufacturers, eliminating the need and cost of the PVUSA safety design review.

Although the PCU design was an improvement over an earlier version, factory inspection by the owner or its representatives was perceived to be necessary. Three factory visits for PCU inspections would have been eliminated if the PCU was a commercially mature product.

The PVUSA RFP included a site soils report, but fell short of guaranteeing it as a design basis for APS. Thus, to determine their design basis, APS performed its own site soils study, duplicating the PVUSA effort. The cost of a separate soils study can be avoided if the buyer will underwrite (stand behind) its soils report.

The APS-provided soil anchor foundations were innovative; however, there was insufficient data on the allowable forces (stress and strain) for use in design calculations. APS conducted special testing for gathering data and maximizing its design. The cost and effort for conducting soil anchor special tests would have been saved if previous data were available.

The largest cost-saving potential would be in installing a similar PV system but with a previously approved and certified set of design documents. This first-of-a-kind APS system installed for PVUSA required approximately 100 new drawings and associated design calculations. That engineering activity represented numerous engineering hours spread over two years. APS required approximately one man month of engineering effort to modify the existing PVUSA design for the SMUD 100-kW system that was recently awarded to APS. The APS project manager attributes the award from SMUD to the APS experience and engineering oversight gained through PVUSA.

The APS system design included some provisions that may be reduced or avoided depending on owner preference:

- The PCU circuit topology resulted in excessive harmonics which required output filter capacitors to meet IEEE 519 and owner specifications.
- The PCU output required power factor correction capacitors to meet owner specifications.
- The medium-voltage cable termination at the disconnect required field modification to meet owner specifications.

If the PV system improvements proposed in **Table 2-1** were adopted, the maximum estimated cost reduction potential to APS would be $141,000, or $0.29/W based on the 479-kW rating. The maximum estimated PVUSA labor cost reduction potential is $29,000 ($0.06/W).

Failure-Related Maintenance Costs

The APS design reflects innovation with no significant adverse effect anticipated on maintenance costs. Failure-related costs are indicated in **Figure 2-5**. These costs do not include preventive maintenance.

Failure-related maintenance costs represent two major and several minor events distributed among 22 of the 27 months from October 1992 through December 1994. In May 1993, APS repaired PCU damage sustained during a PG&E grid disturbance (no other Davis PCUs were damaged). In October 1994, APS replaced 26 glass-on-glass PV modules that cracked due to unknown causes. All of the remaining failure-related maintenance events were PCU related.

Labor and material account for 62% and 38%, respectively, of the total failure-related maintenance costs. The APS system demonstrated failure-related maintenance costs of 1.2 cents/kWh in 1993, 1.0 cents/kWh in 1994, and 1.0 cents/kWh for the overall 27-month period.

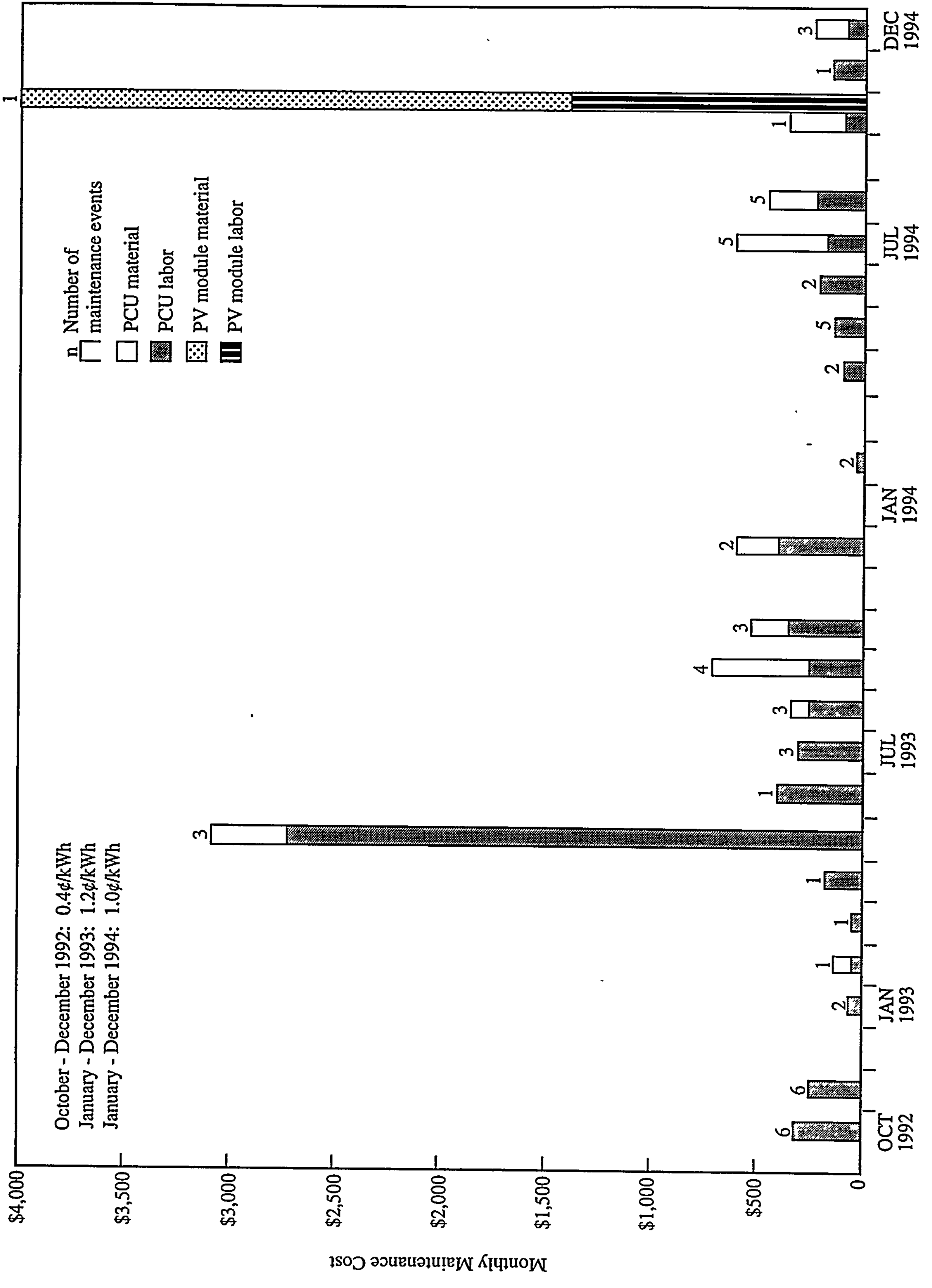


Figure 2-5. APS Davis failure-related monthly maintenance costs.

Section 3

INTEGRATED POWER CORPORATION

This section describes the Davis US system supplied by Integrated Power Corporation (IPC). System design, chronology, and costs are discussed. PV system BOS lessons learned and the estimated impact on design and cost are provided.

PV SYSTEM DESCRIPTION

The 196-kW IPC PV system (**Figure 3-1**) consists of 11 single-axis active tracking PV array rows, one PCU, and a power step-up transformer equipped with bayonet fuses. The array field consists of 11 bi-polar source circuits that are paralleled in a dc collection box. All IPC drawings referenced are located in **Appendix A**.

Drawing 002456 is the single-line diagram. The array source circuit operating voltage is 700 Vdc pole-to-pole, with a maximum open circuit voltage of almost 1,000 Vdc pole-to-pole. Each of the 11 rows is a source circuit that has 100 series-connected Mobil Solar Ra220 modules, for a system total of 1,100 modules. Each panel has two modules, supported by a two-module frame. Each module is protected by one bypass diode that is external to the junction box and mounted to the module frame.

Mobil Solar manufactured the largest modules in the United States until Mobil Oil Company sold the PV technology rights and manufacturing capability to Nukem GmbH, which renamed the subsidiary ASE Americas in 1994. The modules for PVUSA were originally designed and constructed with module termination disks (two positive and two negative) rather than conventional junction boxes. The disk design is innovative, simplifies field wiring, and is a promising strategy to minimize installation and maintenance labor. Unfortunately, after installation and exposure to the elements, the module disk connector material was determined to be unsuitable, and the modules were field-retrofitted with module junction boxes (**Figure 3-2**).

The 11 dc source circuits are collected at monopole source circuit disconnect switches. There are two monopole source circuit disconnect switches per source circuit at the center of each tracker row. The source circuit wiring is then routed underground through PVC conduits up to the dc collection cabinet near the PCU area (Drawing 002774). At the dc collection cabinet, the 11 source circuits are individually terminated, then paralleled together. The dc collection cabinet contains the dc source circuit shedding contactor. Output of the dc collection cabinet is fed into a main dc disconnect switch mounted on the side of the PCU enclosure.

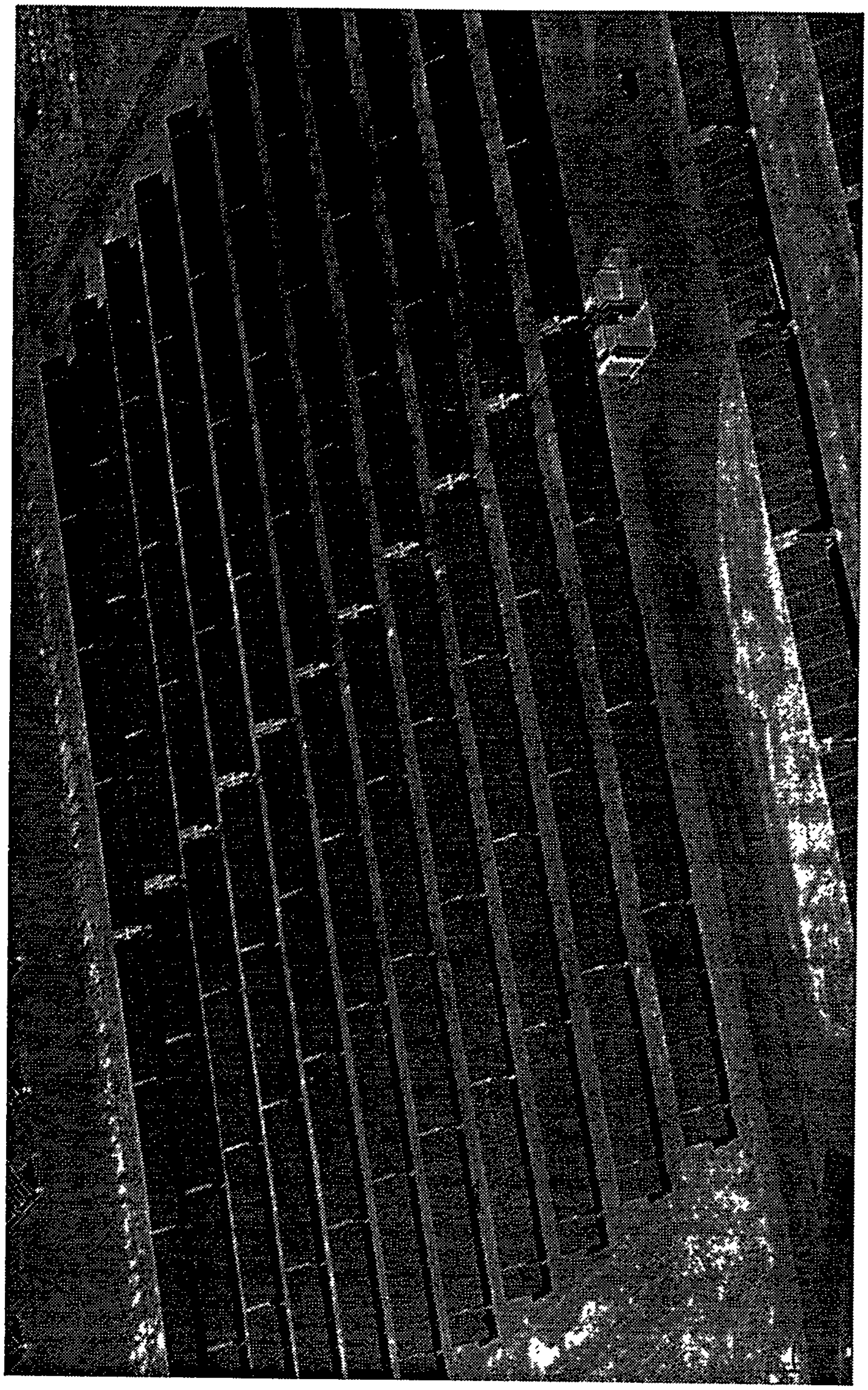


Figure 3-1. IPC Davis array.

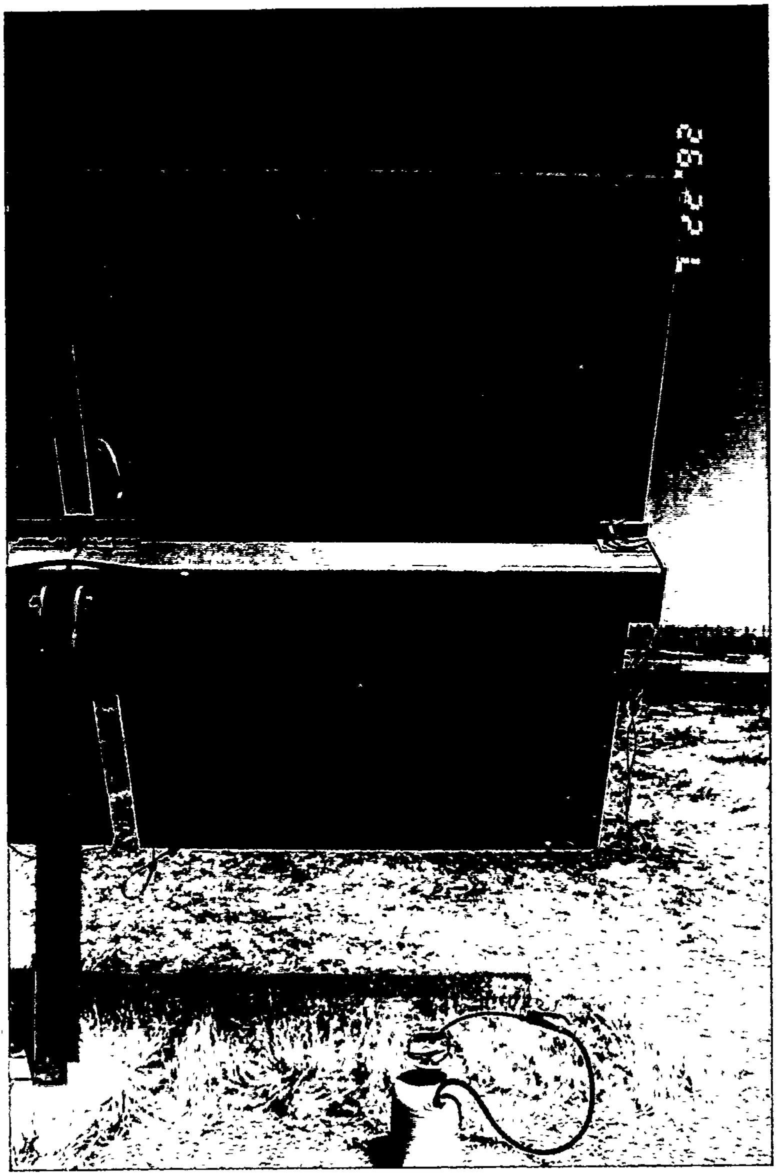


Figure 3-2. Mobil Solar module termination disks and junction boxes.

The Omnion series 3200 PCU is located on the east side of the PV array and is exposed to direct sunlight, requiring a PCU air conditioning unit (**Figure 3-3**). The input power for the PCU comes from the main dc disconnect switch. The PCU has a set of dc and ac contactors that operate during start-up and shutdown. The PCU has five bridge modules (power electronics) that are controlled by a central processing unit. The output of each PCU bridge module is 380 Vac, three phase. The five PCU bridge module outputs are paralleled before going into a 400-A, 600-Vac circuit breaker. The 400-A circuit breaker feeds the ac power through a 400-A, 600-Vac load-break disconnect to the step-up transformer. The circuit breaker is equipped with a stored energy trip device, essentially a capacitor device. There are three utility-grade overcurrent with voltage control relays (51C).

The 225-kVA step-up transformer is configured as a wye-delta transformer, with a 380-V wye to 12.47-kV delta transformation ratio. The neutral of the PCU output (380-V wye) is ungrounded. Power factor correction capacitors and harmonic filter capacitors are not necessary for this system. The high side of the step-up transformer, 12,470 V, is connected to the 15-kV metering enclosure before it is connected to the PVUSA-provided 15-kV cable.

All of the instrumentation from the PV system is brought to and terminated in the PVUSA-provided interface junction box (IJB). PVUSA collects all DAS information through the IJB. The IJB contains the utility-type revenue meter (JEM®1), the DAS data logger, and the UPS circuit provided by PVUSA.

For the PV system grounding, the 110 concrete array foundations with imbedded steel pedestal columns are utilized as ground rods. A #2/0 AWG bare copper ground wire is bonded to each of 11 steel columns (one at the center of each row), and is connected to a bare #2/0 AWG bare copper ground wire that is run along with IPC's dc electrical underground conduit and wires to the PCU area. IPC installed a ground grid at the PCU area to which all equipment grounding are connected. The ground grid consists of a #2/0 AWG bare copper ground wire and four ground rods. The IPC-provided ground system is connected to the PVUSA-provided ground system at the 15-kV metering enclosure.

Each IPC array row has 10 concrete foundations spaced 36.7 ft apart (Drawings 002497 and 002441). Each structural steel pedestal is imbedded in its concrete foundation, which eliminates rebar. IPC has re-evaluated the embedded pedestal design and found that it is less expensive than using rebar, as long as soil conditions are such that the augered holes do not collapse immediately after augering. However, imbedding a structural steel pedestal in a concrete foundation leaves very little margin for error (tolerance); a more detailed discussion is contained in *PVUSA Construction and Safety* (Shipman 1994).

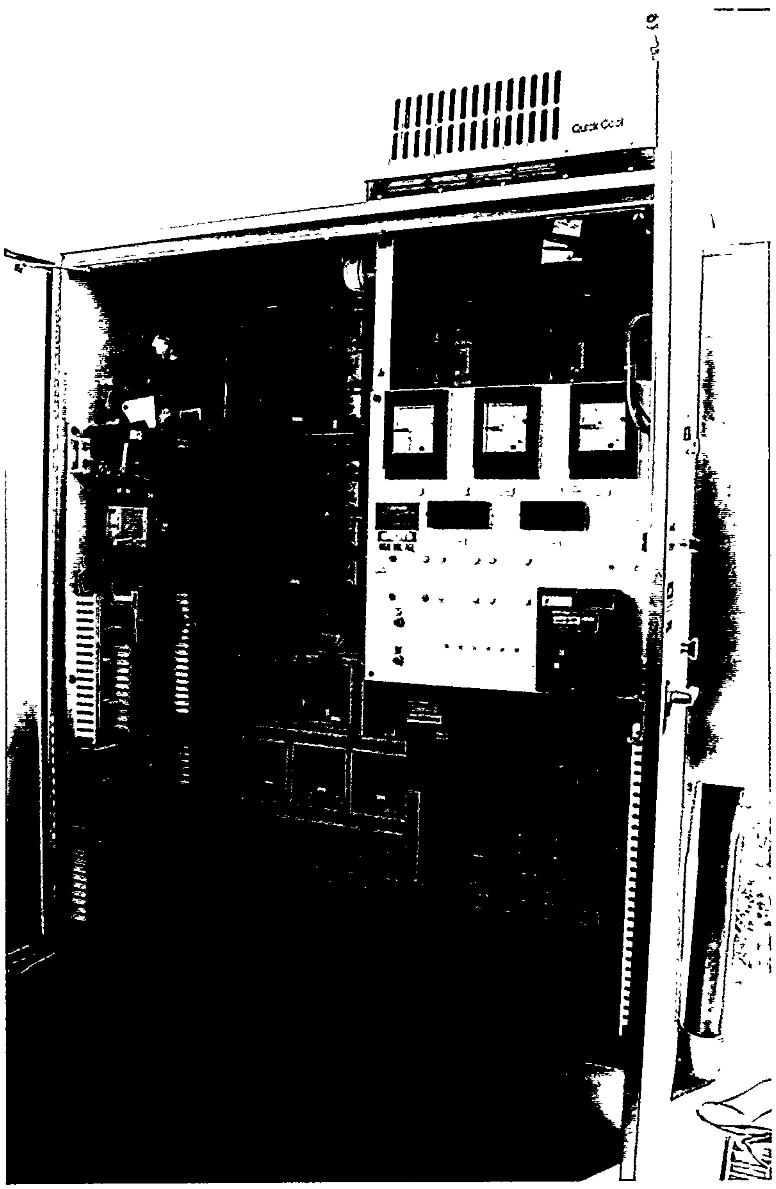


Figure 3-3. IPC Davis Omnion PCU.

The IPC tracker structure mechanical assembly is shown on Drawings 002442, 002496, and 002497. The concrete-imbedded steel pedestals support the one-axis tracker structure. Each row tracker structure is supported by 10 flange unit bearings. Concrete counterweights attached to the torque tubes below the bearing centerline provide the counter balance weight for the torque tube and PV panels, and minimize torque requirements on the tracker drive motor (**Figure 3-4**).

The computer-controlled, motor-driven tracking system consists of an IPC TM3 tracker controller, a winch assembly, a 1-3/8-in. diameter wire rope assembly, a 21-ton capacity turning sheave, and a torque

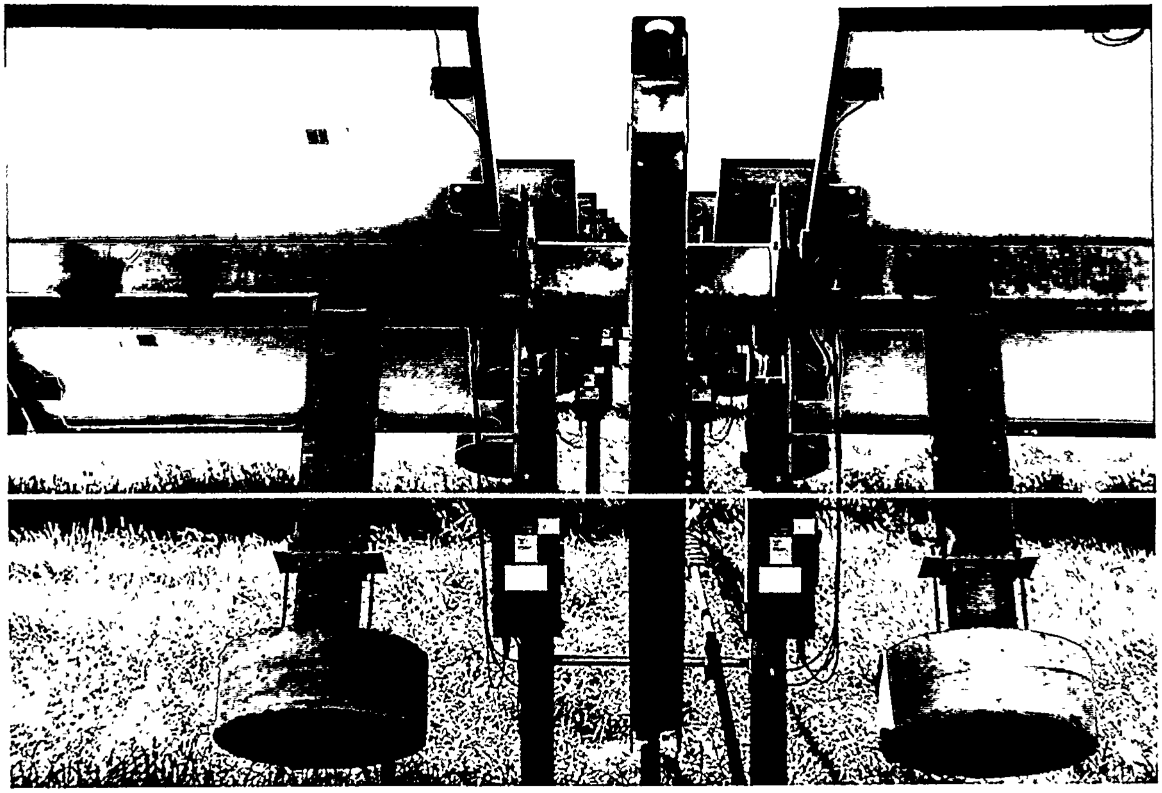


Figure 3-4. IPC Davis support structure (back of array with counterweights).

rim at the center of each tracker row. The winch and turning sheave are located at the PV array center line, east and west ends, respectively. The tracker cable extends from the winch in a continuous loop across the center of the array field in the east-to-west direction, and makes a turn around the turning sheave, then returns to the winch. The cable is attached to each of the 11 center torque rims with attachment cables and wire rope clips (Drawing 002496). Also, the cable requires retensioning approximately every 2–3 years.

CHRONOLOGY

IPC activities are shown chronologically in **Figure 3-5**. The duration from contract award to system acceptance by PVUSA was 49 months. The contract was established in June 1989. Hardware deliveries to the site began in May 1990, and PV system construction began in August 1990. Start-up began on October 23, 1991. The conditioning period ended in June 1993 and included unplanned PCU problems and a field retrofit by Mobil Solar of module junction boxes. The performance rating period ended in July 1993. The PCU problems that occurred during the conditioning and performance rating periods are fully described in *PVUSA Construction and Safety* (Shipman 1994).

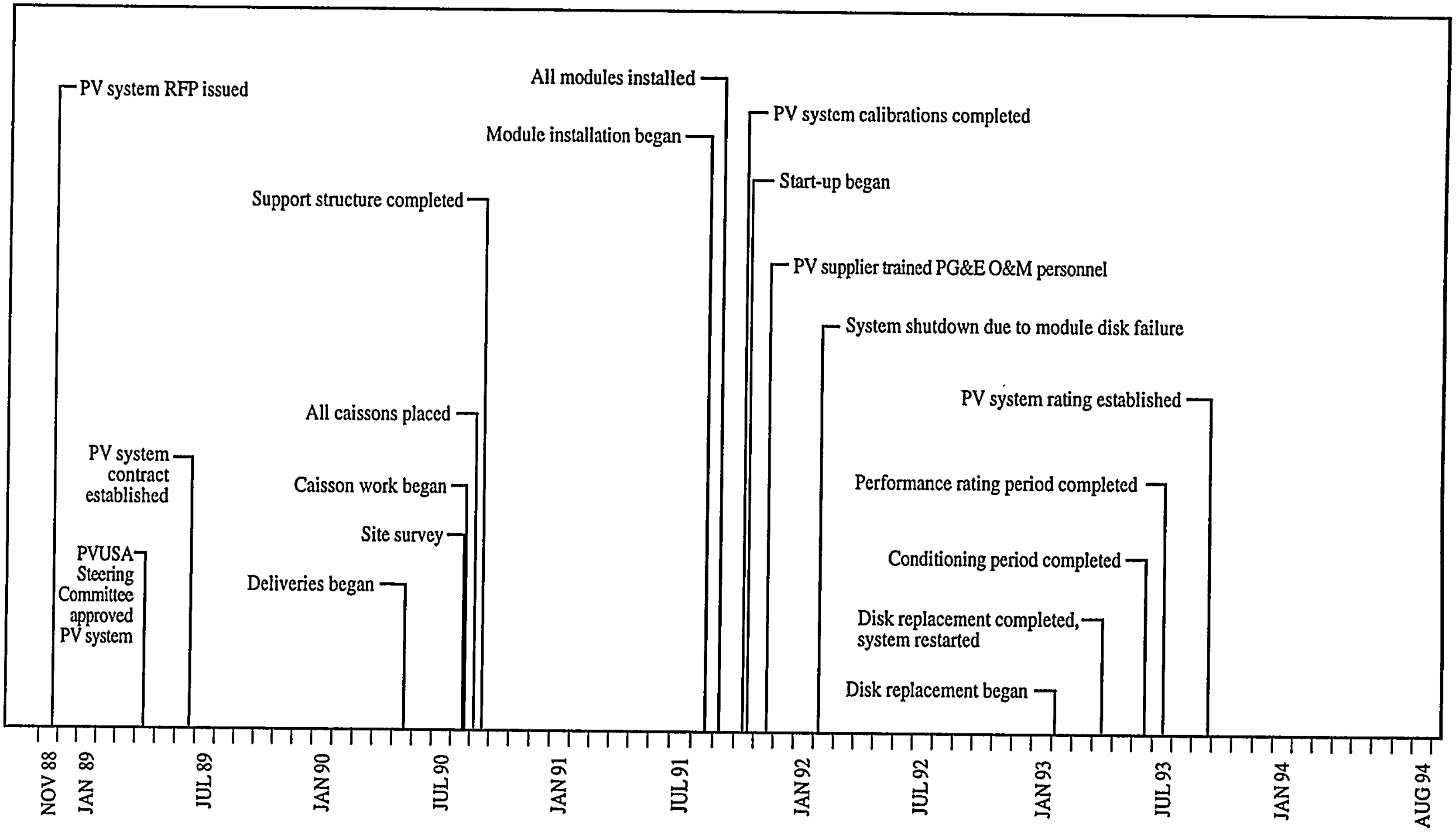


Figure 3-5. IPC Davis chronology.

PV SYSTEM COSTS

PVUSA paid $1,836,364 ($9.37/W) for the IPC system. IPC disclosed their actual cost data except for the PCU cost, which was provided by Omnion. The IPC contract price was 10% less than the actual cost. The $10.40/W actual cost includes $5.19/W for modules (50%), $1.12/W for the support structure (11%), $1.10/W for system installation (11%), $1.00/W for the PCU (10%), and $1.00/W for engineering and project management (10%).

PV SYSTEM LESSONS LEARNED

Successful Innovations

IPC satisfied all contract requirements. The system design is robust and is expected to operate reliably for at least 20 years except for the PCU, which to date has had intermittent problems of varying severity. Drawing from the experience gained by IPC and PVUSA, the following paragraphs describe the lessons learned.

Cost reduction was encouraged from the beginning, starting with the PV system RFP. The PV system was competitively bid, and responses were evaluated with equal weights on the following criteria:

- System price
- System design's adequacy for low O&M cost and high reliability
- System's suitability for long-term cost goals, or as a worthwhile intermediate step
- Bidder's capability

IPC selected the largest high-powered PV modules to reduce field installation work. Two unframed modules were mounted into an aluminum panel frame. The panel frame was set directly on the tracker torque tube and bolted in place during field installation. Since the module open circuit voltage is 10 V, panel mounting and handling were possible without protective gloves. After all the panels were mounted to the array structure, electrical rubber gloves (for personnel protection) were necessary when installing the module-to-module wire harnesses. Initially, modules were supplied with module termination disks, which facilitated installing factory-fabricated wiring harnesses.

The tracker design requires no electrical BOS components that need to be distributed throughout the 11 tracker structures. The active tracking controls allow for backtracking, minimizing row-to-row shading at the beginning and end of the day. It also allows closer row-to-row spacing without sacrificing significant energy loss. There is only one tracker drive, centrally located on the east side of the array for convenient maintenance.

BOS Problems and Resolutions

The IPC dc wiring included innovations, such as the use of module termination disks and factory-assembled wiring harnesses. These had the potential to save field labor in wiring installation. The module termination disks and wiring harnesses were initially tested by Mobil Solar and deemed suitable for outdoor installation. However, after installation, it was determined that the disks and harnesses allowed water intrusion. NREL reported that its two test panels showed signs of corrosion in the module termination disks. PVUSA personnel found similar corrosion problems at Davis but not as advanced as seen by NREL. IPC and Mobil Solar directed PVUSA to shut down the IPC system while they evaluated the problem. Following evaluation, IPC/Mobil Solar decided that the most effective way to fix the deficiency was to replace the module termination disks in the field with new module junction boxes. The disks had passed the module qualification process, but no field test of panels and harnesses had been performed. New wiring systems should be given rigorous outdoor testing to avoid potentially expensive delays and retrofits. Although ASE Americas still likes the module disk and harness concept for their large-area modules, their present approach is an innovative, UL-listed hermetically-sealed box with module bypass diodes and two wires with quick-connect plugs to connect to adjacent module boxes.

The PCU was installed with no shading and no active air conditioner. Although the unit was designed with external forced-air convective cooling for the power devices and internal circulating fans, the additional heat gained from solar radiation was underestimated by the manufacturer. After several overtemperature trips in the summer, Omnion added an air conditioning unit for the PCU. The PCU has also exhibited several periods of inconsistent performance with trips indicated as regulator or crowbar fault, ac overvoltage, dc overvoltage, and bridge fault. Some trips were linked with component failure, others could be immediately reset, and the remaining required some level of diagnostics to be performed. No clear trend or single root cause has yet been identified. Part of the difficulties may be related to the ability of the PV array to often generate power in excess of the PCU capability.

Potential for Improvements

IPC proposed a 180-kW system to PVUSA, using 10 rows of PV array. The efficiency of initial Mobil Solar modules was lower than expected but improved during the module production run, which is not uncommon. Both IPC and Mobil Solar opted for a conservative approach to array sizing and decided to supply an extra row. The 11 rows were rated at 196 kW, indicating that 10 rows would have furnished approximately 180 kW and that the added row was unnecessary.

PVUSA provided three overcurrent with voltage control (51C) relays and a UPS circuit for the 51C relays. The 51C relays trip the Omnion PCU's ac output circuit breakers. The utility requirement for the 51C relays is a technical requirement for conventional rotating generators but for PV generating systems is redundant to the protection system of the PCU. Additionally, the limited energy available from the PV array field requires the 51C relays to be applied as a voltage-controlled device rather than an overcurrent device. The cost of specifying, engineering, installing, and testing the 51C relays and the UPS circuit could have been saved if PG&E protection requirements had been less conservative.

The PVUSA specification required a submittal of a system O&M manual. IPC created an original document, with a one-time cost, since no standard document existed as a model. PV suppliers who have standard or model O&M manuals can achieve cost savings. PVUSA-specifications include a sample table of contents for an acceptable O&M manual. Turnkey PV systems with no research requirements can eliminate some PVUSA-specified items, including:

- PCU display meters
- PCU factory witness testing
- Additional modules
- Three back-of-module thermocouples
- Dc instrumentation

PCU display meters serve as a visual aid to visitors. The display meters provide little or no value to normal O&M tasks. The 10 additional modules delivered to the national laboratories are not necessary for mature commercial modules in a nonresearch project.

PVUSA required a safety design review of PCUs that lacked UL labeling (or similar) to meet NEC 90-6, Examination of Equipment for Safety. This review was also extended to the entire PV system for safety considerations. As PV system technology matures, UL listing will become standard practice for component manufacturers, eliminating the need and cost of the PVUSA safety design review.

Although the PCU design is an improvement over an earlier PCU version, factory inspection by the owner or its representatives was perceived to be necessary. The factory visit by the owner to conduct inspection and witness the factory PCU testing would have been eliminated if the PCU was a more commercially mature product. PCUs designed for indoor installation may require additional cooling means when installed outdoors.

If the PV system improvements proposed in **Table 3-1** were adopted, the total estimated cost reduction potential to IPC would have been $340,500, or $1.74/W based on the 196-kW rating. The maximum estimated PVUSA labor cost reduction potential is $20,000 ($0.10/W).

Failure-Related Maintenance Costs

Of all of the Davis and Kerman systems, PCU problems have the greatest impact on maintenance costs for the IPC system, which relies on a single PCU (**Figure 3-6**). The IPC PCU experienced insulated gate bipolar transistor (IGBT) and fuse failures on May 28, 1994, the third occurrence since system acceptance. The system was placed back in service on August 30, 1994. Failure-related maintenance took less than 1 week during the 3 months of downtime. The energy that might have been produced during this period would have significantly reduced the IPC failure-related maintenance cost per kilowatt-hour. The 3-month downtime included time for diagnostics, data gathering, determining a planned course of action, PVUSA acceptance of the plan, and implementation of the repairs and modification.

Labor and material account for 59% and 41%, respectively, of the total failure-related maintenance costs from July 1993 through 1994. The IPC system incurred failure-related maintenance costs of 6.3 cents/kWh in 1993, 3.6 cents/kWh in 1994, and 4.4 cents/kWh for the overall 18-month period. Failure-related maintenance costs will continue to be monitored as additional PCU problems occur and are addressed.

Table 3-1
Cost Reduction Potential of IPC Davis BOS

BOS Component	Component Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PV Supplier's Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
PCU inspection	Factory inspection by owner	Not required for mature equipment.	Procedural change. Eliminate trip to Omnion if mature equipment.	2,000	2,000
PCU protective circuit	Separate 51C relays	Controls that include all protection requirements.	Procedural change. Include all control and protection in PCU circuitry such as the over- current with voltage control relay (51C). Utility to eliminate the requirement for utility-grade relays.	12,000	4,000
PCU safety design review	No UL listing	Does not meet NEC required by PVUSA to ensure safety features are incorporated in design.	Procedural change. With mature PCU technology and as the equipment is listed, this requirement can be eliminated.	1,000	1,000
15 additional modules	Delivered to National Labs	Research-related.	Research item. Eliminate.	15,500	0
dc instrumentation	Installed	Research-related.	Research item. Eliminate.	5,000	0
PCU display meters	Installed	Visual aid to visitors only.	Research item. Eliminate.	5,000	0
UPS circuit	Installed	UPS circuit for research data logger.	Research item. Eliminate.	0	1,000
Module thermocouples	Installed	Research-related.	Research item. Eliminate all 3 thermocouples.	3,000	0
Air conditioning for PCU enclosure	Installed in the field	Air conditioning load reduces the power output by 3%. More PV required to get same power output.	Supplier efficiency issue. Design and install a shade over the PCU or install the PCU under a shade.	57,000	0
Module junction box	Field installed	Modules passing the qualification test had module junction boxes. Modules delivered had unproven module termination disks.	Supplier efficiency issue. Use design and materials that pass the qualification tests. Do not use innovative designs without adequate testing.	40,000	10,000
11 PV rows instead of 10 proposed	Added 1 more array row	Target PV module efficiencies were not attained during early production stage.	Supplier efficiency issue. Use proven modules with adequate field data.	170,000	0
O&M manual	Submitted	Customized document. IPC had to create the O&M manual from scratch.	Supplier efficiency issue. With standardized installations, only minor custom PV system features and printing cost will accrue.	30,000	2,000
		Subtotal Cost Reduction Potential		340,500	20,000
		Grand Total Cost Reduction Potential		360,500	($1.84/W)

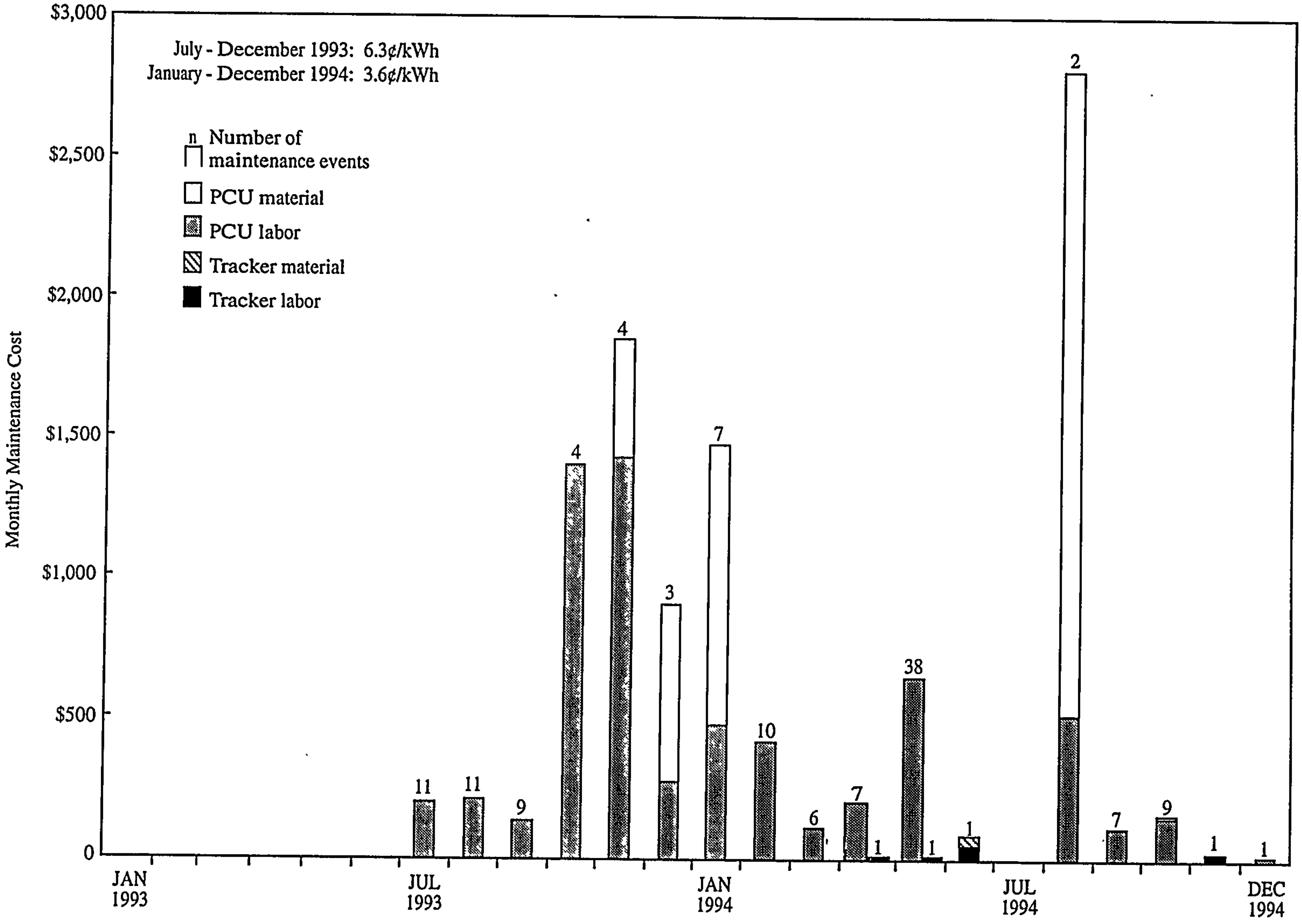


Figure 3-6. IPC Davis failure-related monthly maintenance costs.

Section 4

SIEMENS SOLAR INDUSTRIES

This section describes the Davis US system supplied by Siemens Solar Industries (SSI). System design, chronology, and costs are discussed. PV system BOS lessons learned and the estimated impact on design and cost are provided.

PV SYSTEM DESCRIPTION

The SSI PV system (**Figure 4-1**) was designed to have a peak power output of 174 kW. As proposed and installed, the system includes eight single-axis passive tracking PV array rows, two PCUs (Bluepoint Associates Inc. Model 3), a power step-up transformer, and a 15-kV fused disconnect switch. The array field has eight bi-polar source circuits, each source circuit providing the dc input power to one bridge. Four source circuits provide dc input power to each PCU, labeled PCU A and PCU B.

PVUSA accepted the SSI PV system with one PCU and its corresponding four dc source circuits operational. With four source circuits operating, the system rating is 67 kW. The other PCU is inoperative and serves as a spare. The four dc source circuits associated with the spare PCU are functional but left open circuited. All SSI drawings referenced are located in **Appendix A**.

Drawing 017660 is the single-line diagram. The array source circuit operating voltage is 630 Vdc pole-to-pole, with a maximum open circuit voltage of 944 Vdc pole-to-pole. Each bi-polar source circuit has two monopoles; a monopole has 62 series-connected four-module subpanels. Each bi-polar source circuit is composed of two half rows. There are eight rows in the array field corresponding to eight bi-polar source circuits, for a total of 3,968 M54J modules.

The M54J modules are designed with two module junction boxes. The junction box is provided for systems that are to be field wet resistance tested. Each panel has eight modules or two 4-module subpanels, supported by an extruded aluminum channel frame. Each 4-module subpanel is protected by a bypass diode external to the modules. The bypass diode assembly is a dual diode, packaged into one dual pack assembly.

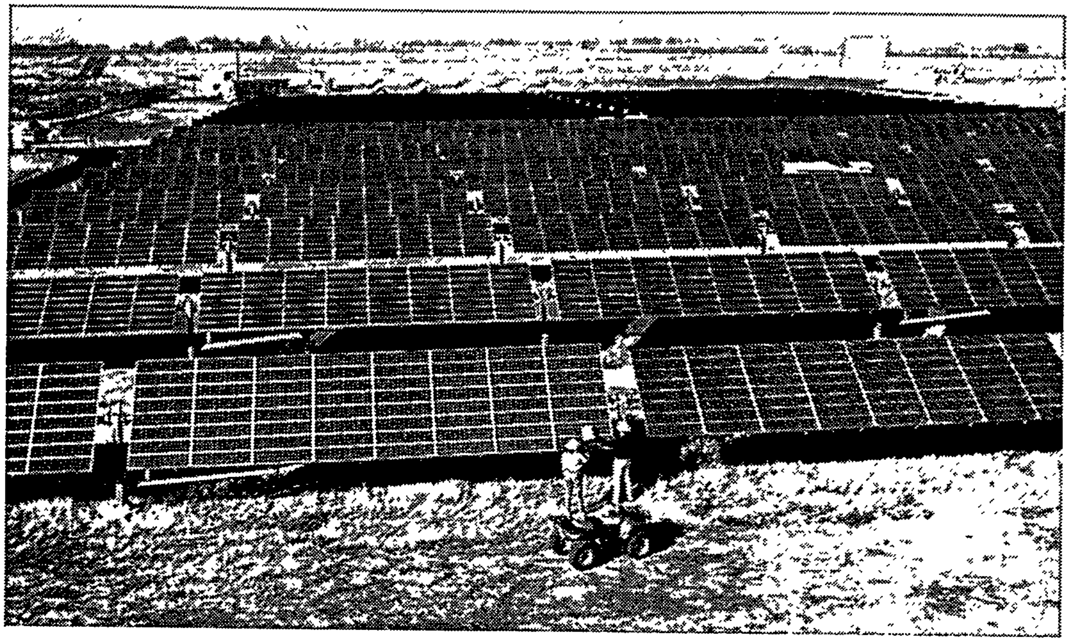


Figure 4-1. SSI Davis array.

Each bi-polar dc source circuit is collected at its respective source circuit junction box (no disconnect switch) located at the geometric center of the array row. The source circuit wiring is routed underground through PVC conduits to the four dc 4-pole disconnect switches near the PCU area (Drawing 017859). The output of each dc 4-pole disconnect switch is fed to one (of four) PCU bridge module.

Each 100-kW (nominal) PCU has four bridge modules (power electronics) that are controlled by a central processing unit. The four bridge modules are grouped electrically into two 50-kW modules. Both 50-kW PCU modules (two-bridge modules) provide 480 Vac, three phase. The output of each 50-kW PCU module is fed into one of two 100-A, 600-Vac circuit breakers located in the PCU enclosure. Two sets of three-phase ac wires, six #2 AWG, are routed via underground PVC conduits from the PCU enclosure to the 480-V switchgear area (the switchgear area is located at the center of the array field). These wires are landed on two 150-A circuit breakers that feed the ac power to the delta and wye windings of the step-up transformer. Each 150-A circuit breaker is equipped with a stored energy trip device, essentially a capacitor discharge device.

The SSI system has two sets of three 51C relays (overcurrent with voltage control), one for each of the two 150-A circuit breakers.

The 200-kVA, 480V-12,470V step-up transformer is configured with two secondary windings—a 480-V wye and a 480-V delta. The primary winding is 12,470-V delta. The primary side of the step-up transformer is connected to the 15-kV metering enclosure before it is connected to the PVUSA-provided 15-kV cable.

Power factor correction capacitors were not necessary for the SSI system. However, harmonic filter capacitors were required. A separate harmonic filter capacitor box houses the harmonic filter capacitors. This box is mounted outside the enclosure housing the two 150-A circuit breakers.

As with APS, the 72 concrete array foundations with imbedded steel rebars are utilized as ground rods. A #2 AWG bare copper ground wire is bonded to each of the eight steel columns (one each at the center of each row). These #2 AWG bare copper ground wires are connected to a #2 AWG bare copper ground wire that is run along with SSI's dc electrical underground conduit and wires. At the PCU area, SSI bonded all electrical equipment to the #2 AWG ground wire (Drawing 017795 sheet 1 of 5). The SSI-provided ground system is connected to the PVUSA-provided ground system at the 15-kV metering enclosure.

Each SSI array row has nine concrete foundations spaced 36.5 ft apart (except for the northernmost concrete foundation), and each row is 42 ft apart. Each structural steel pedestal has a baseplate that is bolted to its foundation with anchor bolts, leveled with grout, and in turn is grounded to the rebar. This mechanical connection serves as the connection to ground.

Nine structural steel pedestals support one row of the one-axis tracker structure (**Figure 4-2**). Each tracker is supported by bearings located on top of the steel pedestals. Each row has four passive tracker actuators, supplied to SSI by Robbins Engineering Inc. The actuators are SUN SEEKER® thermo-hydraulic tracking systems, filled with a mixture of oil and R22 refrigerant. Each actuator is designed to operate two eight-panel sections. All of the panel sections in one row are mechanically linked such that the entire row moves east-to-west in unison during the day.

CHRONOLOGY

SSI Davis system activities are shown chronologically in **Figure 4-3**. The duration from contract award to system acceptance by PVUSA was 60 months. The contract was established in June 1989. Hardware deliveries to the site began in January 1990, and PV system construction began in February 1990. Start-up began on January 18, 1991. On January 28, 1994, after 3 years, SSI was able to complete a PVUSA-

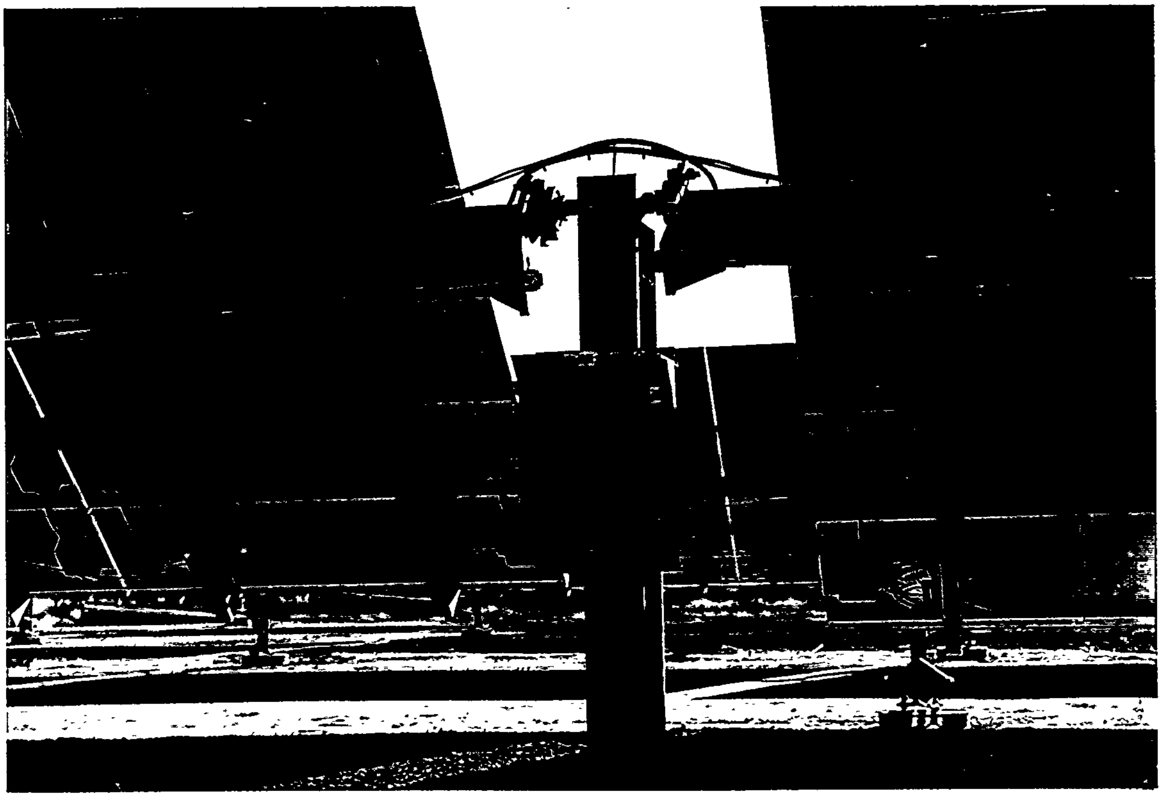


Figure 4-2. SSI Davis support structure (back of array).

mandated 28-day operational test, with 96.7% availability, exceeding the 95% requirement. Subsequently, this operational performance with both PCUs running could not be sustained. The conditioning period ended in May 1994. The performance rating period ended in June 1994 with sufficient run time to establish an acceptable database. SSI and PVUSA entered into negotiations for acceptance of an incomplete system, which resulted in contract closure in July 1994. The PCU problems that occurred during the conditioning and performance rating periods are described in *PVUSA Construction and Safety* (Shipman 1994).

PV SYSTEM COSTS

The contract price for the SSI system was $1,805,136. The terms of the subsequent settlement between PVUSA and SSI remain confidential. SSI's actual costs were presented by Siemens (SSI's parent company) at a July 1994 conference (Cunow 1994). The reported costs do not include 1993-1994 system start-up costs. The contract price was 20% less than the reported costs to SSI. The $2,252,800 SSI Davis cost includes $1,027,400 for modules (46%), $358,600 for engineering and project management (16%), $299,200 for the support structure (13%), $250,800 for panelization (11%), and $149,600 for the PCUs (7%).

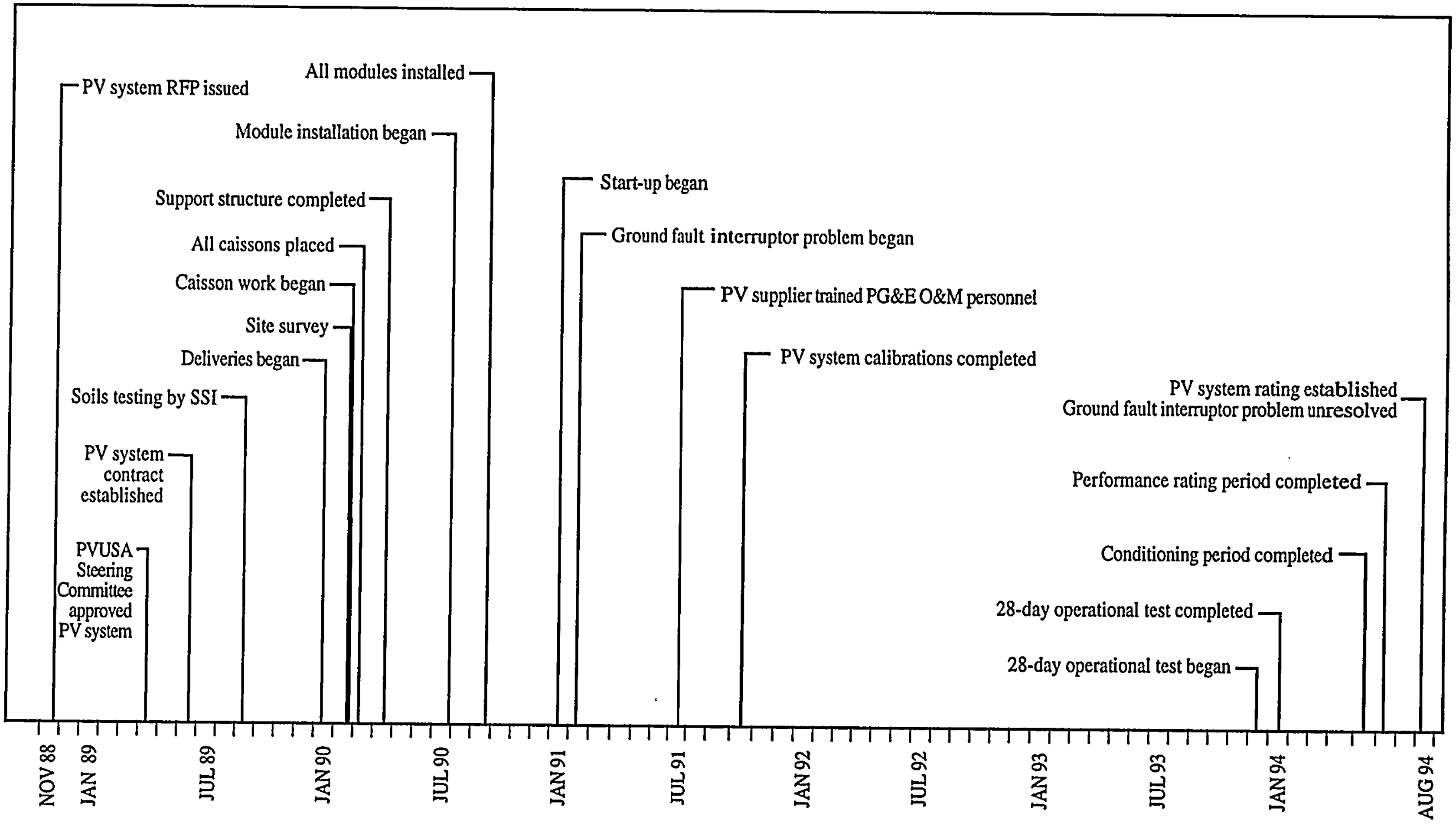


Figure 4-3. SSI Davis chronology.

PV SYSTEM LESSONS LEARNED

Successful Innovations

Cost reduction was a PVUSA objective starting with the PV system RFP. The PV system was competitively bid, and responses were evaluated with equal weights on the following criteria:

- System price
- System design's adequacy for low O&M cost and high reliability
- System's suitability for long-term cost goals, or as a promising intermediate step
- Bidder's capability

The modules were panelized at the SSI factory to minimize field installation. Each panel included eight modules, completely mounted and wired on the aluminum panel supports. These were shipped in a bob-tail 2-ton moving truck and off-loaded directly into the tracker structure.

Installation was achieved using a three-man crew. After all the panels in a row were installed on the structure, the four-module subpanel series wiring and bypass diode wiring were installed.

The PCU design and topology promised a high dc-to-ac conversion efficiency of 99%, primarily due to the absence of inductors and capacitors in the bridge or power circuit. The power quality of the output, or harmonic content, is a function of the impedance between the PCU and the point of connection to the utility grid (in this instance, the impedance of the 15-kV cables and the impedance of the step-up transformer).

BOS Problems and Resolutions

Each PCU was initially configured with nine different enclosures mounted on a rack. The nine enclosures consisted of four dc disconnect switches, two ac disconnect switches, one PCU bridge enclosure, one dc contactor enclosure, and an instrumentation enclosure. Workmanship was below commercial norms, and the equipment was close to being laboratory prototype. After deployment in the field, several operational problems were encountered, including unreliable operation when both PCUs ran simultaneously. Some component problems were discovered during PVUSA testing in 1990 and 1991 (Shipman 1994).

SSI retained the services of a consultant, Wes Joshi, to analyze the Dickerson inverter hardware. Suspected problem areas included electrical noise, an improperly designed heat sink, faulty dc and ac contactors, loose and inadequate wiring, and an intermittent problem with the SSI-provided array ground fault detection system. SSI decided to repackage one PCU into a larger free-standing enclosure.

A new set of PCU design drawings was submitted to PVUSA for review and comment. PVUSA conducted the review, and also obtained a safety design review from Frank Beane, a PVUSA consultant on equipment safety. The repackaged PCU B was operational in September 1992. SSI then decided to repackage the second PCU, which was later installed at Davis in January 1993. A repackaged PCU is shown in **Figure 4-4**.

The "Delayed Completion" provisions of the contract required the installation to be ready for acceptance testing by September 30, 1990. Delays past this date were agreed to as liquidated damages at the rate of $400 for each calendar day of delay. This provision was a consideration of the final settlement. System construction was substantially complete on December 20, 1990, although punch lists identifying deficiencies remained to be cleared.

Delays past this date are mainly attributable to the difficulties experienced by SSI in getting the Bluepoint PCUs and the SSI ground fault protection system to function reliably. The initial three-month construction delay was due to several factors, including:

1. SSI drawings were received late, were unchecked, and contained errors. The ground fault protection system and the meters required for visual aid were omitted in the initial drawings submitted. These caused delays in the drawing acceptance process.
2. SSI did not use a CPM schedule, and delivery of PV panels to the site was intermittent. Craft work force stopped work (demobilized) three times because of lack of material.
3. The PVUSA FWRT and other tests and inspections found numerous quality control problems, which include:
    - Dual diode cases with inadequate environmental seal
    - Cracked plastic module junction boxes
    - Wiring polarity reversals
    - Column anchor bolt spacing was changed by engineering during construction
    - Torque tube bearing problems

The 3-month delay in completion of the construction work could have been avoided by better planning and a better engineering effort up-front. The planned completion date of September 30, 1990, should have been attained or bettered.

Turnkey PV systems could be engineered and constructed more inexpensively than the PVUSA US systems. This can be done by eliminating or reducing components or inspections or other factors.

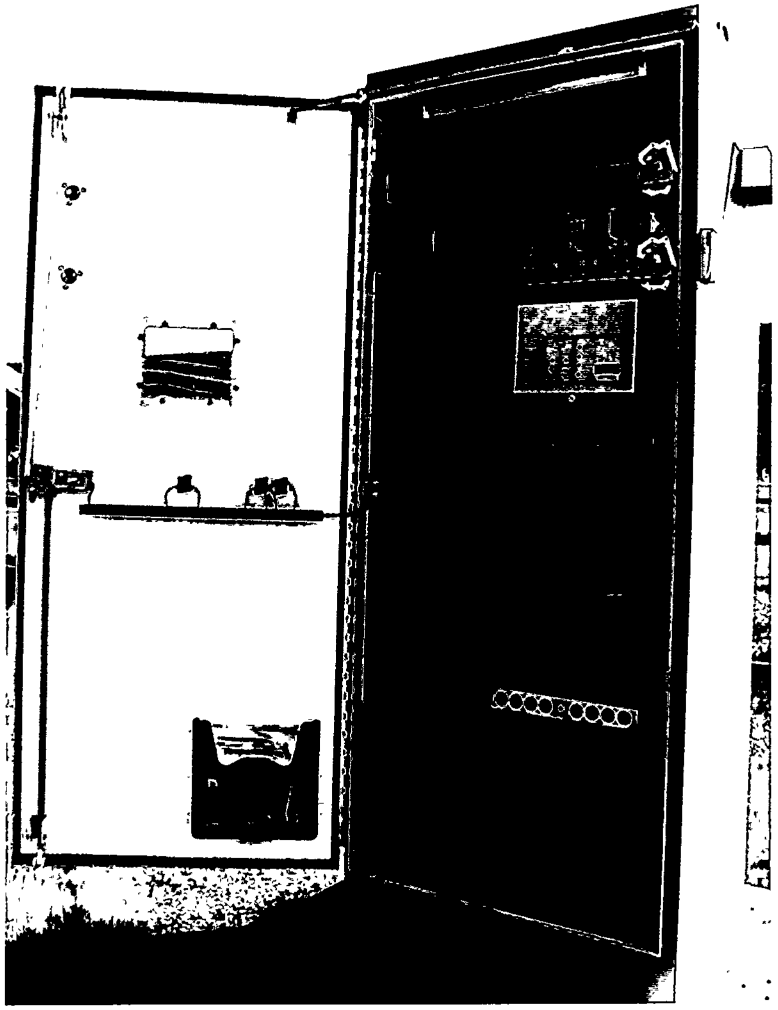


Figure 4-4. One of two repackaged Bluepoint PCUs.

Table 4-1 gives a listing of potential cost reductions to a turnkey PV plant using SSI system costs as the base case. The potential cost reductions fall into one of the following categories.

1. Elimination of components required only for research applications. Five items fall under this category. Examples are thermocouples and other DAS inputs.

Table 4-1
Cost Reduction Potential of SSI Davis BOS

BOS Component	Component Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PV Supplier's Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
15 additional modules	Delivered to National Labs	Research-related.	Research item. Eliminate.	4,000	0
dc instrumentation	Installed	Research-related.	Research item. Eliminate.	5,000	0
Module thermocouples	Installed	Research-related.	Research item. Eliminate all 3 thermocouples.	3,000	0
PCU display meters	Installed	Visual aid to visitors only.	Research item. Eliminate.	5,000	0
UPS circuit	Installed	UPS circuit for research data logger.	Research item. Eliminate.	0	1,000
Bypass diode	Field retrofit	Bypass diode failed FWRT. SSI field-added sealing compound, silicone.	Quality control issue. Select bypass diode that is suitable for outdoor environment.	10,000	2,000
Module junction box	Field fix of failed junction boxes	Several module junction boxes failed during FWRT due to hairline cracks.	Quality control issue. Improve the implementation of the factory quality assurance, quality control plan.	5,000	500
Tracker actuators	Replaced leaking actuators	Design and materials used does not warrant against leaks.	Quality control issue. Proper design and selection of materials.	10,000	2,000
PCU inspection	Factory inspection by owner	Not required for mature equipment.	Procedural change. Eliminate 1 trip to Bluepoint Associates Inc. if mature equipment.	1,000	1,000
PCU protective circuit	Separate 51C relays	Controls that include all protection requirements.	Procedural change. Include all control and protection in PCU circuitry such as the overcurrent with voltage control relay (51C). Utility to eliminate the requirement for utility-grade relays.	24,000	7,000
PCU repackaged	Both PCUs re-packaged	Original layout and workmanship resembles prototypical or laboratory equipment.	Procedural change. Specify non-developmental equipment, or specify commercial equipment.	30,000	5,000
PCU safety design review	No UL listing	Does not meet NEC, required by PVUSA to ensure safety features are incorporated in design.	Procedural change. With mature PCU technology and as the equipment is listed, this requirement can be eliminated.	1,000	1,000
Repackaged PCU inspection	Factory inspection by owner	Not required for mature equipment.	Procedural change. Eliminate 1 trip to Bluepoint Associates Inc. if mature equipment.	1,000	1,000
Soils report	Duplicated by SSI	Owner did not guarantee its own soils report.	Procedural change. Eliminate if owner guarantees soils report.	5,000	0
dc ground fault protection	Not acceptable	Dc ground fault is a technical requirement that was overlooked and was done as an afterthought, caused improper operation.	Supplier efficiency issue. Adhere to specifications and select proper devices or equipment.	10,000	15,000
Engineering: O & M Manual	Submitted late and incomplete	Delays in submitting an incomplete O & M manual, not responsive to specifications.	Supplier efficiency issue. Prepare a complete O & M manual according to schedule. More follow through.	10,000	2,000
Engineering: Internal review	Internal design reviews not done	Design documents have errors and omissions, also created a "domino effect."	Supplier efficiency issue. Implement internal design reviews, provide adequate and proper engineering staff.	10,000	2,000
Engineering: Submittals	Submittals were late	Delays in submitting contract documents (drawings, etc.) causes cascading delays.	Supplier efficiency issue. Assign adequate and proper resources to engineering activities.	10,000	2,000
Equipment delivery	Intermittent delivery	Module deliveries were intermittent and caused 3 separate mobilizations by craft or construction personnel.	Supplier efficiency issue. Formalize the schedule, use a CPM tool and incorporate detailed activities, including engineering, construction, and deliveries.	10,000	2,000

Table 4-1
Cost Reduction Potential of SSI Davis BOS (continued)

BOS Component	Component Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PV Supplier's Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
Management: Coordination	Ineffective coordination	Lack of coordination with major equipment suppliers, impacts schedule.	Supplier efficiency issue. Use CPM schedule. Improve coordination and establish good communications with equipment suppliers.	50,000	25,000
O&M manual	Submitted	Customized document, SSI had to create the O&M manual from scratch.	Supplier efficiency issue. With standardized installations, only minor custom PV system features and printing cost will accrue.	30,000	2,000
PCU display meters	Field installed in separate enclosure	SSI omitted display meters during initial design. Installation was a field retrofit.	Supplier efficiency issue. Fully comply with the owner's specification, unless the omission is approved.	2,000	500
		Subtotal Cost Reduction Potential		236,000	71,000
		Grand Total Cost Reduction Potential		307,000	($1.76/W)

2. Changing the utility procedure. Examples include avoiding redundant protection, the owner furnishing and guaranteeing the site soils report, and avoiding prototype (noncommercial) components.
3. Improving the efficiency of the PV suppliers or system integrators. Supplier efficiency will improve with more contract experience. Eight instances of avoidable costs are furnished.
4. Improving PV supplier quality control programs. Three examples are furnished of deficiencies that could have been avoided.

If the PV system improvements proposed in **Table 4-1** were adopted, the maximum estimated cost reduction potential to SSI would be $236,000, or $1.36/W based on 174 kW (design). The maximum estimated PVUSA labor cost reduction potential is $71,000, or $0.41/W.

Failure-Related Maintenance Costs

SSI failure-related maintenance costs are indicated in **Figure 4-5.** These costs do not include costs for preventive maintenance based on PV system supplier recommendations.

SSI failure-related maintenance costs from system acceptance in July 1994 through December 1994 are solely labor costs incurred to address PCU problems. The SSI system demonstrated failure-related maintenance costs of 0.9 cents/kWh during the last 6 months of 1994 and will continue to be monitored.

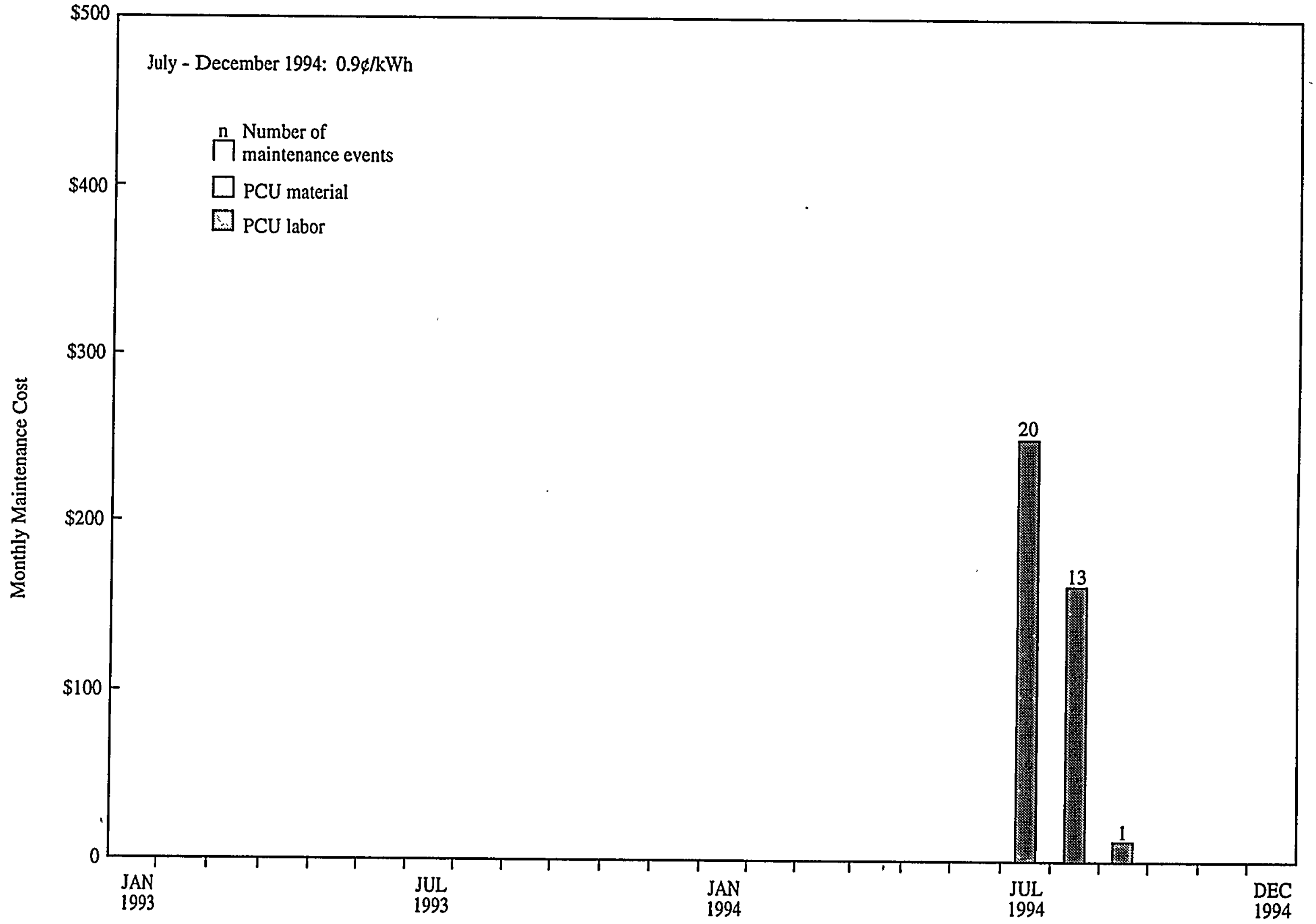


Figure 4-5. SSI Davis failure-related monthly maintenance costs.

Section 5

KERMAN PV PLANT

This section focuses on the Kerman PV plant owned by PG&E. It describes the US system supplied by SSI and the PVUSA-provided BOS, outlines the chronology in plant construction, provides a breakdown of the work of the construction labor force, and itemizes the costs for the PV system and PVUSA-provided BOS. The section also discusses lessons learned, and in light of these lessons, describes the design, schedule, and costs of the owner-provided BOS for commercial plants of varying sizes with requirements similar to the Kerman PV plant. Recommendations for PV plant installation based on PVUSA experience are also made.

PLANT OVERVIEW

The Kerman PV plant was built as a grid-support demonstration, and is located about 8.5 circuit miles from PG&E's Kerman substation in California's Central Valley (**Figure 5-1**). Companion reports describe the grid-support concept and the selection of Kerman feeder #1103 for the demonstration (Shugar et al. 1992); the methodologies used to assess the benefits of distributed PV, with benefits quantified for Kerman (Hoff and Wenger 1994); and Kerman plant performance (PVUSA Project Team 1994, Hoff and Wenger 1994).

The Kerman PV plant consists of a turnkey 498-kW PV system supplied by SSI and PVUSA-provided infrastructure. **Appendix A** contains drawings of the plant layout (PG&E Drawing 4008179), PV system design (SSI Drawings 018347, 018242, 018349, 018356, and 018361), civil site improvements by PVUSA (PG&E Drawings 359638 and 359639), electrical single-line diagrams (PG&E Drawings 4008186 and 4008187), and SCADA input/output point list (PG&E Drawing 065761). The PV system occupies about 4 acres of the 10-acre site. The 2 acres south of the PV system are developed for civil and electrical infrastructure; the 3 acres north of the PV system and a total of 1 acre on the west and east sides of the PV array field are undeveloped.

PV SYSTEM DESCRIPTION

The Kerman PV plant consists of 12,240 SSI M55VJ single-crystal silicon modules mounted on eight and one-half rows of horizontal one-axis SUN SEEKER® passive trackers. The system provides power to PG&E's grid through two nominal 275-kW Omnion Series 3200 PCUs (**Figure 5-2**).

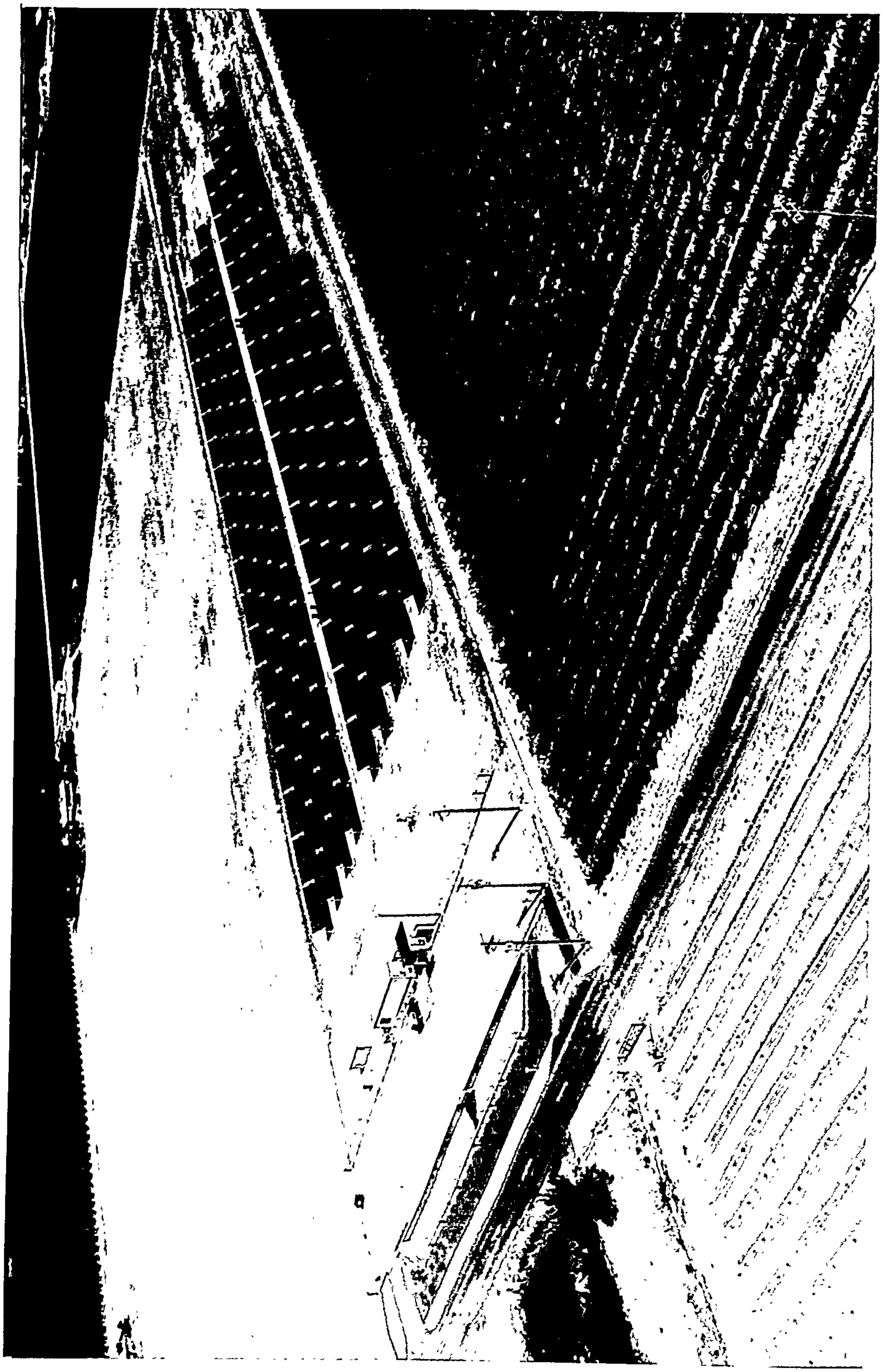


Figure 5-1. PVUSA Kerman PV Plant, January 1993.

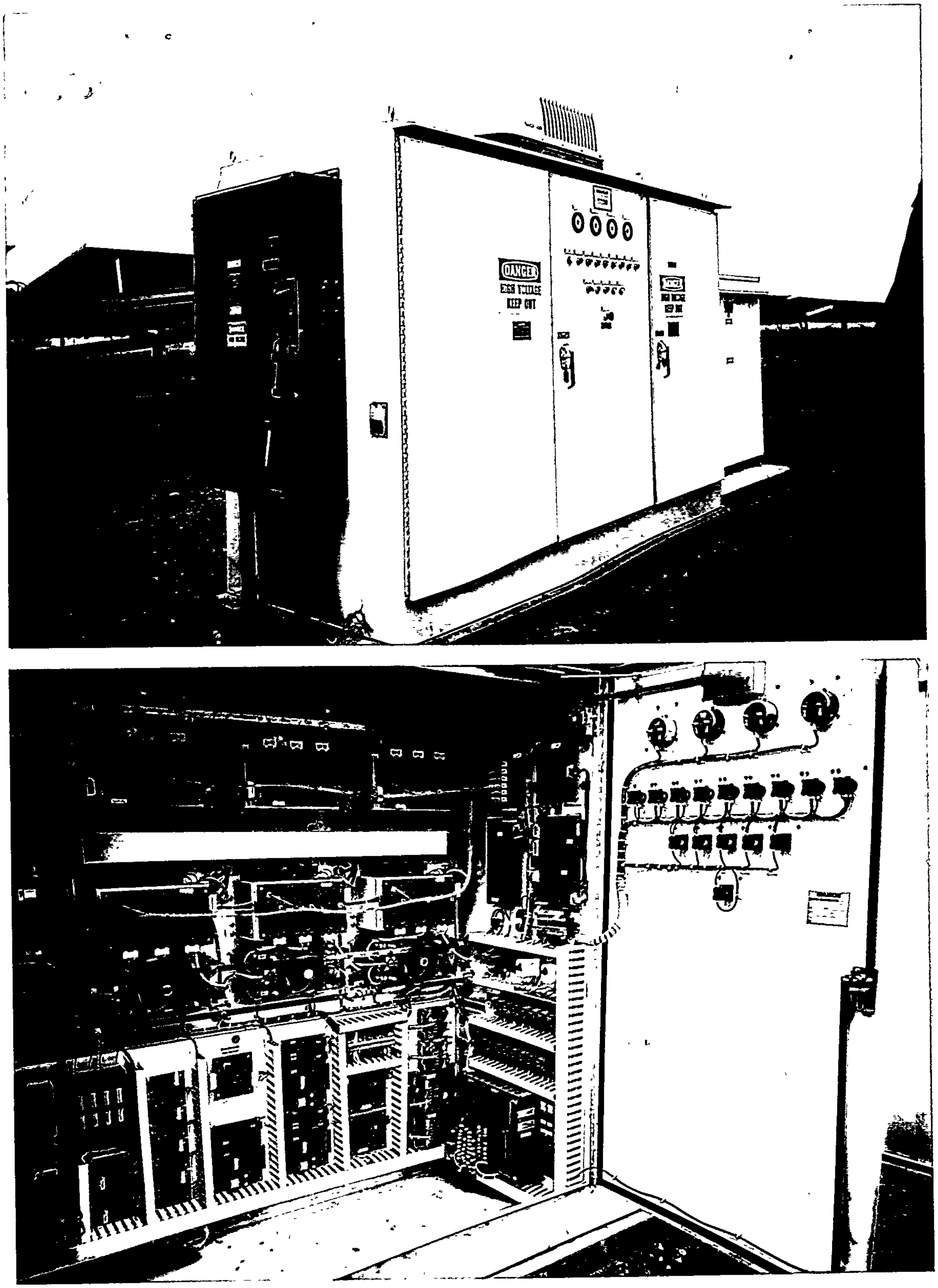


Figure 5-2. One of two SSI Kerman Omnion PCUs.

Each M55VJ glass-EVA-tedlar module has three parallel strings of 12 cells in series, positive and negative junction boxes, and an aluminum frame, which is grounded to the support structure with a flat-braid ground strap. The 13.0- x 50.9-in. module has a design output power of 48.25 W and an efficiency of 11.34% at PVUSA Test Conditions. Ten modules are mounted at four points with 1/4-in. nuts/bolts onto two aluminum support channels to form a panel. Within each 10-module panel, each of two separate subpanels has five modules electrically connected in parallel using #6 AWG wire. A bypass diode is wired in parallel with each subpanel (one diode per 12 series cells). Three modules within the array have type T back-of-module thermocouples.

Each tracker support beam holds eight panels using Delrin spacers to prevent galvanic corrosion. The support structure consists of steel column posts, torque tubes, and panel support beams. Support structure and reinforced concrete foundation material requirements and costs are documented in *PVUSA Construction and Safety* (Shipman 1994). Each of the eight full-length rows is driven by nine passive trackers; the half row is driven by five trackers. The trackers within each row are connected together by torque arm crossovers. Although the PVUSA-procured land is in a good grid-support location, it is not the optimum shape for SSI and other PV system bidders. The asymmetrical eight and one-half rows of trackers are due to PVUSA's long rectangular property and 500-kW design constraints.

The SUN SEEKER® passive tracker consists of a pair of cylindrical evaporator tubes, a double-acting actuator, and a pair of galvanized steel reflectors. The evaporator tubes are connected to the opposite sides of the actuator piston with flexible hydraulic hoses. The tubes and actuator are filled with R-134a (tetrafluoroethane) refrigerant; enough void exists in each tube to allow the actuator to stroke fully in each direction. The passive tracking design has a 0–10° lagging accuracy during the summer months, a 2-hr morning wakeup interval, and 100° total travel ($\pm 50^{\circ}$ from horizontal).

The PV array has 17 identical subarrays, each of which consists of 144 subpanels connected in series. Subarrays 1-9 are connected to PCU #1 and subarrays 10-17 are connected to PCU #2. Each subarray forms a source circuit with an operating voltage of ±360 Vdc and an operating current of ±48 Adc. To reduce the circuit-to-ground potential, each source circuit has a grounded center-tap neutral. The two monopoles of each subarray are connected in series to produce a source circuit that operates at 720 Vdc.

The dc power collection boxes in the middle of each of the 17 subarrays contain the positive, neutral, and negative take-offs from each source circuit. Each box also contains a pull-apart disconnect switch (to facilitate subarray maintenance), a metal oxide varistor (MOV) surge protector (to protect the monopole from large voltage transients) protected by a 50-A fuse (to prevent the energy dissipated by the MOV from exceeding the MOV's rating), a blocking diode (to prevent reverse current flow into the monopole), and a

60-A main fuse (for backup protection if the blocking diode fails shorted). The dc power is conducted from the boxes to the main dc disconnect switches at each PCU via insulated #4 AWG copper wire in Schedule 40 PVC conduit.

Each self-commutated Omnion Series 3200 PCU has six parallel three-phase insulated-gate bipolar transistor (IGBT) bridges and is designed to deliver ac power with less than 5% current harmonic distortion and a 95% efficiency at 500-kWac plant output. The two separately controlled 275-kW nominal PCUs convert the PV array dc power to 374-V, three-phase ac power, and the step-up transformer (374 V/12.47 kV) raises the voltage to 12.47 kV. A one-to-one isolation transformer is connected at the output of PCU #2 prior to parallel connection to the output of PCU #1, providing electrical isolation of, and preventing ground currents between, the two PCUs. SSI constructed foundations for the PCUs and isolation transformer.

The PV system is grounded using the concrete caissons as the ground electrodes and the steel structure as the ground grid. Every trench with SSI underground cables also has bare copper wire that runs the entire length of the trench and is connected to the ground grid .

The SSI project/construction manager supervised PV system construction from an SSI-provided, temporary 8- x 20-ft construction trailer equipped with power and telephone. SSI was required to deliver, in addition to the PV system, construction drawings updated to reflect as-built conditions, monthly progress reports, an O&M manual, a system warranty period of 2 years with an additional 3-year warranty period for the PV modules, and 15 additional modules for separate research purposes (i.e., not intended to be used as spares).

PVUSA-PROVIDED BOS DESCRIPTION

PVUSA-provided BOS includes

- Fencing
- Grounding
- Asphalt approaches
- Drainage pond
- Landscaping
- Parking and access facilities
- Construction trailer

- Site well and septic system
- Control building with battery bank
- Communications
- Instrumentation and control
- Utility interconnection

In addition, the BOS includes a storage container, 12-kV switchgear and maintenance tools, meteorological equipment, and foundations for the construction trailer, site well, control building, SCADA equipment, meteorological equipment, and PG&E meter. Additionally, medium- and low-voltage cables, pull boxes, and vaults were installed.

Fencing

The 10-acre site is secured by a standard PG&E perimeter property fence. The fence has three rows of barbed wire on single extension arms over 7 ft of #9 gauge chain link fabric for an overall height of 8 ft. The west perimeter fence has a 22-ft double-swing gate that was installed for SSI's access to the array field during concurrent SSI and PVUSA construction activities. PVUSA constructed an access road on 1 acre of leased farmland adjacent to the site; the gate is no longer needed but was left in place.

An intermediate east-west cross fence 100 ft north of the south property line was installed to separate the parking area from the array field and provide site security to SSI during construction. The 300-ft intermediate fence is 6-ft high #9 gauge chain link fabric and includes two 22-ft double-swing gates and one 4-ft personnel gate for array field access. To comply with grounding requirements, the intermediate fence has two sections that are electrically isolated using standoff insulators.

Grounding

Grounding for the PVUSA-provided BOS consists of ground electrodes and buried #4/0 bare copper ground wire encircling equipment foundations. The number of grounding electrodes was based on reducing the resistance of the ground grid to earth ground to 5 ohms or less. Buildings and major equipment are connected to the ground grid. Every trench with PVUSA-provided underground cables also has a #4/0 bare copper ground wire that is connected to the ground grid and runs the entire length of the trench. The fence is grounded via grounding electrodes spaced no more than 75 ft apart, per PG&E substation grounding standards.

Approaches

The site is accessed via West McKinley Avenue by two asphalt encroachments serviced by 25-ft rolling gates. The other three sides of the site are bounded by farmland. The site is relatively level with a 2-ft drop from the north to West McKinley Avenue on the south. The roads and parking area are sloped for drainage. The yard area elevation increase of 3 ft from its original level required importation of 1,300 cu yd of general fill material.

Drainage Pond

To prohibit runoff onto West McKinley Avenue, a concrete-walled drainage pond was installed to capture approximately 30,000 sq ft of yard-area runoff (**Figure 5-3**). The drainage pond is designed to control the equivalent runoff produced from a total of 6 in. of rain over a 10-day period, expected of a 100-year storm. The remaining 9 acres of the site have no drainage structures, except for a small ditch adjacent to the west perimeter fence, which prevents normal levels of irrigation water from entering the site.

Landscaping

The drainage pond and the irrigated frontage landscaping are "good neighbor" (but costly) BOS components, although the drainage pond would have been required if PVUSA had not been successful in obtaining an exemption from Fresno County land-use and building permit requirements. Not in the original PV plant design, the landscaping was intended to address a neighbor's concerns about PV plant aesthetics. Consisting of trees, bushes, and red lava rock, the landscaping is along West McKinley Avenue in front of the perimeter fence.

Parking

The 6-in. aggregate base yard area, located between the drainage pond and the intermediate fence, provides parking for 20 vehicles; seven parking spaces, including one asphalt handicapped parking space, are marked. The yard and gate configuration allow adequate maneuvering space for semitrailer trucks. The PV system is serviced by a 9-in. aggregate base road that extends from the parking area northward through the center of the array field.

Construction Trailer

PVUSA supervised plant construction from a 10- x 40-ft prefabricated field construction trailer. Given PVUSA's research nature, the trailer was modestly designed to serve as a visitor center for at least 2 years after plant construction. The trailer is serviced by a 240-V heat pump system, service water, UPS power, smoke detectors, telephone outlets, and 115-V power receptacles. Security lights on the south side are activated by photocells. The trailer is surrounded on the north and west sides by an 8-ft wide deck; the south side has a handicap ramp for access to the trailer and lavatory facilities. The trailer has a service water shutoff valve in a concrete box at the base of the ramp.

Figure 5-3. Kerman drainage pond.

Well

The site well is 58 ft west of the construction trailer and is 160 ft deep, 8 in. in diameter, and produces 100 gallons per minute (gpm). Capable of producing 25 gpm at 35 psi, the pump is set 120 ft into the well; the static water level is 57 ft. The well services the lavatory, two hose bibs, and the landscaping irrigation.

Control Building

The control building contains the control, SCADA, telecommunication, and metering equipment. The prefabricated 16- x 12-ft (ARMCO) building is equipped with a thermostatically controlled heat pump, lights, telephone, power receptacles, 120-Vac UPS, and a 48-Vdc 200-Ahr battery system.

The 374-V output from the PCUs flows through a circuit breaker into the main transformer, which steps up the voltage from 374 V to 12.47 kV, then through a disconnect switch before entering PG&E's grid. The plant output feeds PG&E's Kerman substation distribution circuit #1103. A pole-mounted disconnect switch (#1475) serves as the interface point with the utility. A 15-kV pad-mounted, metal-enclosed, fused -

disconnect switch (#89-1) serves as a clearance point between the plant and feeder #1103. Primary metering instrument transformers are also contained in the enclosure for switch #89-1.

There are three auxiliary electrical power systems: 240/120-Vac, 120-Vac UPS, and 48-Vdc. Two pole-mounted transformers (10-kVA and 25-kVA) connected in open delta provide three-phase 240/120-Vac auxiliary power. A 240/120-Vac distribution panel board serves all auxiliary electrical loads except SCADA, telecommunication, and protection equipment. A 3-kVA, 120-Vac, single-phase UPS powers the research computer and future critical 120-Vac loads. A 48-Vdc battery and charger provide power through the 48-Vdc panel board to protective relays, circuit breaker control circuits, and SCADA equipment.

Instrumentation and Control

Designed to facilitate unattended plant operation and to be integrated with PG&E's existing SCADA network, the PVUSA Kerman SCADA equipment provides remote control capability and performance and status information to PG&E operations personnel. A total of 117 analog and digital input/output points are monitored, providing data for analysis by PVUSA (**Figure 5-4**). Although all of the 117 SCADA points are available to PG&E operations, approximately 40% are used for remote monitoring and control.

The data acquisition system features electronic metering connected to a SCADA backbone. The SCADA system uses Harris (formerly Westronic) hardware and a special software protocol developed by PG&E. The 48-Vdc power requirement for the SCADA equipment is provided by the battery bank in the control building. SCADA collects data on weather, ac and dc power, ac and dc voltage, ac and dc current, and various status information. Conversion of data into engineering units is performed at the local research data computer and at the PG&E Fresno Dispatch Office, which monitors plant operation in real time via radio link. The SCADA control functions include PCU breaker control and PCU start, stop, and reset.

Figure 5-4. Kerman telecommunications, SCADA, and control racks (left to right).

All plant metering, except auxiliary power metering, are recorded through the SCADA. Some data points are also displayed locally at each SCADA rack or enclosure. Complete reporting of real power, voltage, and current for the 12-kV interface is provided in the control building. Power, voltage, and current are also metered at the field SCADA enclosures by each PCU.

Ambient temperature; relative humidity; and direct normal, one-axis tracking, and global horizontal irradiance are measured at the meteorological station between the array and the control building (**Figure 5-5**). Wind speed and direction are measured 10 m above grade on a wooden utility pole next to the control building. All weather signals are conditioned to ±5 V for use by SCADA. Signal conditioning is provided by a Campbell Scientific Incorporated 21X data logger for weather data collection and linearization/excitation of specialized transducers. The data logger also provides data backup for the weather instrumentation.

Module temperature, plane-of-array (POA) irradiance, and array tilt angles are provided through SCADA cabinet #1. Signal conditioning for back-of-module thermocouples and POA irradiance is accomplished

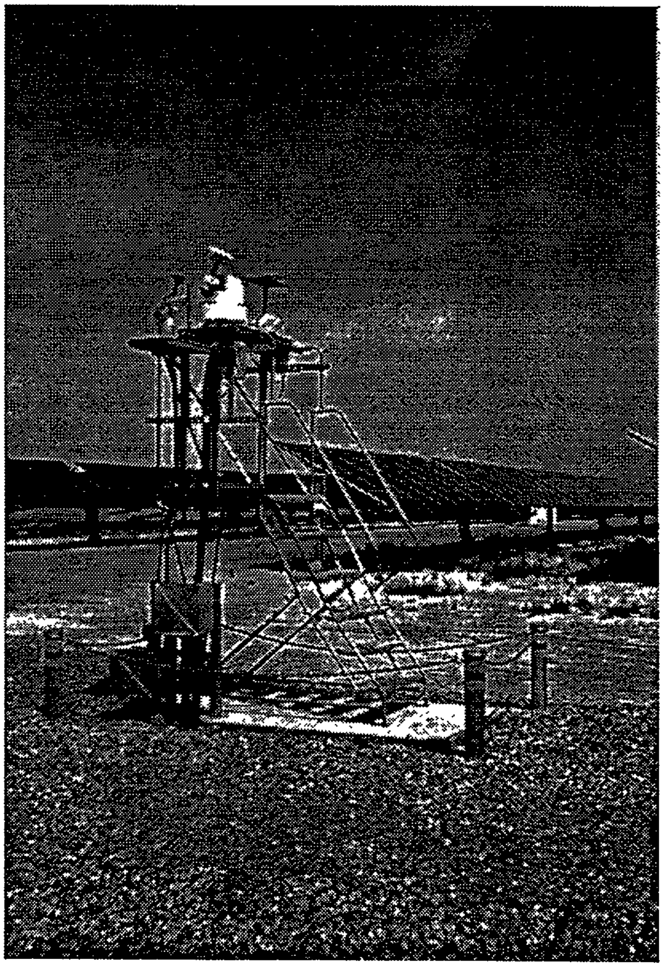


Figure 5-5. Kerman meteorological station.

using Analog Devices 5B series modular signal conditioners. Supply power is provided by a simple line power 5-V power supply in the same enclosure. The 5-Vdc power supply used for the signal conditioners also provides excitation for the clinometers mounted on each row. The clinometers contain variable resistors (voltage divider). As the row rotates, the weighted wiper travels across the resistor, providing row tilt angle.

Metering of the 12-kV line is provided through standard instrument transformers of ANSI accuracy class 0.3 in the site's main disconnect switch 89-1. Signals from instrument transformers are routed to the SCADA rack in the control building. Energy, power, voltage, and current are monitored by Bitronics meters, a Square D power transducer, a Joule Energy Meter (JEM®[1]), and a BMI PQNode recorder. Bitronics meters display the ac current and voltage, and provide analog signals monitored by SCADA. Energy is reported visually and as pulses by the JEM®[1].

All data are presented on the video display screen on a research data computer in the construction trailer; several options for data display are available. This research data computer provides data averaging and onsite storage for later analysis by research engineers.

Interconnection

Protection requirements are consistent with PG&E's Independent Power Producer's Handbook, which is based on California Public Utilities Commission (CPUC) Electrical Rule 21. The basic protection requirements are transfer trip, voltage, frequency, and current protective functions, disconnecting means, and an isolation transformer. Dedicated leased phone lines transmit signals from two transfer trip systems: feeder #1103 recloser R2686, and PG&E's Kerman substation. Abnormal events at Kerman substation or recloser R2686 cause the transfer trip system to send a signal that shuts down both PCUs. The plant's protective relays consist of a ground fault overvoltage relay in the control building (senses feeder #1103 ground faults and trips PCU breakers) and three single-phase overcurrent with voltage control relays at each PCU (senses feeder faults and trips its associated PCU breaker). For PCU protective functions, each PCU has a utility interface board that senses over- and undervoltage, over- and underfrequency, autosynchronization, and overtemperature.

CHRONOLOGY

The Kerman PV plant installation activities are shown chronologically in **Figure 5-6**. All activities indicated in the schedule were used to manage the PVUSA Kerman project **(Figure B-1)**. PG&E purchased the 10-acre site specifically for the grid-support demonstration in November 1991.

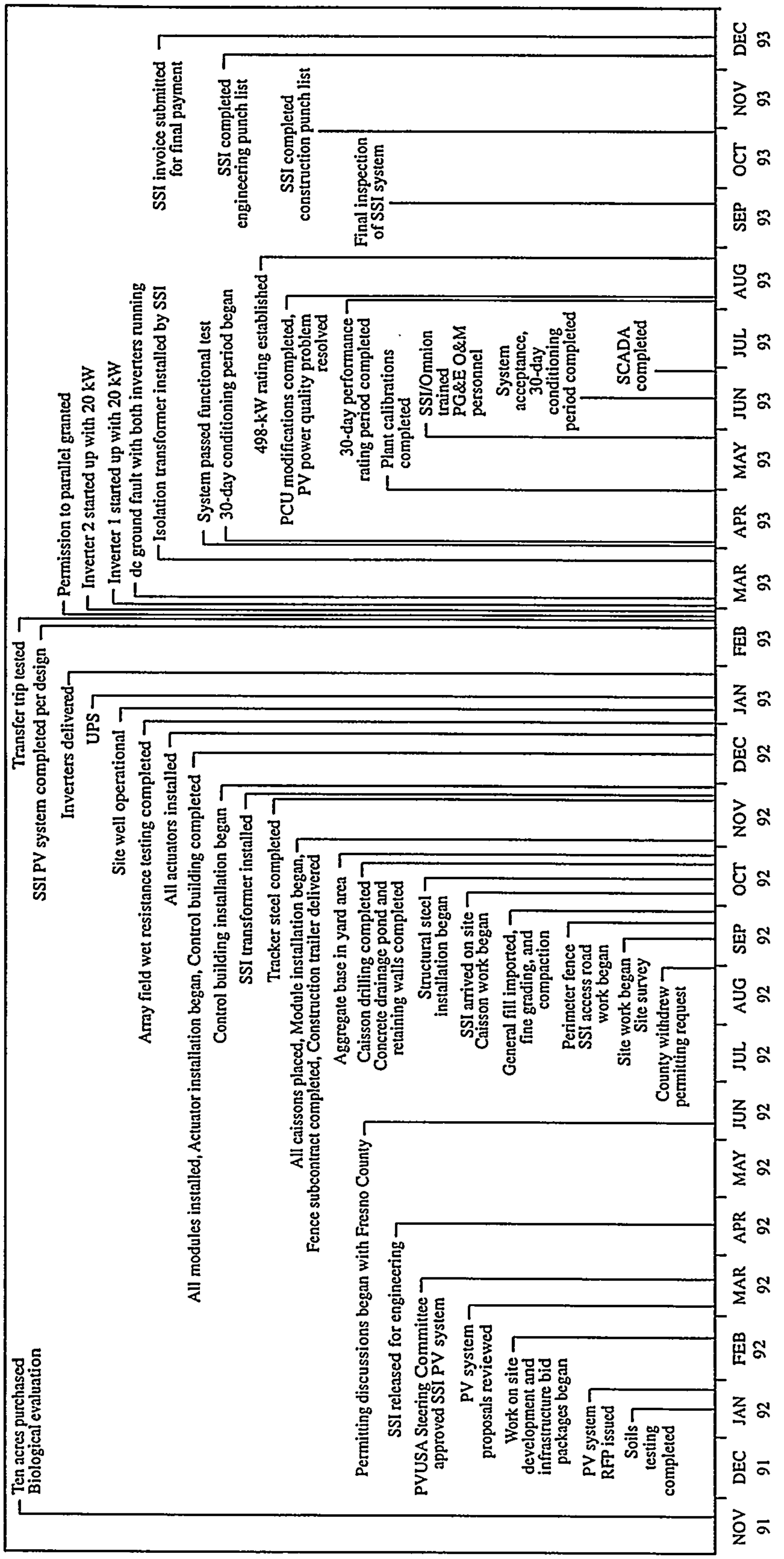


Figure 5-6. PVUSA Kerman chronology.

Fresno County permitting issues delayed the site mobilization date from May 1992 to September 1992; at the end of August 1992, Fresno County approved PG&E's request for the Kerman PV plant to be exempt from land-use and building permit requirements. This exemption resulted from an agreement between the CPUC, PG&E, and Fresno County, and is an important precedent for the permitting of utility-owned PV plants. PVUSA successfully avoided setting a precedent that would have adversely affected the schedule and cost of future PV installations within the same jurisdiction.

Bid package preparation and engineering work continued during the permitting discussions. PV system RFP development time was minimized by using, with some modifications, the RFP for the Davis US systems. PV plant construction took nine months from mid-September 1992 to mid-June 1993, and included an unplanned field retrofit by SSI of a 380-V isolation transformer to prevent neutral current from circulating between the two PCUs. Favorable weather and site soil conditions facilitated timely completion.

The 30-day conditioning period started ahead of schedule on April 1, 1993, and ended on June 14, 1993. (The 30-day conditioning period was established for all PVUSA systems to perform "shakedown" tests, calibrate instruments, and stabilize module power.) The 30-day performance rating period started on June 15, 1993, and ended on August 1, 1993 (data are collected during the 30-day performance period to base the system rating). Both the conditioning and performance rating periods were extended beyond 30 days due to PCU problems, which are fully described elsewhere (Shipman 1994). All SSI construction punch list items, final inspections, and verifications by utility personnel were completed on October 18, 1993. SSI engineering punch list items were completed on December 7, 1993, followed by final payment to SSI.

The plant was completed on schedule, 9 months after construction began and 15 months after the PV system contract was awarded to SSI. PVUSA-provided BOS construction was completed in 5.5 months. SSI construction activities lasted 5 months, from October 1992 through February 1993. Start-up, including the 30-day conditioning period, lasted 3.5 months, from March through mid-June 1993.

CONSTRUCTION LABOR FORCE

The number of people working in various capacities during the course of construction is shown in **Figure 5-7**. As this figure indicates, the delay caused by permitting issues was compensated for by exploiting the ability to have concurrent PVUSA and SSI construction activities, allowing adherence to the original overall schedule. The PV system labor force consisted of SSI construction management and subcontractors. PVUSA subcontracts were established for the site survey; grading, aggregate base, roads,

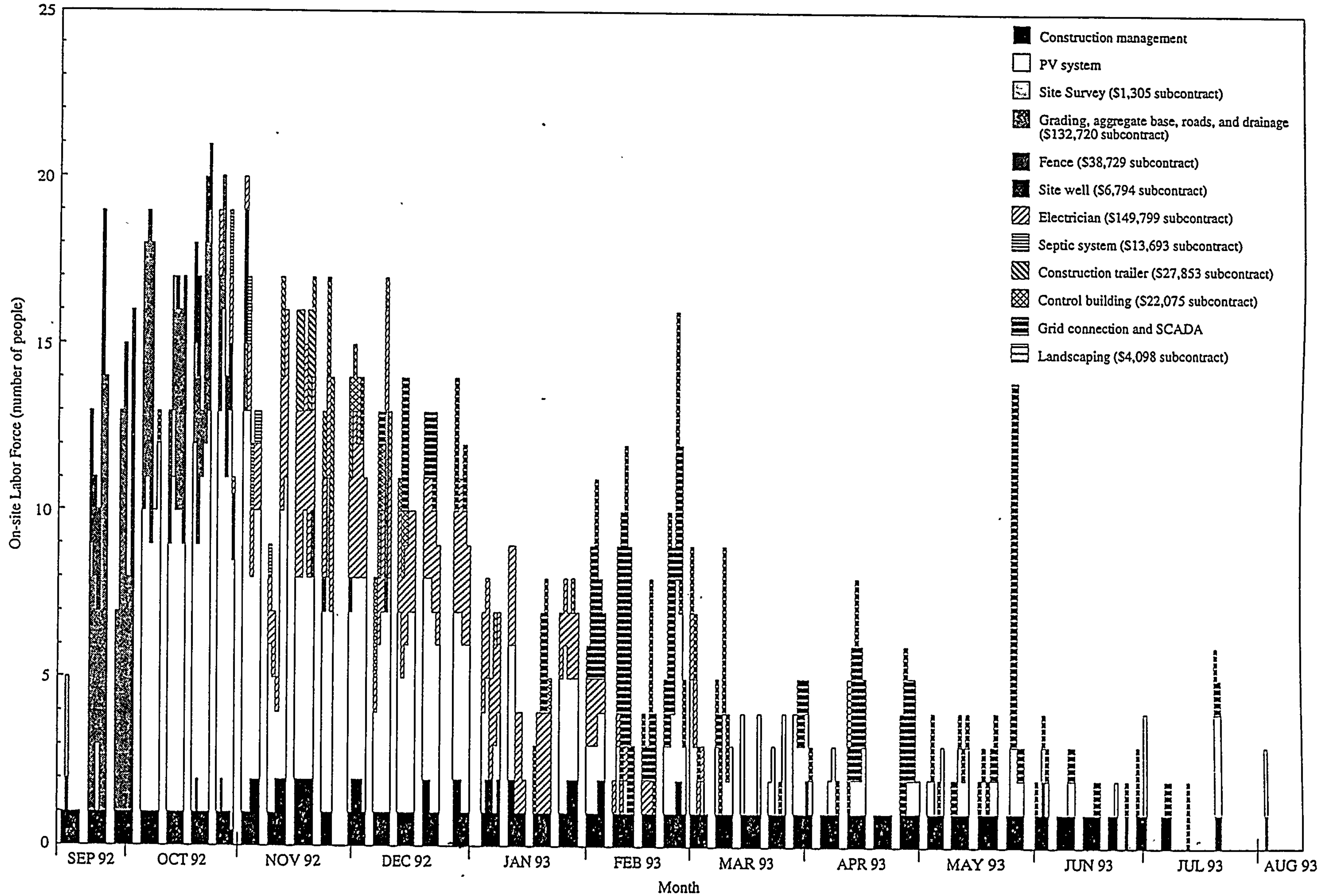


Figure 5-7. PVUSA Kerman daily on-site labor force.

and drainage; fencing; the site well; the majority of PVUSA's electrical work; the septic system; the construction trailer; the control building; and the landscaping.

Construction activity was heaviest during the first 3 months, with a peak of 21 laborers during the sixth week. Except for construction management, grid connection, and SCADA, all on-site work was performed by subcontractors, not PVUSA or PG&E personnel. As described earlier in this section, PVUSA constructed an intermediate east-west cross fence and leased one adjacent acre of neighboring farmland during construction for SSI to gain access to the array field area by a PVUSA-constructed side gate and temporary aggregate base access road, allowing concurrent construction of the PV system and the PVUSA-provided BOS. A schedule incentive clause in SSI's contract provided SSI with added motivation for timely completion.

SSI's daily on-site labor force (including their subcontractors) is classified by activity in **Figure 5-8**. The on-site labor force worked an equivalent of 604 man-days, or 4,830 man-hours. SSI on-site activity occurred from September 23, 1992 to August 4, 1993. For 134 days of this 315-day period, at least one laborer was on-site. SSI's construction activity peaked during the fourth through eighth weeks of site construction with a 1-day maximum of 14 laborers. The start of SSI construction slightly lagged PVUSA's construction to allow for array field grading, temporary access road construction, and temporary and permanent fencing by PVUSA subcontractors.

The total on-site labor force worked an equivalent of 1,607 man-days, or 12,856 man-hours. Only 38% of the on-site labor hours is attributable to the PV system; 45% is attributable to the PVUSA-provided BOS, and 17% for overall construction management. On-site labor hours are aggregated by category in **Figure 5-9**; the "SSI Electrical" category includes PV panel installation.

COSTS

PV System

PVUSA paid SSI $4,772,489 (including California sales tax but not including $15,159 for spare parts or the $10,816 paid directly to Omnion for support services) for the 498-kW PV system. PV system target completion was scheduled for 14 months after award. To encourage timely completion, PVUSA offered SSI an incentive of $2,000 for each day in advance of the early target completion date (up to a maximum of 60 days) that the PV system was completed and a charge of $2,000 for each day beyond the late target completion date (up to a maximum of 120 days) that SSI failed to achieve completion. The Kerman PV plant RFP included this incentive clause to offset the estimated cost of protracted schedule slippages like those associated with the Davis PV systems. If the SSI Kerman system had not had PCU start-up

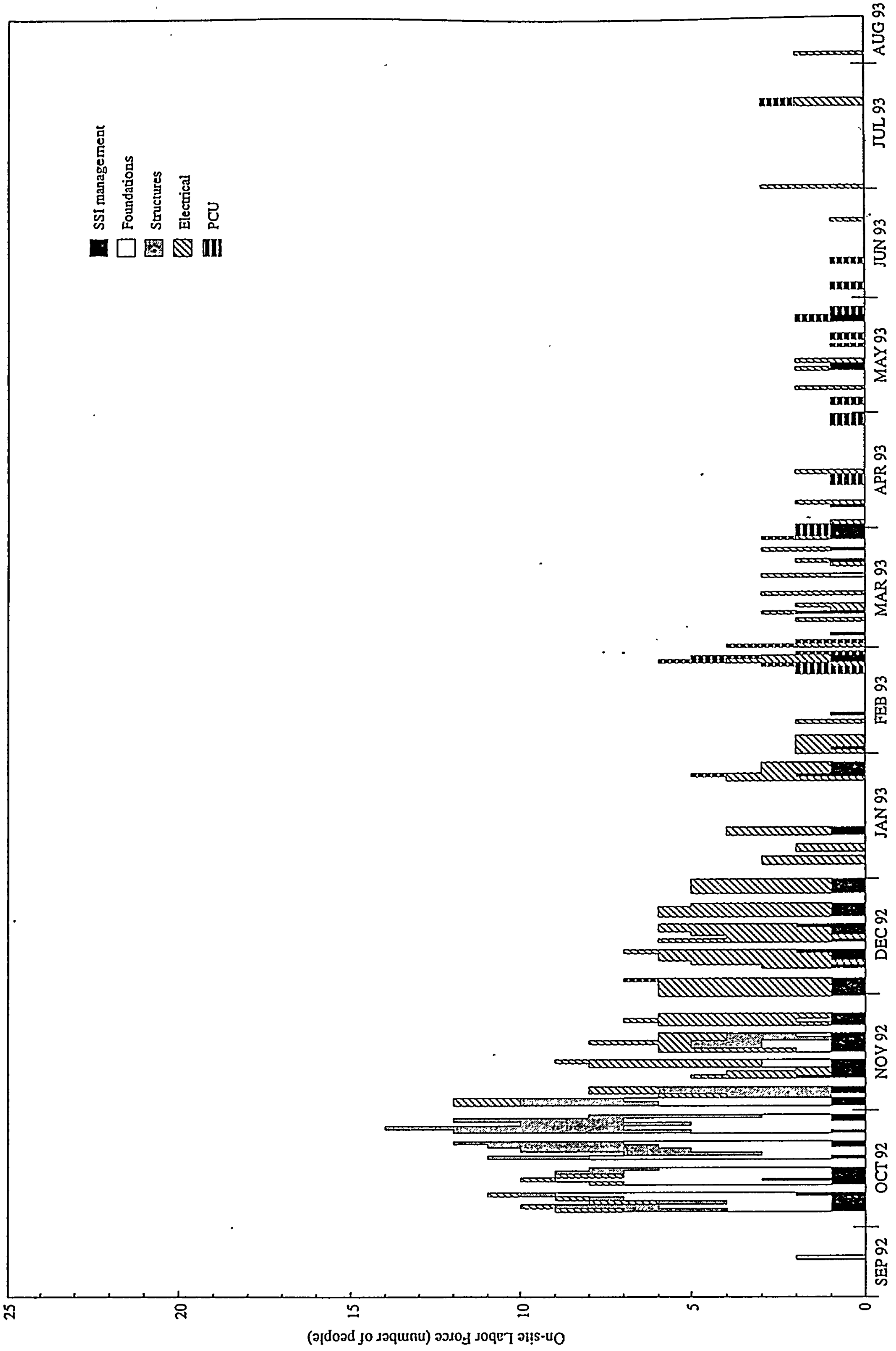
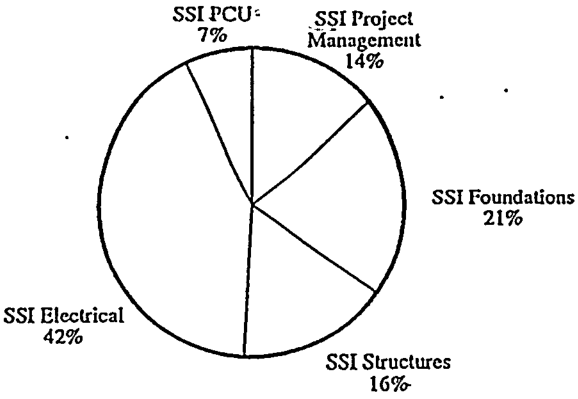


Figure 5-8. SSI Kerman daily on-site labor force.

Category	Labor-Days
SSI Project Management	85
SSI Foundations	129
SSI Structures	94
SSI Electrical	253
SSI PCU	43
PVUSA Site Development	277
PVUSA Electrical and SCADA	460.5
PVUSA Project Management	265.5
Total	1,607



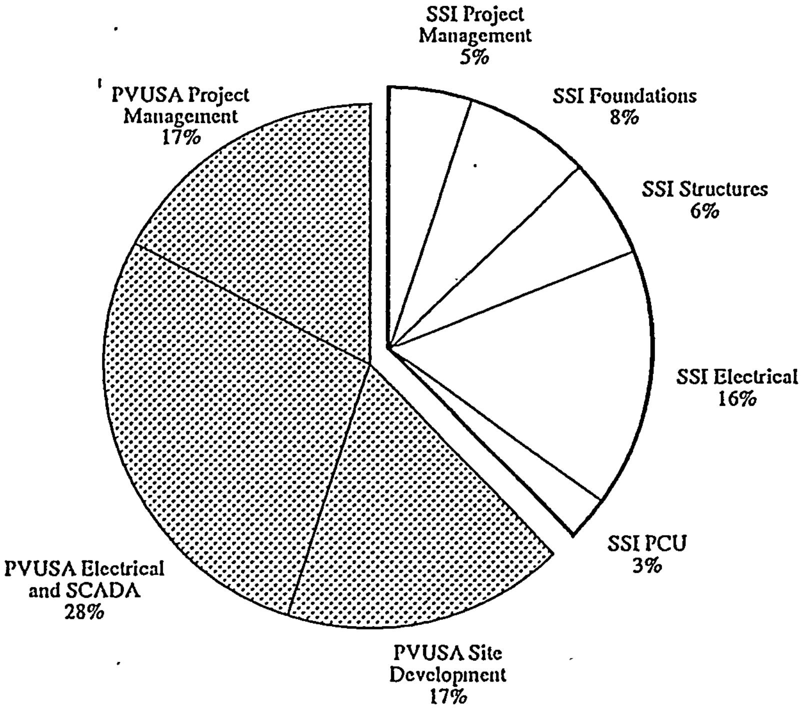


Figure 5-9. PVUSA Kerman on-site labor.

problems, SSI might have qualified for all the $120,000 incentive. Despite the start-up problems, the PV system was completed on time, between the early and late target completion dates, with no incentive adjustment to SSI.

Budgeted and actual PV system costs reported in July 1994 by Siemens Solar GmbH (SSI's parent company) are shown in **Table 5-1** (Cunow 1994). SSI's price was approximately $300,000 (5.9%) less than SSI's published costs. Siemens's cost breakdowns indicate that the cost overrun was primarily attributable to an unanticipated SSI module cost increase ($5.32/W budgeted vs. $6.34/W actual), which was partially offset by SSI engineering and project management under-budget costs. Material, field labor, and equipment cost for SSI foundations ($138,000) and structures ($285,000) estimated by PVUSA (Shipman 1994) excluded tracker actuators and home-office labor, and was within Siemens's published tracker cost ($557,000). PV system start-up problems associated with the Omnion PCUs (Shipman 1994) do not appear to have significantly affected SSI's costs, although Siemens indicated that PCU costs were estimated as of July 1994. Subsequent communication with SSI did not generate new information.

Table 5-1
SSI Kerman Budgeted and Actual PV System Costs Published by Siemens

Category	Budget		Actual	
	($)	($/W)	($)	($/W)
SSI project management	73,985	0.15	47,780	0.10
SSI engineering	66,900	0.13	33,685	0.07
Installation	159,382	0.32	159,718	0.32
PV panels	2,944,823	5.91	3,454,388	6.94
Trackers (inc. structure and foundation)	533,764	1.07	557,461	1.12
PCUs	516,108	1.04	~524,354	1.05
Contingency	64,635	0.13		0
SSI PV system less PV modules	1,709,681	3.43	~1,617,905	3.25
Total (pre-tax)	4,359,597	8.75	~4,777,386	9.59
Sales tax	294,907	0.59	~294,907	0.59
Total (after tax)	4,654,504	9.35	~5,072,293	10.19

PVUSA-provided BOS

The PVUSA-provided BOS cost $2,012,724 ($4.04/W), for a total after-tax Kerman PV plant cost to PVUSA of $6,796,029 ($13.64/W). SSI's PV system price accounts for 70% of the total plant cost to PVUSA.

PVUSA solicited competitive bids and awarded subcontracts for site development and electrical infrastructure. The site survey cost $1,305; grading, aggregate base, roads, and drainage cost $132,720; fencing and gates cost $38,729; the well, pump, and pressure tank cost $6,794; the septic system and plumbing cost $13,693; the construction trailer cost $27,853; the control building cost $22,075; and landscaping with an irrigation system cost $4,098. Sole-sourced to a subcontractor who demonstrated efficient, high-quality service at PVUSA Davis, the PVUSA-provided electrical work at Kerman cost $149,779. The cost of these contracts total $397,046, or $0.80/W. **Appendix C** outlines the work breakdown structure (WBS) used by PVUSA, describes a structure more in line with common construction practices, and provides recommendations to those considering cost tracking of US PV plants.

The primary PVUSA-provided BOS cost driver is PVUSA home-office labor costs and expenses. Aggregated by employer in **Table D-1**, notations indicate data that are not available or embedded in other categories. The $1,073,779 ($2.16/W) total for home-office labor costs and expenses consists of PVUSA engineering labor costs ($1.37/W), support services labor costs ($0.28/W), procurement labor costs ($0.15/W), site studies labor costs and expenses ($0.12/W), travel expenses ($0.07/W), miscellaneous material expenses ($0.06/W), management labor costs ($0.05/W), living expenses ($0.05/W), and permitting labor costs ($0.01/W). Research activities and transaction costs between project team members from different employers are significant but embedded within the home-office labor costs and expenses.

Categorized by the PVUSA WBS used during construction, the PVUSA-provided electrical infrastructure cost $1.44/W, site development cost $1.20/W, SCADA cost $0.72/W, and project management cost $0.68/W (**Tables D-2 through D-5**).

Retrofitting the cost data into the alternate WBS (see **Appendix C**) provides more detailed information (**Table 5-2**). PVUSA-provided BOS consists of PVUSA home-office labor costs and expenses ($2.16/W), PVUSA and electrical subcontractor construction labor costs and expenses and subcontracted foundation costs ($0.72/W), subcontracted site preparation and improvement costs ($0.40/W), instrumentation and control costs ($0.30/W), land price ($0.20/W), building material and subcontracts ($0.11/W), electrical material ($0.11/W), spare parts ($0.03/W), and custom maintenance tools ($0.01/W).

Table 5-2
PVUSA Kerman Costs to PVUSA

Acct. No.	Description	Labor (Hr)	Labor Unit Rate ($/Hr)	Mat'l. Qty. Unit	Mat'l. Unit Rate ($/Qty)	H.O. Labor ($)	Const. Labor ($)	Material ($)	S/C ($)	Total Costs ($)
1000	Owner Home-office Mgmt., Eng'r., & Proc.									
1100	Management Services	354				24,561				24,561
1200	Engineering Services	7,391				679,777				679,777
1300	Procurement Services	1,158				77,253				77,253
1400	Acct., Admin., Corp., Legal, & Safety Support Services	2,172				138,516				138,516
1500	Travel Expenses					34,074				34,074
1600	Employee-related Expenses					24,077				24,077
1700	Misc. Office Expenses					32,047				32,047
1800	Geotechnical Studies and Other Site-specific Tests	1,108				59,072				59,072
1900	Permits	79				4,402				4,402
	Total Home-office	12,262				1,073,779				1,073,779
2000	Construction									
2100	Owner On-site Labor									
2110	Owner On-site Manual Labor	383					22,403		149,779	172,182
2120	Owner On-site Nonmanual Labor	2,731					122,735			122,735
2130	Owner Start-up Services	794					65,768			65,768
	Total Owner On-site	3,908					210,906		149,779	360,685
2200	Site Selection, Land Acquisition						8,554	89,500	3,716	101,770
2300	Site Preparation and Improvements									
2310	Clear and Grub								1,305	1,305
2320	Grading								W/2350	W/2350
2330	Drainage								W/2350	W/2350
2340	Utilities								20,788	20,788
2350	Paving and Roads								132,720	132,720
2360	Landscaping and Vegetation Control								4,098	4,098
2370	Fencing								38,729	38,729
	Total Site Preparation & Improvements	W/2120							197,640	197,640
2380	Buildings									
2381	Control								22,075	22,075
2382	Construction Trailer							4,743	27,853	32,596
2383	Storage							1,995		1,995
	Total Buildings	W/2120						6,738	49,928	56,666
2400	Foundations									
2410	Buildings								W/2110	W/2110
2420	Owner-provided Equipment								W/2110	W/2110
	Total Foundations	W/2120							W/2110	W/2110
2500	PV System									
2510	Foundations for PV Array and Equipment								110,905	110,905
2520	PV Array Structure								403,575	403,575
2530	PV Modules/Panels								2,626,380	2,626,380
2540	Power Conditioning Unit								545,378	545,378
2550	dc Wires, Raceways, Switches, Boxes, Grounding								104,341	104,341
2560	Balance of PV System								992,726	992,726
	Total PV System	W/2120							4,783,305	4,783,305
2600	Electrical Equipment									
2610	Transformers								W/2560	W/2560
2620	Switchgear							27,886		27,886
2630	Field Interconnect Wiring							8,241		8,241
2640	Protective Relays							8,625		8,625
2650	Interconnection to Grid							11,338		11,338
	Total Electrical Equipment	W/2120						56,090	W/2560	56,090
2700	Instrumentation and Control									
2710	SCADA							60,564		60,564
2720	DAS							50,167		50,167
2730	Meteorological Instruments							23,544	12,203	35,757
2740	Security Systems							2,555		2,555
	Total Instrumentation and Control	W/2120						136,830	12,203	149,033
2800	Specialized Maintenance Tools and Equipment	W/2120						1,902		1,902
2900	Spare Parts for PV System and Owner-provided BOS	W/2120						15,159		15,159
	Total Project Cost					1,073,779	219,459	306,220	5,196,571	6,796,029

LESSONS LEARNED

PV System

Successful Innovations. SSI satisfied all contracted requirements in a timely manner, providing a robust PV system that is expected to have a useful life of at least 20 years. PVUSA and SSI experience at Davis (see **Section 4**) helped to maintain project schedule and minimize costs at Kerman.

Innovations that reduced cost while meeting the PV system requirements were encouraged from the beginning of the project, starting with the PV system RFP. The PV system was competitively bid, and responses were evaluated according to the following weighted criteria:

- Cost (40%)
- Peak load correlation (20%)
- Fielded module experience (15%)
- Capability of bidder's team (15%)
- Warranty coverage (10%)

Taking advantage of the favorable Kerman soil conditions, SSI modified the SSI Davis structural steel design to accept more modules per panel and subarray at Kerman. The passive tracking accuracy is better for SSI Kerman than for SSI Davis due to tracker design modifications. Significant schedule improvement is attributable to the schedule incentive in the PV system contract, the development of a PVUSA CPM schedule, SSI's planning and scheduling, and SSI's use of a more proven PCU technology at Kerman than at Davis (although PCU start-up problems were not entirely avoided). PVUSA required a PV system safety design review in lieu of a UL listing to comply with NEC 90-6 requirements, Examination of Equipment for Safety. As PV system technology matures, UL listing may become standard practice for component manufacturers, eliminating the need and cost of a safety design review.

Construction aids, such as jigs for rebar and bolt placement in caissons, were highly successful.

SSI shipped 10-module panels to reduce the number of field terminations. Typically about 10 minutes is needed for each field termination. Module panelization at the factory is more efficient, less expensive, and subject to better quality control/assurance than module panelization in the field.

Array panels are electrically interconnected with "cam-lock" connectors. These connectors are suitable for easy connection and disconnection points. For maintenance activities, each panel can be disconnected from the rest of the panels at the cam-lock connectors, which isolates the panel with an open-circuit voltage of less than 50V. This allows maintenance activities to be carried out without the use of electrical gloves. However, this feature cost an estimated additional $5,000.

BOS Problems and Resolutions. All BOS problems were resolved. The only BOS component with significant problems was the PCU, which had start-up problems and a couple of operational problems thereafter. However, PVUSA expects that the lessons learned by SSI at Kerman would result in no significant problems or schedule delays for a second-generation, "Kerman-type" system. The PV system BOS problems and resolutions are detailed below.

The module-to-module terminations lacked adequate factory quality surveillance as approximately 10 (0.04%) loose connections were identified after installation at the site. During start-up, dc voltage imbalances were traced back to loose module wiring terminations. Loose terminations were identified and properly re-torqued, resolving array dc voltage imbalances.

Panel-to-panel electrical connections made in the field were made adequately; the only deficiency was one loose bypass diode connection, which, along with a loose module connection, caused four modules to burn. Loose module connections can cause heating and burning of the terminals. The few cases of loose module junction box covers or improperly installed cover gaskets were apparent during the field wet resistance test. Whenever there is moisture or water intrusion into an electrically conducting component such as a terminal, PVUSA experience indicates that in 1 or 2 years the electrical component often corrodes to failure, and is manifested as an array voltage imbalance. Using larger modules would reduce the number of terminations.

Improperly torqued panel mounting bolts and nuts were corrected after identification during field quality surveillance. Loose mounting bolts can further loosen during high winds, eventually allowing damage to the modules. The installation contractor's quality assurance/quality control (QA/QC) plan needs improvement in implementation.

The tracker actuators operate satisfactorily for a summer-peaking grid-support PV system. Drawbacks include a designed aiming inaccuracy of up to 10° during the summer and the possibility for actuator seizing or refrigerant leakage. Failed actuators can mechanically stress the tracker structure and neighboring actuators, and cause multiple actuator failures and structural damage. Upon discovery of a passive tracker actuator failure, immediate replacement is advised and an inventory of tracker actuator spares should be maintained.

PCU start-up problems included a circulating neutral current between the two PCUs that prevented simultaneous operation. A 374-V isolation transformer was later installed to prevent the circulating current to flow from one PCU to the other through the step-up transformer's single low-voltage winding. Overtemperature problems indicated that the solar gain was not adequately addressed in the PCU design; the factory-installed PCU air conditioners were replaced in the field with significantly higher-capacity units. Excessive high-frequency harmonic distortion was resolved by field-added capacitive filters accommodated by the PCU enclosures. Although the PCU output current total harmonic distortion was within the specifications, an excessive single current harmonic distortion around the PCU switching frequency (and above-normal utility test frequency range) caused problems. These high-frequency harmonics resulted in misoperation of clocks, smoke detectors, and other electronic equipment at the site and two nearby residences.

The PCU design should be modified to include a circuit or circuit component that minimizes PCU harmonics. PCU output can be arranged and superimposed such that the harmonics from one bridge (PCU power electronics) cancels the harmonics produced by another bridge. PCU output filter capacitors can then be minimized or eliminated.

A current sensor failed when an improperly torqued bus connection caused excessive heating, melting the sensor's case. Consequently, a few PCU control boards were damaged because the signal wires from this sensor were elevated to the higher voltage of the bus bar. The failed components were replaced.

Water or water vapor collected inside the PCU display meters even though they were listed as suitable for outdoor use. The meters were replaced with different ones.

Failure-Related Maintenance Costs. SSI Kerman failure-related maintenance costs are indicated in **Figure 5-10.** These costs do not include costs for preventive maintenance based on PV system supplier recommendations.

SSI Kerman failure-related maintenance costs from system acceptance in August 1993 through December 1994 were 77% labor and 23% material. The system incurred failure-related maintenance costs of 1.3¢/kWh in 1993, 0.4¢/kWh in 1994, and 0.6¢/kWh for the overall 17-month period. Unlike the Davis systems, the Kerman failure-related maintenance is distributed among several components in addition to the PCUs. Failed module junction boxes (five in 1993; one in 1994), passive trackers (requiring refrigerant recharges), and circuit fuses contributed to the failure-related maintenance costs.

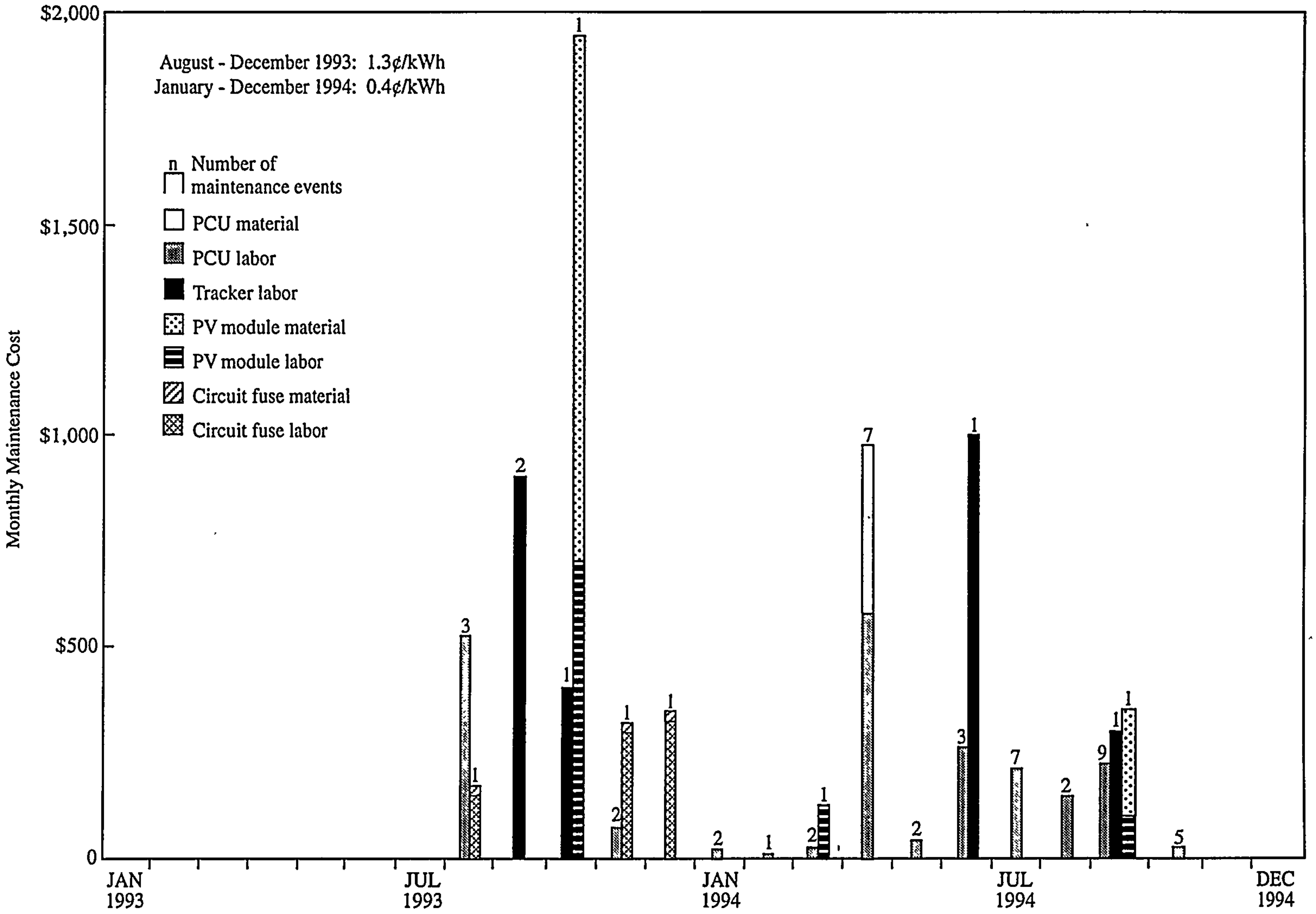


Figure 5-10. SSI Kerman failure-related monthly maintenance costs.

Potential for Improvements. The 9-month construction period included more than 3 months of start-up time associated with PCU problems. Based on PVUSA experience, a 7-month construction schedule for a 500-kW PV plant is presently achievable assuming a comparable construction labor force, favorable weather conditions, and an improved start-up period of 3–4 weeks. The delivery of PV panels and PCUs would likely control the schedule. The construction schedule for large (5+ MW) systems would be comparatively shorter in duration due to redundant modularization, larger crew sizes, and assembly line operations.

Several BOS components have significant PV system cost reduction potential with either positive or no effect on plant performance (**Table 5-3**). The step-up isolation transformer has one low-voltage winding, servicing two PCUs. If this isolation transformer had been designed with two low-voltage windings, one for each PCU, there would not have been a need for the field-added isolation transformer at the output of PCU #2.

PCU heating by direct sunlight would have been reduced by installing a structure that shaded the PCUs, perhaps eliminating the need for the PCU air conditioning units. The estimated 3% increase in plant power output achieved by eliminating the PCU #2 isolation transformer and the two PCU air conditioning units would have translated into a higher PVUSA payment to SSI, with no increase in costs to PVUSA on a $/W basis.

Field-added filter capacitors may not have been required if the PCUs were designed to limit harmonic content of their outputs. The oil-filled step-up transformer has a foundation design that retains the oil if the transformer ruptures due to failure or an electrical fault, satisfying a PVUSA requirement. An air-cooled transformer and its associated simple foundation may be less expensive but is less efficient than an oil-filled transformer. SSI elected to use an oil-filled transformer primarily due to its higher efficiency.

If SSI used direct-hire labor instead of subcontractors, SSI may have saved the estimated 10% profit associated with each subcontractor and the in-house costs associated with contractor scope-of-work development, bid process, contractor award, and coordination. About 86% of the PV system construction labor hours are attributable to SSI subcontractors (**Figure 5-9**).

If the Kerman PV plant involved a mature, standardized PV system without any research components, there would be no need for a PV system safety design review, a customized O&M manual, back-of-module thermocouples, clinometers, or extra modules for research. More innovative PV system designs that use wooden structural columns (e.g., SMUD's PVUSA system completed in 1994) or other inexpensive support structures would also lower costs.

If the PV system improvements proposed in **Table 5-3** were adopted, the total estimated cost reduction potential to SSI is $399,500, which would have reduced SSI's actual pre-tax BOS cost of about $1,618,000 by 25%, to $1,218,000 ($2.45/W). At $6.34/W, the PV modules account for about 66% of the actual PV system pre-tax costs and 72% of the improved PV system pre-tax costs. PVUSA labor costs would have been reduced about $13,000 ($0.03/W) if the proposed PV system improvements were adopted.

PVUSA-provided BOS

Infrastructure development is simpler for PV plants than for conventional power plants. PV plants require no process systems, cooling water, fuel handling, or waste treatment/disposal. PV plant infrastructure costs are driven by utility safety and interconnection requirements, site characteristics, and local codes. Consistent with typical utility practice, PVUSA communicated early and throughout power plant construction with neighboring property owners to promote supportive relationships.

PVUSA subcontractors satisfied all requirements in a timely manner, providing BOS that supports PV plant operation for at least 20 years. Start-up for PVUSA-provided BOS proceeded smoothly.

Re-evaluation of the design suggests that PVUSA-provided BOS costs can be significantly reduced (**Table 5-4**) with no effect on plant performance. As a PV grid-support application validation, PVUSA Kerman has research elements, including the construction trailer, office furniture and equipment, septic system, site well, storage container (primarily intended for long lead-time spare parts), research computer hardware and software, dc instrumentation, meteorological equipment, power quality monitoring equipment, UPS, and about 40% of the SCADA system instrumentation channels. Cost savings by eliminating research-related BOS components include the associated PVUSA labor for management, preparation of material specifications, scope-of-work development, and field installation.

As PCU technology matures, SCADA features and protection requirements can be incorporated in the PCU control circuitry to reduce total costs. With PCU technology maturing and with adequate field experience, utility distribution personnel should accept built-in protective features. The two transfer trip systems for Kerman would be reduced to one. The transfer trip protection is essentially redundant protection to shut down the plant when there is a utility distribution problem or outage. One transfer trip scheme between the utility distribution substation and the PV plant would be the typical minimum requirement. The 15-kV switchgear is not necessary but was installed to facilitate special testing and site equipment maintenance. Metering in the equipment serves as a noncritical visual aid to visitors. A smaller battery for protective relays and protection circuits is possible.

Table 5-3
Cost Reduction Potential of SSI Kerman BOS

BOS Component	Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PV Supplier's Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
Isolation transformer for PCU #2	Field addition	Main isolation step-up transformer has 1 low-voltage winding, path for circulating ground currents.	Main isolation transformer has 2 electrically separate windings for the 2 PCUs.	20,000	5,000
Isolation transformer for PCU #2	Field addition	Reduces power output by 1%.	Eliminate.	50,000	0
Air conditioning for PCU enclosures	Changed to larger units	PCU exposed to direct sunlight.	Design shade over PCU, eliminate air conditioner, keep fans.	11,000	0
Air conditioning for PCU enclosures	Installed	Air conditioning load reduces power output by 2%.	Design shade over PCU.	100,000	0
PCU output filter capacitors	Field addition	PCU output contains high-frequency harmonics.	Design PCU with minimal total (THD) and single-frequency harmonics.	15,000	4,000
Installation subcontractors	SSI used subcontractors	Additional cost in RFP, bid, and supervision of subcontractors.	Use direct-hire labor.	10,000	0
Installation subcontractors	SSI used subcontractors	Additional cost due to profit and overhead charged by subcontractors.	Use direct-hire labor.	25,000	0
Safety design review	No UL listing	Does not meet NEC, required by PVUSA to ensure safety features are incorporated in design.	With mature PCU technology and as the equipment is listed, this requirement can be eliminated.	4,000	4,000
O&M manual	Submitted	Customized document, although SSI Davis O&M manual provided a useful starting point.	With standardized installations, only minor custom PV system features and printing cost will accrue.	15,000	0
Module thermocouples	Installed	Research-related.	Eliminate all 3 thermocouples.	3,000	0
Clinometers	Installed	Research-related.	Eliminate 9 clinometers.	5,000	0
15 modules	Delivered	Research-related.	Eliminate.	4,000	0
PCU display meters	Installed	Visual aid to visitors only.	Eliminate.	2,500	0
Concrete foundation and steel structure	Installed	Owner should have less restrictive design criteria and accept lean requirements.	Allow wooden structural columns.	135,000	0
		Subtotal Cost Reduction Potential		**399,500**	**13,000**
		Grand Total Cost Reduction Potential		**412,500 ($0.83/W)**	

Table 5-4
Cost Reduction Potential of PVUSA-provided Kerman BOS

BOS Component	Component Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PVUSA Material Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
Construction trailer	Trailer installed for visitors	Research-related.	Temporary construction trailer with portable bathroom.	25,000	5,000
Office furniture and equipment	Installed	Research-related.	Eliminate.	2,500	500
Septic system	Installed	Research-related.	Eliminate.	13,000	3,000
Site well	Installed	Research-related.	Eliminate.	6,500	4,000
Storage container	Installed	Not required if no long lead-time spares.	Eliminate.	2,000	500
Data base computer and software	Installed	Research-related.	Eliminate.	39,500	60,000
dc instrumentation	Installed	Research-related.	Eliminate.	5,500	1,000
Meteorological equipment	Installed	Research-related.	Eliminate.	35,500	5,000
Power quality equipment	Installed	Research-related.	Eliminate.	13,000	3,000
UPS	Installed	UPS for research computer.	Eliminate.	10,000	2,000
SCADA	Installed	Includes research-related instrumentation.	Eliminate research-related SCADA components.	9,500	5,000
Research labor and overhead	Costs incurred	Research-related.	Eliminate.	0	86,500
SCADA incorporated in PCU	Separate SCADA enclosure	SCADA can be incorporated in PCU.	Eliminate SCADA boxes.	18,000	4,000
PCU inspection	Factory inspection by owner	Not required for mature equipment.	Eliminate if mature equipment.	3,000	3,000
Switchgear	Installed	Redundant for research testing convenience.	Eliminate, rely on pole-mounted air switch.	24,000	28,000
Square D transducers	Installed	Research-related.	Eliminate.	3,500	1,000
Transfer trip	Installed 2 systems	PV controls recognize and trip on outage.	Eliminate 1 transfer trip.	10,000	5,000
Battery	Sized for 8-hour backup	Utility requires minimum 8-hour backup time.	Use smaller battery for protective relays.	4,000	2,000
PCU controls	Not optimized	Controls that include all protection requirements.	Include all control and protection in PCU circuitry.	23,000	14,000
Standard design details	Used outdated PG&E standard details, materials specified no longer available	Up-to-date standards unavailability.	Verify if standards are still current before referencing.	3,000	1,000
Land	Extra area, premium price	3 acres larger.	Purchase exact area needed at a cheaper price.	54,500	5,000
Fence	Perimeter fence on entire property	Unused area is fenced	Eliminate the unnecessary fence sections.	9,000	2,000
Fence	Intermediate fence installed	For visitor purposes only.	Eliminate.	5,500	2,000
Landscaping	Installed	Site visual enhancement only.	Eliminate.	4,000	1,000
Parking	Installed aggregate base and asphalt	Aggregate base unnecessary for parking area.	Provide aggregate base for access to major equipment only.	15,000	3,500

Table 5-4
Cost Reduction Potential of PVUSA-provided Kerman BOS (continued)

BOS Component	Component Status	Issue	Proposed Improvement	Improvement's Estimated Impact on PVUSA Material Cost ($)	Improvement's Estimated Impact on PVUSA Labor Cost ($)
Parking	Existing grade was elevated	Imported fill material to meet the designed elevation.	During design, try to balance the cut and fill material.	18,000	4,000
Handicap access	Installed	Research-related.	Eliminate.	2,000	500
Site availability	Site mobilization delayed	Permit process started late.	Allow adequate time for permits.	3,000	10,000
Concrete pond	Designed to contain 100-year storm	Unrealistic local requirement.	Compliance to unrealistic local codes should be questioned, design alternatives should be considered.	13,500	3,000
Project team	Represents several employers and geographically distributed	Coordination and transaction activities not optimized.	Build the project team from one employer at one home-office location.		100,000
Drawings	Drawings not issued adequately ahead of construction	Drawings finalized during construction.	Start and complete drawings early, maintain a drawing release schedule that complements the construction schedule.	10,000	5,000
Detailed design	Available data were incomplete	Data were finalized during detailed design.	Finalize all engineering data before detailed design.	10,000	15,000
Switchgear delivery	Arrived on time	Extra cost for expediting.	Order switchgear early.	4,000	5,000
Material delivery	Some materials were late	Installation work is extended.	Order materials early.		5,000
PV system supplier mobilization	Site preparation work was coincident with PV supplier mobilization	Site preparation should be done prior to PV mobilization.	Start site work early.		10,000
Start-up	2 months longer than scheduled	Did not delay overall completion but eliminated contingency.	Eliminate design deficiencies that surfaced during start-up by addressing Kerman lessons learned.		30,000
		Subtotal Cost Reduction Potential		**399,000**	**434,500**
		Grand Total Cost Reduction Potential		**833,500 ($1.67/W)**	

An improved PV plant site would not be purchased at a premium price and would not have extra land. The Kerman perimeter fence would have been reduced by 25% if the north 3 acres of fallow land had not been purchased. An improved site would not need an intermediate fence, landscaping, or a visitor parking area. The permitting issue delayed site construction mobilization and required installation of a graveled temporary access road and fence gate to maintain the overall schedule. If the permitting exemption by Fresno County had been ensured prior to the infrastructure design work, the drainage system costs would have been reduced by adopting a less conservative design.

An improved project team would be developed from one agency at one site to minimize transaction costs. Project management, planning, scheduling, engineering, procurement, and testing activities required more coordination with PVUSA's distributed three-agency, four-site team than would be expected from a one-agency, one home-office team. Improved completion of construction drawings by engineering design/drafting should allow enough time for constructability review; cost savings will be realized with this opportunity to identify design enhancements, design errors, and other items that can potentially reduce construction time and effort.

Materials with long lead times should be procured as early as possible to allow adequate time for manufacturing, testing, and delivery. If the schedule is a key driver, material deliveries may be expedited for a price. For example, PVUSA spent an additional $4,000 to accelerate delivery by 4 weeks of the medium-voltage switchgear (delivery 18–24 weeks after ordering is typical). Procurement time for PV-specific commodities is expected to decrease with PV system market growth, encouraging automation, inventory optimization, and competition.

The Kerman PV plant has significant costs in addition to the turnkey PV system price. Even after applying estimated cost savings assuming improved conditions, the results indicate that utility-provided BOS costs are not trivial; costs are site specific, and should be taken into account when evaluating utility PV economics. If PVUSA Kerman were not a research project and if the site, schedule, infrastructure, and PV system were improved, PVUSA-provided BOS cost may have been reduced by $846,500 ($833,500 from **Table 5-4** plus $13,000 from **Table 5-3**). Therefore, the $4.04/W cost of PVUSA-provided BOS may have been reduced to around $2.30/W (**Table 5-5**).

While the $/W cost of the PV system has substantial cost reduction potential, it is beyond the scope of this report to provide an estimate. With increased PV plant efficiency, the cost of land decreases. Less site area would require less fence on a $/W basis. Although larger systems require more land, access road costs provided by the utility are assumed constant. Access roads to major equipment are considered as part of the PV turnkey contract.

OWNER-PROVIDED BOS FOR A COMMERCIAL PV PLANT

Applying the experience gained at PVUSA Davis and Kerman, the PVUSA team roughly estimated what the minimum owner-provided BOS costs might be today for commercial PV plants, defined in **Table 1-3.** Various plant sizes from 500 kW to 5 MW are considered to be reasonable extrapolations from PVUSA experience and indicate the economies of scale for owner-provided BOS. PV system costs are not estimated in this report because these are more accurately and appropriately estimated by PV system suppliers than by PVUSA.

Table 5-5
Actual and Improved Kerman PV Plant Cost

Acct. No.	Description	Actual Costs ($)	Nonresearch Costs ($)	Improved Costs ($)
1000	**Owner Home-office Mgmt., Eng'r., & Proc.**			
1100	**Management Services**	24,561	19,809	19,842
1200	**Engineering Services**	679,777	443,525	421,750
1300	**Procurement Services**	77,253	59,647	59,788
1400	**Acct., Admin., Corp., Legal, & Safety Support Services**	138,516	110,223	110,479
1500	**Travel Expenses**	34,074	19,838	16,371
1600	**Employee-related Expenses**	24,077	10,464	10,119
1700	**Misc. Office Expenses**	32,047	30,716	33,103
1800	**Geotechnical Studies and Other Site-specific Tests**	59,072	38,379	38,379
1900	**Permits**	4,402	4,402	4,402
	Total Home-office	1,073,779	737,003	714,233
2000	**Construction**			
2100	**Owner On-site Labor**			
2110	Owner On-site Manual Labor	172,182	114,257	114,257
2120	Owner On-site Nonmanual Labor	122,735	79,273	63,397
2130	Owner Start-up Services	65,768	18,909	18,909
	Total Owner On-site	360,685	212,439	196,564
2200	**Site Selection, Land Acquisition**	101,770	47,270	47,270
2300	**Site Preparation and Improvements**			
2310	Clear and Grub	1,305	1,305	1,305
2320	Grading	W/2350	W/2350	W2350
2330	Drainage	W/2350	W/2350	W2350
2340	Utilities	20,788	302	0
2350	Paving and Roads	132,720	132,720	86,288
2360	Landscaping and Vegetation Control	4,098		
2370	Fencing	38,729	29,512	29,512
	Total Site Preparation & Improvements	197,640	163,839	117,105
2380	**Buildings**			
2381	Control	22,075	22,075	22,075
2382	Construction Trailer	32,596	3,600	3,600
2383	Storage	1,995	1,995	1,995
	Total Buildings	56,666	27,670	27,670
2400	**Foundations**			
2410	Buildings	W/2110	W/2110	W/2110
2420	Owner-provided Equipment	W/2110	W/2110	W/2110
	Total Foundations	W/2110	W/2110	W/2110
2500	**PV System**			
2510	Foundations for PV Array and Equipment	110,905		
2520	PV Array Structure	403,575		
2530	PV Modules/Panels	2,626,380		
2540	Power Conditioning Unit	545,378		
2550	dc Wires, Raceways, Switches, Boxes, Grounding	104,341		
2560	Balance of PV System	992,726		
	Total PV System	4,783,305		
2600	**Electrical Equipment**			
2610	Transformers	W/2560	W/2560	W/2560
2620	Switchgear	27,886	0	0
2630	Field Interconnect Wiring	8,241	8,241	8,241
2640	Protective Relays	8,625	8,625	8,625
2650	Interconnection to Grid	11,338	8,327	8,327
	Total Electrical Equipment	56,090	25,194	25,194
2700	**Instrumentation and Control**			
2710	SCADA	60,564	19,053	12,790
2720	DAS	50,167	0	0
2730	Meteorological Instruments	35,747	0	0
2740	Security Systems	2,555	0	0
	Total Instrumentation and Control	149,033	19,053	12,790
2800	**Specialized Maintenance Tools and Equipment**	1,902	1,815	1,815
2900	**Spare Parts for PV System and Owner-provided BOS**	15,159	837	837
	Total Project	6,796,029		
	Owner-Provided BOS	2,012,724	1,235,120	1,143,477
	Owner-Provided BOS $/W	4.04	2.48	2.30

The owner-provided BOS for a 500-kW commercial PV plant with an ac efficiency of 10% at PVUSA Test Conditions is estimated to cost roughly $1,143,000 ($2.30/W). The difference between the estimated $/W costs of a 500-kW commercial PV plant ($2.30/W) and the improved version of the Kerman PV plant ($2.35/W) is attributable to labor overhead rate differences, which vary monthly at PG&E and Bechtel. Labor overhead costs for the commercial PV plants were based on September 1994 Bechtel overhead rates (i.e., the project team consists of Bechtel employees only). The primary owner-provided BOS cost driver would continue to be home-office labor costs and expenses ($1.26/W) (**Table D-6**). Secondary cost drivers include owner and electrical subcontractor construction labor cost, expenses, and subcontracted foundation costs ($0.51/W) and subcontracted site preparation and improvement costs ($0.25/W). If the research nature of the plant is eliminated, several former cost drivers are significantly diminished: instrumentation and control (I&C) costs decrease by about 85% (to $0.04/W), while land acquisition, buildings, and electrical equipment costs decrease by about 50% (to $0.09/W, $0.06/W, and $0.05/W, respectively).

Schedules for various commercial PV plant sizes from 500 kW to 5 MW are provided in **Figure B-3**. If the PV system construction labor force is similar to that at Kerman, the improved overall project schedule is 15 months for 500 kW, 17 months for 1 MW, and 24 months for 5 MW. Exploiting PV's modularity, the plant size could be doubled from 500 kW to 1 MW and still be constructed in 7 months, assuming timely PV panel delivery and the doubling of the labor force constructing the PV array field; a 15-month overall project schedule from site selection through the optional 30-day performance test is achievable for 500-kW to 1-MW plant sizes.

Table 5-6 shows the estimated BOS cost of different "Kerman-like" PV plants with 10% efficiency, and reflects the following assumptions:

- The site has an optimal size and shape, a low price, minimal fencing, and no temporary access requirements. Ideally the site does not require an environmental impact report or attract intervenor activity, although project team labor must be expended to establish these conditions.
- The schedule reflects a permitting process without complications, the soil report with caisson test results guaranteed in the RFP, engineering design/drawings developed before construction, a reasonable lead time for materials, and cooperative weather.
- The infrastructure includes a secured area; all-weather access to critical equipment; remote monitoring and control capability (for an unattended plant); electrical switchgear, underground electrical supply, uninterruptible power supply (UPS) for control and protection equipment, protective relays, and other utility-specific requirements (e.g., control building, meters, telephone, signs); and minimal drainage or flood control measures.
- The project team is experienced in constructing US PV plants and work for the same company at one home-office location and onsite, minimizing coordination and transaction costs.

Table 5-6
Estimated BOS Costs for 10% Efficient PV Plants

Acct. No.	Description	500 kW Costs ($)	1 MW Costs ($)	5 MW Costs ($)
1000	**Owner Home-office Mgmt., Eng'r., & Proc.**	628,500	715,000	903,500
2000	**Construction**			
2100	**Owner On-site Labor**			
2110	Owner On-site Manual Labor	114,500	129,000	604,500
2120	Owner On-site Nonmanual Labor	132,500	194,500	491,000
2130	Owner Start-up Services	7,500	13,000	57,500
	Total Owner On-site	254,500	336,500	1,153,000
2200	**Site Selection, Land Acquisition**	62,000	106,000	459,500
2300	**Site Preparation and Improvements**			
2310	Clear and Grub	1,000	2,500	13,000
2320	Grading	W/2350	W/2350	W/2350
2330	Drainage	W/2350	W/2350	W/2350
2340	Utilities			
2350	Paving and Roads	86,500	86,500	86,500
2360	Landscaping and Vegetation Control	0	0	0
2370	Fencing	29,500	46,000	109,500
	Total Site Preparation & Improvements	117,000	135,000	209,000
2380	**Buildings**			
2381	Control	22,000	22,000	22,000
2382	Construction Trailer	3,500	3,500	3,500
2383	Storage	2,000	2,000	2,000
	Total Buildings	27,500	27,500	27,500
2400	**Foundations**			
2410	Buildings	W/2110	W/2110	W/2110
2420	Owner-provided Equipment	W/2110	W/2110	W/2110
	Total Foundations	W/2110	W/2110	W/2110
2500	**PV System**			
2510	Foundations for PV Array and Equipment			
2520	PV Array Structure			
2530	PV Modules/Panels			
2540	Power Conditioning Unit			
2550	dc Wires, Raceways, Switches, Boxes, Grounding			
2560	Balance of PV System			
	Total PV System			
2600	**Electrical Equipment**			
2610	Transformers	W/2560	W/2560	W/2560
2620	Switchgear	0	0	0
2630	Field Interconnect Wiring	8,000	8,000	8,500
2640	Protective Relays	8,500	8,500	8,500
2650	Interconnection to Grid	8,500	8,500	9,500
	Total Electrical Equipment	25,000	25,000	26,500
2700	**Instrumentation and Control**			
2710	SCADA	13,000	13,000	13,000
2720	DAS	0	0	0
2730	Meteorological Instruments	0	0	0
2740	Security Systems	0	0	0
	Total Instrumentation and Control	13,000	13,000	13,000
2800	**Specialized Maintenance Tools and Equipment**	2,000	2,000	2,000
2900	**Spare Parts for PV System and Owner-provided BOS**	15,000	15,000	31,000
	Total Owner-Provided BOS	1,144,500	1,375,000	2,825,000
	$/W	2.29	1.37	0.56

- The PV system is commercial-grade, requires minimal vendor inspections and factory testing, and has a minimum 20-year life expectancy and low O&M requirements. A one-axis tracking system with an ac efficiency of 10% is assumed to evaluate a near-term PV plant scenario.

- Engineering, procurement, and management services are based on estimated labor hours and associated labor costs. Although PV systems are modular in nature, hours are expected to increase with increase in PV plant size (though not linearly).

- The PV plant contractor-to-utility interface is at one location. For power, interface is at the step-up power transformer. For control and instrumentation, interface is at one SCADA Interface Junction Box (IJB). The PV plant contractor will be responsible for collecting the power, control, and instrument cables and bringing these to the interface point.

- Site preparation costs related to the fence will vary according to PV plant size. Ideally a site will have the same yard area, drainage, and utilities regardless of PV plant size. Drainage costs are estimated for the constant yard area only, and thus would not vary with PV plant size.

- The PCU and its protective relay (features) and SCADA requirements are integral within the PCU enclosure. For estimating purposes, a 0.5-MW PCU size was selected for all the PV plant sizes.

Since owner labor has a significant fixed component (i.e., independent of PV plant size), the cost per watt decreases with commercial PV plant scale-up (**Table 5-6**). Owner labor estimates (**Table D-6**) are based on the schedules in **Figure B-3**. Costs are not escalated to account for multiyear project durations.

Permitting, buildings, electrical equipment, and I&C costs are essentially unaffected by PV plant scale-up for the size range considered. The economies of scale are indicated in **Figure 5-11**. Owner home-office labor at $1.30/W for 500 kW decreases dramatically to $0.18/W for 5 MW. Owner-provided BOS for a commercial PV plant is estimated to cost the owner $2.29/W for 500 kW, $1.37/W for 1 MW, and $0.56/W for 5 MW, with an estimated uncertainty of -5 to +15%. The estimated cost uncertainty range is primarily driven by hours, labor rate, and overhead rate uncertainties.

RECOMMENDATIONS FOR PV PLANT INSTALLATION

PV Plant Owner

1. Build the project's home-office team from one agency at one location. It is essential to define the PV plant objectives (e.g., commercial vs. research, unattended vs. staffed) and operator interface functions and preferences prior to initiating plant design. This facilitates individual design decisions and avoids redesign costs and schedule delays. Budget for owner-provided BOS costs, particularly home-office labor costs and expenses, which will likely be the largest owner-provided BOS cost component.

2. Optimize the site selection. Identify candidate sites and compare soil conditions, site preparation (including drainage and permitting) requirements, proportions, solar orientation and access, price, PV plant value, and the neighboring property owners' support of the project.

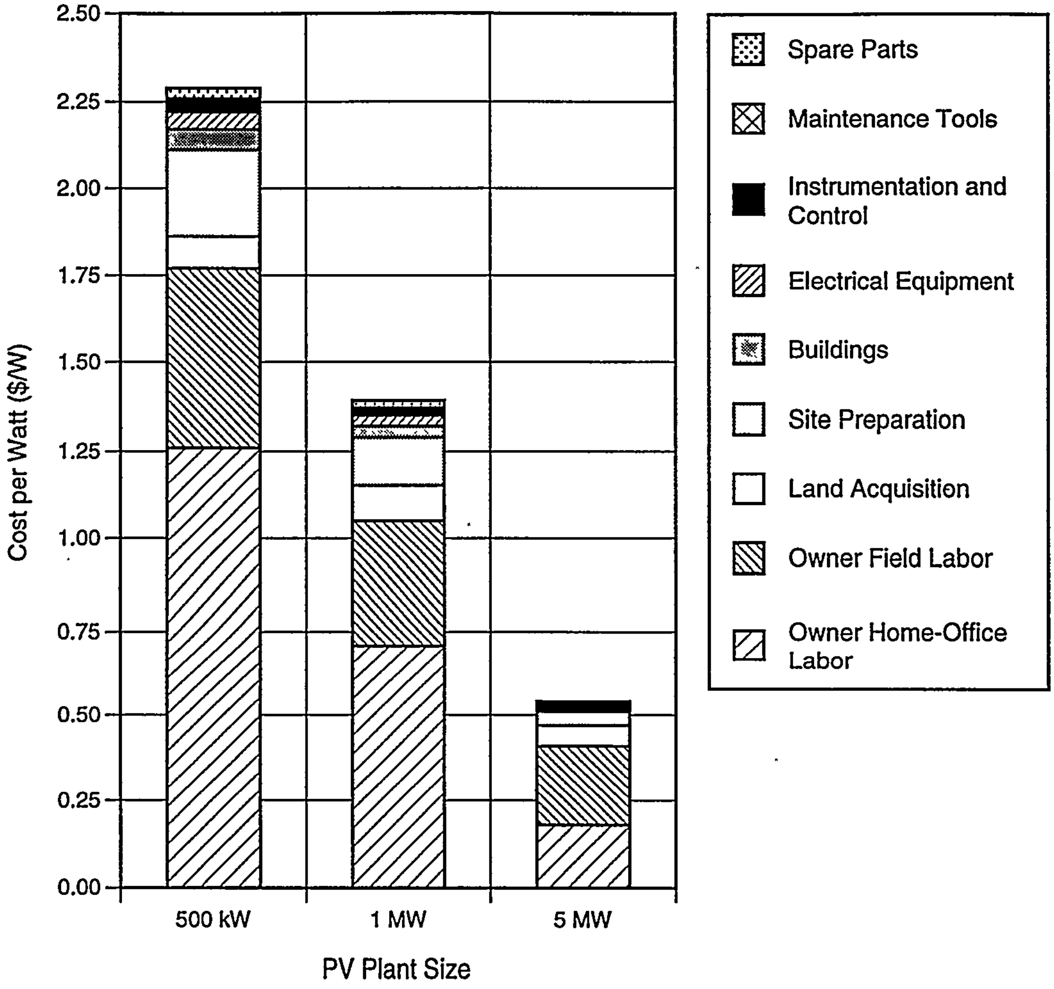


Figure 5-11. Owner-provided BOS costs for 10% efficient commercial PV plants.

3. Begin the permitting process early. Avoid setting permitting precedents that may negatively affect the schedule or cost of future PV installations within the same jurisdiction.

4. Use a comprehensive technical specification (such as PVUSA's) as a model for the PV system specification to minimize RFP development costs, bidder misinterpretation, and system design, construction, and O&M problems. Consider compliance with the latest applicable codes and standards to the extent possible. Encourage the PV system supplier to order long lead-time items such as the PCU as early as possible.

5. Base infrastructure design off existing owner (or utility) standards, but such standards should be carefully reviewed and modified to accommodate differences such as low-fault current availability from plant (grounding, protection, bus bracing), smaller power breakers (control devices and wiring, battery bank), lack of process systems (thermal, corrosion and vibration considerations, fewer required controls and instrumentation), and possible shorter design life (20 years instead of 30).

6. Order long lead-time items, particularly medium voltage switchgear if used, as early as possible. If the project duration and risk need to be minimized, consider using field-proven PV system components and providing schedule bonus payments to suppliers on the critical path.

7. Consider scheduling PV system and complementary plant infrastructure activities in parallel to reduce the schedule duration.

8. Separate signal circuits from power circuits, to the extent practical, to minimize the possibility of electrical noise interference that may cause improper operation. Consider using fiber optic cable for critical circuits.

9. Conduct a field inspection prior to start-up to verify proper wire terminations. For utility-scale commercial systems, a random sampling should be taken, since field inspection of all wire terminations is not practical.

PV System Supplier

1. Perform a detailed analysis of possible circulating current between PCUs, for multiple PCUs feeding into one step-up power transformer, prior to finalizing the system design. Alternatively, design the low-voltage side of the step-up power transformer with separate windings for each PCU.

2. Design the PCU ac voltage output at a nominally standard voltage such as 480 V (Kerman is 380 V) to eliminate the additional cost and manufacturing time of custom transformer windings.

3. Design the system to account for solar gain. Consider designing a shade over the PCU to potentially eliminate the need for PCU air conditioning.

4. Consider using large and highly efficient PV modules to minimize the number of factory and field terminations, reducing labor time and cost, and improving reliability.

5. Carefully select connector types for signal and control circuits inside the PCU to improve reliability. Use screw-type terminal blocks or strips where practical. Pin-type connectors

should have split pins or sleeves for positive pressure, and a high contact surface area. PVUSA has had operational problems with poor contacts, particularly from commercial ribbon cable connectors, from both corrosion and looseness. Only devices that are frequently removed as part of regular maintenance need to have a connector for easy disconnection and connection.

6. Implement factory and field QA/QC plans rigorously, particularly with respect to module-to-module and panel-to-panel electrical terminations. Maintain strict field quality surveillance on bolted mechanical connections. PV system construction involves repetitive work that may be conducive to the labor force becoming inattentive in their work. Factory electrical connections, although passing strict factory QA/QC programs, may become loose during shipment, handling, and construction. Field inspect devices bolted inside PCU enclosures prior to start-up to minimize the possibility of the devices becoming loose and causing damage.

7. Verify appropriate outdoor ratings of meters, displays, connectors, enclosures, and other exposed components.

8. Maintain awareness of terminations and mounting bolts that may be affected when field modifications and adjustments are performed. Inspect and re-torque affected nuts and bolts.

9. Consider gaining familiarity with utility infrastructure requirements, industry practices, and applicable codes and standards to support offering turnkey utility-grade PV plants.

Section 6

PVUSA HOST UTILITY SYSTEMS

This section briefly describes the utility-scale systems supplied by the Utility Power Group and ENTECH and owned by PVUSA host utilities, the Sacramento Municipal Utility District (SMUD) and Central and South West Services (CSW). The SMUD and CSW systems were installed more recently than those at PVUSA Davis and Kerman.

PV SYSTEM DESCRIPTIONS

Since the completion of the US systems at Davis and Kerman, SMUD and CSW have procured and installed US systems in their service territories. SMUD and CSW are PVUSA host utilities, although their PV system specifications and requirements are based on, but not identical to, PVUSA's. These differences, including system size, electrical protection requirements, and interface point between the PV system supplier and utility, may have influenced the contract prices. The three systems are summarized in **Table 6-1.**

Table 6-1
SMUD and CSW US Systems

Owner	US System Supplier, Location	Technology	Date Completed	Rating (kWac)[a]	Contract Price ($/W)
SMUD	Utility Power Group, Sacramento, CA	Single-crystal silicon, one-axis active tracking, Omnion PCU	April 1994	213[b]	7.20
CSW	Utility Power Group, Ft. Davis, TX	Single-crystal silicon, one-axis active tracking, Omnion PCU	November 1994	100[c]	10
CSW	ENTECH, Ft. Davis, TX	Single-crystal silicon 21x concentrator, Omnion PCU	January 1995	88[d]	13

[a] Rating based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1,000 W/m^2 plane-of-array irradiance for flat plates and 850 W/m^2 for concentrators, 20° C ambient temperature, and 1 m/s wind speed.

[b] Interim rating by PVUSA.

[c] Based on supplier's estimate (system yet to be rated).

[d] Rating by CSW.

Utility Power Group (UPG)

UPG mobilized to the SMUD site in September 1993. System start-up occurred 7 months later on April 18, 1994. The system consists of 4,800 SSI M55 modules, an east-west tracking motor at the center of each row (20 total) (**Figure 6-1**), and a 250-kW Omnion PCU. SMUD specified that the PCU automatically reset after grid fluctuations, but remain down in response to problems internal to the PCU. SMUD believes that this protection scheme will provide a balance between nuisance trips and system damage.

UPG mobilized to the CSW site on July 8, 1994. System start-up occurred 2 months later on September 10, 1994. The system uses 2,400 SSI M55 modules, an east-west tracking system at the center of each row (10 total), and an Omnion PCU. Unlike the 600-V system for SMUD, the CSW system uses 2-kV wiring, although the CSW switchgear is not consistent with the wiring. The wiring is exposed to higher risks than any other system component. It is the least accessible component once installed and experiences the most stress during installation. These considerations led to the decision to use 2-kV wire as a measure to enhance system reliability. Additional system components for CSW, but not for SMUD, include a UPG PVX2000 ground fault protection system installed on the dc side, bronze bearings to interface between torque tubes and steel journal bearings, and Plexiglas plates in all dc enclosures to enhance maintenance safety.

Both UPG systems exploit off-the-shelf components, most notably utility poles serving as array supports, set in augered holes without concrete. Off-the-shelf 1/3-hp ac motors, programmable controllers, and 10-ton screw jacks rotate the rigid steel torque tubes (**Figures 6-2** and **6-3**).

SSI modules for the UPG systems are attached to the support structure by sliding into a custom aluminum extrusion mounted on the torque tube. Like the IPC Davis system, the UPG systems backtrack in the morning and afternoon to reduce shading from adjacent rows. Unlike the IPC Davis system, the UPG arrays stow horizontally at night.

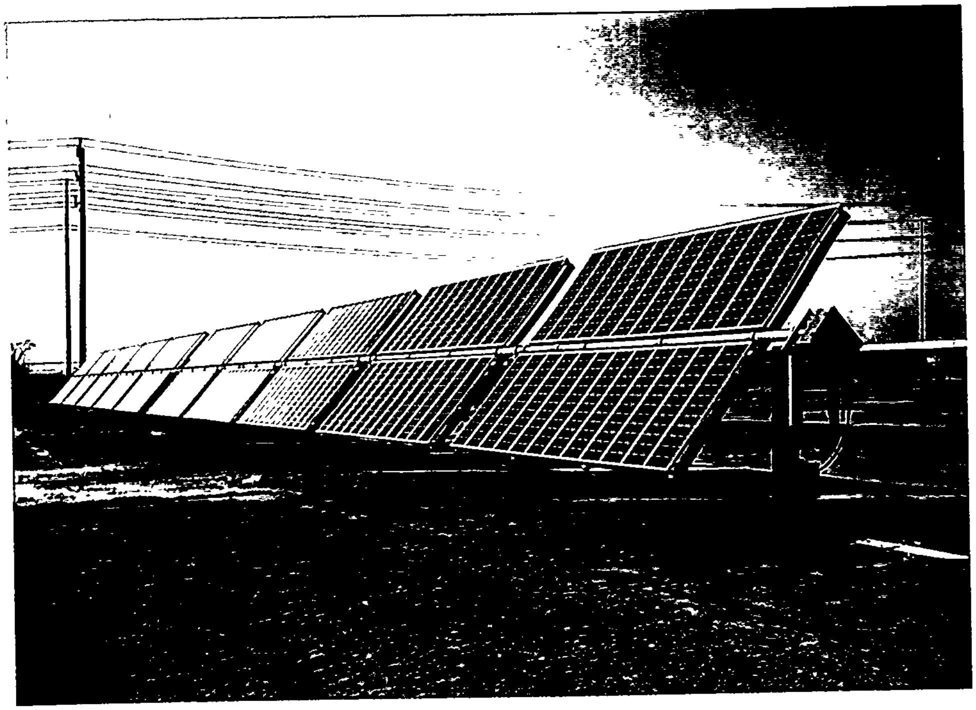


Figure 6-1. SMUD UPG system.

Figure 6-2. SMUD UPG support structure.

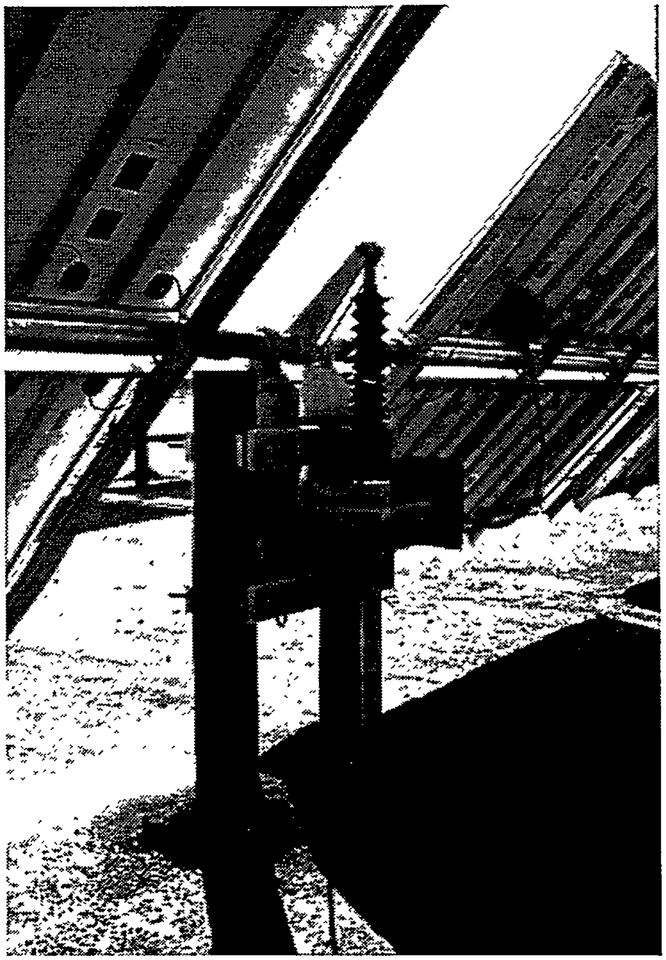


Figure 6-3. SMUD UPG support structure (back of array).

ENTECH

Prior to ENTECH mobilization, pier holes were augered, and concrete and reinforcing steel were placed for the pier foundations in August 1994. ENTECH mobilized to the CSW site on August 29. System start-up began on January 14, 1995. The 288-module system consists of four 340-ft long rows (**Figure 6-4**). Each row consists of 12 typical posts and piers, one center support post and pier, and one pier for support of the tilt jack. Each ENTECH 21x module is composed of 37 prism-covered silicon cell packages, marine-grade aluminum housing, an acrylic Fresnel lens, and an extruded aluminum heat sink.

Tracking is accomplished using dc-powered drives and controls to avoid potential ac-related controller problems. Located at the center of each row is a 10-ton jack for tilt, a 3/4-ton jack for roll, a Prime Manufacturing microprocessor controller, and color-coded, noninterchangeable cables. A dc combiner box on each row combines three monopole circuits and includes blocking diodes, a surge arrestor, fuses, and switches. Like the UPG systems, the ENTECH system uses an Omnion PCU.

Costs

The UPG contract prices were $7.70/W for the 200-kW SMUD system and $10/W for the 100-kW CSW system. Although the local labor force was less expensive for the CSW system than for the SMUD system, UPG attributes the higher CSW price to the smaller size of the CSW system, remoteness, and added system hardware including ground fault protection and bronze tracker bushings. While UPG used the same type of modules for the SMUD and CSW systems, the modules cost UPG 12% more for the CSW system than for the SMUD system due to the smaller quantity and longer transportation distance. Actual UPG system cost data are not available; UPG is reluctant to quantify costs for each system due to their ongoing research and development activities that benefit multiple systems.

The 1994 SMUD PV Program will complete three additional PV systems at the Hedge substation in 1995. Bell Products will supply a 108-kW system using APS modules and a Kenetech PCU for $6.68/W. Resource Management International will supply a 102-kW system using Solarex modules and a Kenetech PCU for $7.35/W. UPG will supply a 107-kW system using SSI modules and multiple Omnion PCUs for $7.38/W.

The actual ENTECH system total cost is unknown, but relative cost breakdowns were provided by ENTECH. BOS accounts for about half of the actual PV system cost to ENTECH. The 50% attributable to module costs involves cell package materials (19%), balance-of-receiver materials (9%), module housing materials (12%), and lenses (10%). ENTECH splits the BOS costs into two categories: (1) structures, drives, controls, and piers (29%); and (2) inverter, junction boxes, and field wiring (21%).

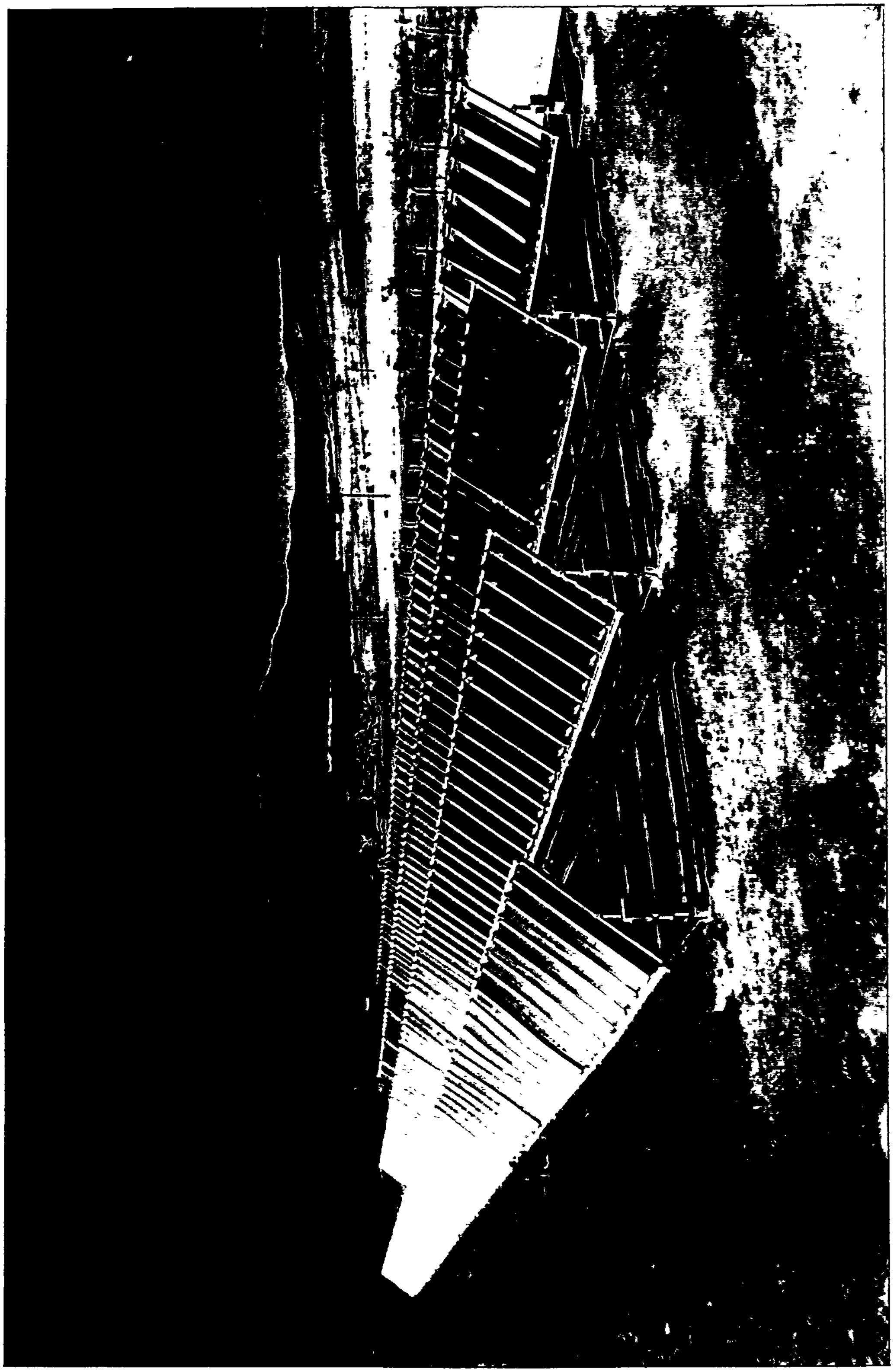


Figure 6-4. CSW ENTECH system.

Lessons Learned

The CSW UPG system experienced numerous trips on overvoltage during the startup period. Adjustments were made to both the isolation transformer in the PCU and the utility transformer bank. The three potential transformers used to sense line voltage were checked. These transformers and associated burden resistors were found to be out of specification, causing an inaccurate representation of line voltage. Consequently, although the line voltage was at an acceptable level, the PCU was tripping on overvoltage. The problem was solved by adjusting the constant voltage reference in the PCU.

During the 3 months since startup of the CSW UPG system, maintenance issues centered on the PCU. Sporadic trips due to "Regulator or Crowbar fault" were corrected by installing a missing ground wire on one of the linear dc power supplies in the PCU. A screw in the PCU master control board that was suspected of shorting a trace on the printed circuit board was removed, significantly reducing total harmonic distortion. Additional minor problems were corrected, and the system is operating satisfactorily.

The CSW ENTECH system is the most streamlined ENTECH system to date. Instead of using concrete piers and j-bolts with steel plates as done previously, ENTECH used Nelson welded studs to mount posts to pier plates, which worked well. To minimize PCU current and cost, ±400 V peak power (±600 V open circuit) bi-polar dc wiring was used.

The ENTECH system for CSW and all future ENTECH systems will use hot-dipped galvanized steel structures; earlier ENTECH systems have painted steel structures which require monitoring for corrosion and repainting. According to ENTECH, when their galvanized structures were hot-dipped, zinc built up more on one side than the other, causing the structure to bow. Despite the bowing, ENTECH recommends the use of galvanized steel structures rather than painted structures.

It was anticipated by PVUSA and CSW that the CSW ENTECH system would benefit from PVUSA's earlier procurement and testing at the Davis site of ENTECH's dc-powered tracker controller. ENTECH modified the controller design to address roll motor stalling problems during high wind speeds at Davis; similar problems were not expected for the CSW ENTECH system. Unfortunately, the CSW ENTECH system is experiencing tracking difficulties, which are at least partially attributable to wind loading on the modules. The CSW ENTECH system uses larger modules than those at PVUSA Davis (12 vs. 10 ft long) with bigger extruded aluminum heat sinks and more modules per row. As of April 1995, ENTECH continues to work on addressing the tracking problem.

Module shipping was the biggest problem; more than 50 lenses were broken in transit and had to be shipped back for replacement. ENTECH could not justify on-site module assembly for the 100-kW CSW

ENTECH system, although ENTECH anticipates on-site module assembly for larger systems. Despite 3M reinforcing strips along the lens edge, eight additional modules were discovered with cracked lenses on February 22. ENTECH and 3M are working on a solution.

ENTECH believes that BOS issues for concentrators (e.g., sun tracking) are not significant barriers and that what is needed is procurement of multi-megawatt systems to exploit the economies of scale. Like the PCU problems, tracker problems will likely be solved when large procurements justify a design freeze and sufficient testing.

UTILITY-PROVIDED BOS

The UPG system for SMUD is located within SMUD's Hedge substation in the Hedge Transmission and Distribution training yard. The substation land was procured, graded, and fenced years before SMUD considered installing PV systems at the site. The UPG system is connected to the 12-kV distribution system. SMUD provided the site preparation and utility grid interconnection. SMUD has less stringent electrical protection, grounding, and interconnection requirements than PG&E. While PVUSA specified that the PV system supplier provide the switchgear for the Davis systems, SMUD provided the switchgear for the UPG system.

CSW's UPG and ENTECH systems are located at their Solar Park near Ft. Davis, Texas (**Figure 6-5**). The Solar Park is a demonstration of state-of-the-art solar energy systems. Future plans include installation of a third 100-kW system as well as a 7.5-kW solar dish Stirling engine.

Site development of CSW's Solar Park began in November 1993; no permits were required. The CSW-provided BOS was installed in four phases. The fourth phase, involving PV system interconnection to the grid, was substantially completed on September 26, 1994. CSW-provided BOS includes site access roads, a parking area, a large hexagonal visitors' pavilion with signage, a raised concrete viewing pavilion with handicap ramp, site service water piping, site well, septic system, electrical distribution to the pavilions, black PVC-coated chain-link fencing, PV system site preparation (grading and compaction), step-up transformers to a 500-kVA bank, control building, switchgear, grounding grid, an office trailer, meteorological/solar monitoring station, a DAS, and foundations for the control building, PCUs, and DAS. CSW has less stringent electrical protection and interconnection requirements than PG&E. Like SMUD, CSW provided the switchgear for the UPG and ENTECH systems.

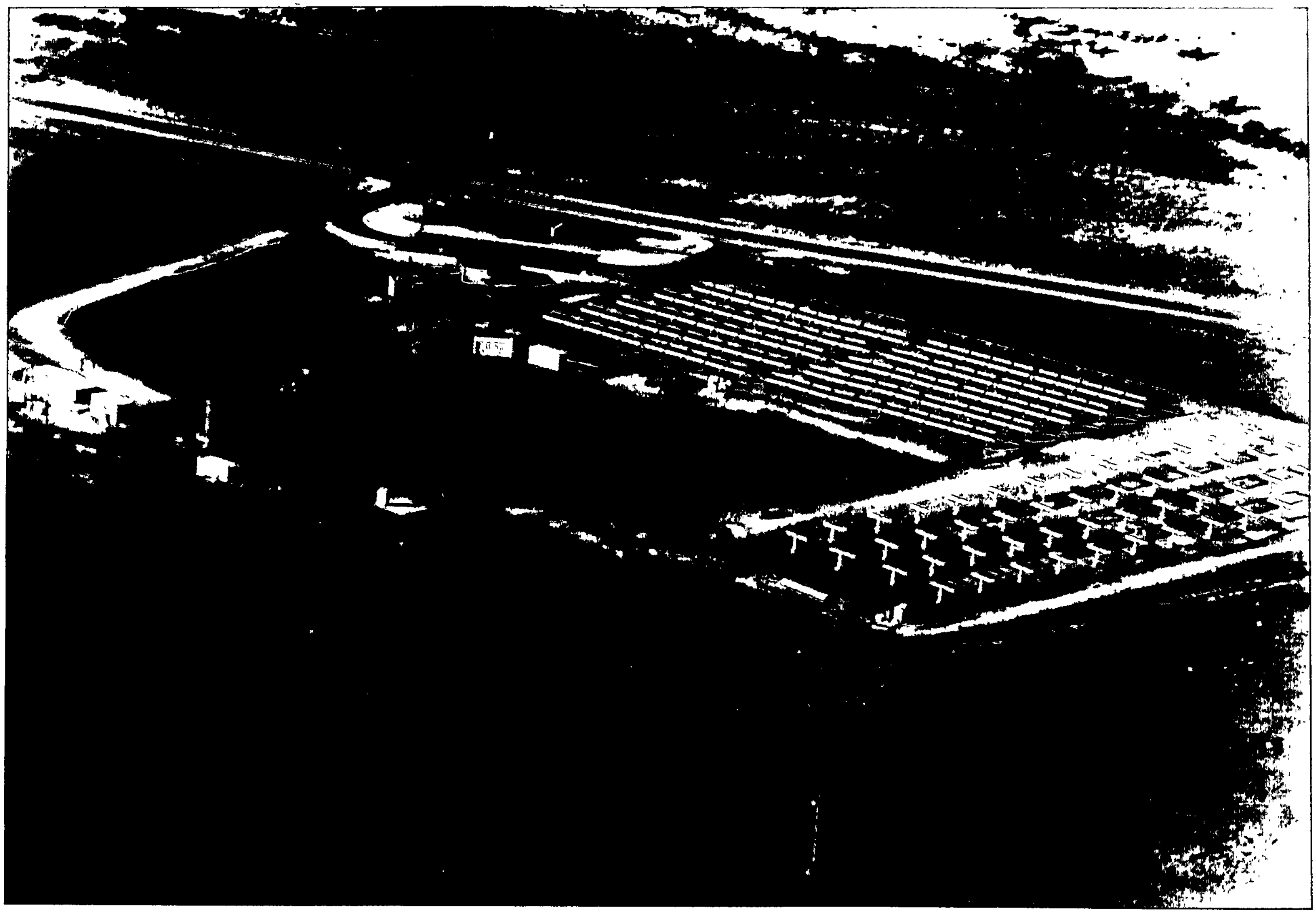


Figure 6-5. CSW Solar Park.

Lessons Learned

SMUD-provided BOS for the UPG system completed in 1994 cost $4.79/W. Site preparation, interconnection, metering, SMUD labor, administration, overheads, tax, bonding, and AFUDC are included. SMUD anticipates that SMUD-provided BOS will cost $1.07/W for the three systems totaling 317 kW to be completed in 1995.

CSW-provided BOS cost $675,000, or $3.60/W of installed systems. Land acquisition, permitting, and utility project management, engineering, and procurement are included. After the third 100-kW system has been installed at the CSW site, the cost is expected to be $2.05/W. If the research-related BOS costs and public education costs were not included, CSW estimates their BOS costs could be reduced to about $228,000, or about $0.75/W.

Material costs outside of California are not necessarily lower, and may be significantly higher, than material costs in California. CSW paid about $90 per cubic yard for concrete, compared to about $55 per cubic yard at Davis. CSW attributes the difference to the remoteness of their site and scarcity of local subcontractors to create a competitive environment.

Section 7
SUMMARY

This section summarizes PVUSA's lessons learned with module and array wiring, foundations and structures, PCUs, and interconnection and utility distribution system requirements. Available capital and failure-related maintenance cost data for the US systems at PVUSA and host utility sites are also discussed.

Utilities installing a PV plant typically determine its purpose, including research-related objectives such as the PVUSA Davis utility-scale and the Kerman grid-support systems. Utilities or owners of PV systems subsequently determine the requirements of the entire PV plant.

PV system suppliers are generally limited in engineering, designing, and installing the PV portion of the PV plant. Utilities are typically more comfortable than PV suppliers in engineering, designing, and installing the connection of the PV system to the utility. This can include the power step-up and isolation transformer, the medium-voltage switchgear (15-kV), protective relays (equipment), revenue metering, and auxiliary systems such as battery banks or uninterruptible power supplies. At the onset of a PV plant installation project, the interface between the utility and the PV system supplier is established. Thereafter, the detailed requirements can be defined in the utility's specifications and request for proposal.

MODULES/PV ARRAY WIRING

In this report modules are not considered BOS components. However, the wiring and structural panel support for the modules are included in the BOS. The PVUSA utility-scale systems at Davis and Kerman are specified as nonresearch, or commercial, products with sufficient favorable field experience. All modules for PVUSA passed the NREL Interim Qualification Tests and Procedures for Terrestrial Photovoltaic Thin-Film Flat-Plate Modules, which were modified to include PVUSA-specific requirements.

Module-to-module wiring for the APS system was achieved by plug-in connectors and panel-to-panel wiring was achieved by piercing connectors, thus eliminating the traditional module junction box and wire terminal electrical connections. This type of array wiring is economical and easy to install. The interpanel connectors were not properly assembled in the shop, however, necessitating labor-intensive field retrofits.

IPC array wiring used module disk connectors and prefabricated wiring harnesses. The concept is ideal in realizing savings in field installation; however, the materials selected were not suitable for the application. This caused catastrophic problems after 2 months of operation. Eventually, the modules were field-retrofitted with junction boxes. The Mobil Solar disk and harness design is a good concept, which has the potential of reducing field labor and O&M costs. Proper selection of materials should lead to a product that can survive the environment and the elements.

The commercially available SSI module is manufactured with SSI's conventional module junction box. However, for modules subjected to the FWRT, SSI manufactures their modules with junction boxes (two per module) such as the type installed at Davis and Kerman. With two junction boxes per module and four screws per junction box, installation labor is greater than that of an array using the commercial SSI module. The PVUSA experience at Davis during FWRT uncovered a factory QA/QC problem with the module junction boxes. Approximately 1% of the boxes failed the FWRT due to hairline cracks. The problem was attributed to the manufacturing process producing a batch of defective boxes. Over time, PVUSA also notes that the neoprene gaskets supplied with the module junction boxes shrunk, as evidenced by loose screws on the module junction box covers.

Both the APS and IPC module supports are integrated into the structure support. Module supports, or panelization, when integrated into the array structure, reduces structural components, and thus contributes to a cheaper BOS. The SSI module supports were not integrated into the array structure, but the modules were panelized at the factory, to minimize field labor. SSI claims that an integrated panel design using adhesives and frameless laminates is possible with system sizes that are almost double the PVUSA installations.

FOUNDATIONS AND STRUCTURES

The APS array structure is made of readily available commercial steel trusses. This is considered an innovative, inexpensive structure. The structure is modularized and supports 80 modules. To date, the PVUSA project has not encountered a more economic design on the basis of dollars per array area or peak power.

The APS foundations include soil anchors for the portion subjected to uplift loading. The concept is innovative, but the highly corrosive soils at the Davis site necessitated that the soil anchors be epoxy coated, instead of the standard galvanized finish. Epoxy coating is very expensive, and for the Davis soil conditions, the potential cost saving could not be realized. Sites with noncorrosive soils may benefit from the soil anchor foundation design, since epoxy coating would be unnecessary.

The single-axis tracking structures for IPC and SSI systems at Davis cost over twice as much as the APS support structure. However, the tracking structures generally collect 25–30% more energy than an equivalently sized fixed-tilt structure.

Foundations for the single-axis tracking structures for the IPC and SSI systems are both reinforced concrete. The SSI system uses traditional rebar cage reinforcement. The IPC system uses the steel wide-flange column as the concrete reinforcement. The IPC foundation installation appears to be more complex and expensive than the SSI foundations. However, IPC claims that its foundation installation was the cheaper of the two.

The IPC active tracking system is superior to the SSI passive tracking system in terms of energy capture. The SSI passive trackers have been observed to have up to 10° tracking error during the summer months. The IPC active tracking system is, however, dependent on a single controller and drive mechanism. Once there is a problem, the entire tracking system requires immediate attention. The SSI system has 32 independent passive trackers. Failure of one tracker does not have a great impact on the system performance. However, since the trackers are mechanically linked together, a defective passive tracker must be replaced, repaired, or disconnected. Otherwise it will affect the performance of another passive tracker in the same array row.

For single-axis tracking arrays with active tracking system, the array should be stowed at least 20° from the horizontal. As observed at Davis, when the IPC array is stowed horizontally during the night and rain falls on the array, dust and/or dirt is not washed. When it is stowed at an angle, soiling is minimized.

The SSI Kerman tracking system utilizes the same basic design as the Davis system, but with a more energetic, non-CFC refrigerant. Tracking accuracy has been observed to be within 5° of ideal during summer months.

POWER CONDITIONING UNITS

The PVUSA specifications delineated functional requirements for the PCUs. Post award, PVUSA worked with PCU manufacturers to determine the best means for meeting specifications and to incorporate safety and operational features that enhanced the PCU design.

Reliability has probably been the largest overall issue, being responsible for most of the maintenance time and resources on not only the Davis systems, but those owned by the PVUSA host utilities as well. No single root cause can be pointed to, but several areas have consistently contributed to the problems:

- Failed components, including integrated circuits, power supplies, opto-isolators, ribbon cable connectors, power semi-conductors (usually in response to other problems), transducers, contactors, and capacitors.

- Overtemperature. This seems to be more related to general enclosure cooling for the overall system than the power devices themselves, which generally have separate means of cooling.
- Insufficient incorporation of design and construction practices (design allowance for abnormal and transient conditions, device electrical and environmental ratings and margins, choice of components, wiring practices, etc.) to produce industrial-grade or "hardened" designs that can withstand the extremes of field operation.

Improvement can also be made in the PCU designs and layout from a maintenance perspective. Providing adequate spacing and layout of components and methods of establishing electrical clearance to ensure a de-energized cabinet will go far in easing troubleshooting or maintenance activities and enhance the safety of the working environment.

PVUSA recognizes the inherent difficulty of insufficient volume and standardization to allow freezing system designs, which is the best way for these types of issues to get worked-out, yielding a reliable/robust product. One way to accomplish this is to partner with electrical equipment manufacturers that produce common industrial equipment.

Since system reliability and overall performance rely heavily on PCU operation, the concept of multiple inverters may again be worth revisiting. If a single inverter goes down, the entire system output is lost, driving down capacity factor and annual generation while driving up the ¢/kWh for operation and maintenance. Smaller multiple inverters, if they are of a more proven design, may actually yield lower maintenance costs and higher capacity factors.

Grid interaction is another area where results have varied. Some PCUs have interfaced well, correctly responding to grid conditions whether they be outages, transients, or harmonics. Some of the systems have exhibited repeated peculiarities. For example, the APS inverter is a fairly robust and reliable design based on SCR technology, but when line transients or outages occur, it self-protects by clearing power fuses (usually several) on the ac buses. This results in additional down time and appreciable cost for labor and replacement fuses. Also, the power factor correction bank on the SSI Davis system was not sized to account for absorption of line-generated harmonics, resulting in burned wiring and failed capacitors.

Based on lessons learned from the Davis US installations, PVUSA specified that the Kerman PCUs be rated 10% above the system peak power rating under PVUSA Test Conditions. The PCUs are able to operate up to 110% of the plant rating such as during high irradiance conditions. However, the site has experienced irradiance conditions where the power is above 110% often due to edge-of-cloud effect. Although both the Davis and Kerman Omnion PCUs are designed to shed generation (drop source circuits) under high irradiance conditions to avoid overpowering the PCU, this scheme has not been 100%

effective. Overpower and enhanced irradiance are issues worth further development by PCU manufacturers.

The PCUs for the US systems were provided and installed by the PV suppliers. Another topical report covering PVUSA's experience with the different PCUs will be issued in 1995.

INTERCONNECTION AND UTILITY DISTRIBUTION SYSTEM REQUIREMENTS

A design review process was conducted for all the PVUSA US systems. During the PV system design, design documents and calculations are submitted for PVUSA review and acceptance. PVUSA reviewed these documents and conducted design review meetings with the PV supplier as well as utility distribution, maintenance, and operations personnel. For Kerman, the design review process proved to be beneficial to the utility and the PV supplier, and was reflected in a fast and smooth construction process.

PVUSA, for its Davis US systems, opted to include the medium-voltage switchgear in the PV supplier's scope-of-work. For the Davis US systems, PVUSA specifications required that the PV supplier provide a means of isolating the PV system from the utility 15-kV circuit. For the Kerman grid-support system, the utility opted to provide the 15-kV switchgear. The utility distribution personnel preference was to obtain a unit that was widely used in its area of service (Fresno PG&E region, in this case). Maintenance personnel's familiarity with the equipment was of prime consideration.

For a nonresearch facility, where there is minimum maintenance and no special tests conducted, elaborate switchgear is not necessary. A pole-mounted disconnect switch at the point of connection to the utility distribution circuit should suffice.

IPC did not install a 15-kV disconnect switch, but provided bayonet fuses in the IPC-provided power step-up transformer to fulfill the specification requirement for a disconnect or isolation point. In practice, this is not practical for system isolation, normal O&M, or research activities at Davis. The utility-grade protective relays installed in the IPC PCU output circuit were not properly wired, and utility personnel field-modified the wiring to conform to utility requirements.

SSI provided 15-kV switchgear for its Davis installation. Included in this switchgear is a set of potential transformers (PTs) and current transformers (CTs) for metering. The PTs were not wired properly at the factory and initially failed the preparallel tests. The CTs were of the wrong turns ratio and had to be replaced in the field. Included in its switchgear installation, the utility-grade protective relays installed in the PCU output circuit were not properly wired, and utility personnel field-modified the wiring to conform to utility requirements.

APS provided a 15-kV disconnect switch that had to be field-modified to conform to the Davis site safety practices. Personnel grounding lugs and fiberglass barriers were added in the field.

Utilities are more familiar and experienced than PV suppliers with medium-voltage switchgear procurement, engineering, and installation. As a result, this should be excluded from the scope of work of the PV supplier. In addition, selection and configuration of protective relays vary by utility and are often a sensitive area; hence, discrete protective relays not integrated into the PCU electronics should remain in the utility's scope of work. The PCU and the power step-up transformer need to be closely matched with the PV array. It is recommended, therefore, that these be included in the PV supplier's scope of work.

There are three basic electrical connections between the utility and the PV supplier.

1. The *electrical ac power cable*, which is normally a medium-voltage (4kV-15kV) cable for PV systems rated larger than 100 kW, is the interface for ac power delivered to a grid-connected PV system. In practice, this cable is normally routed underground, directly buried until it is away from the PV array such that shadowing, which might be caused by overhead wiring, is not an issue. The three Davis US systems are connected to utility-provided switchgear via one medium-voltage underground cable, which is "daisy-chained" to all three systems.

2. The *DAS or SCADA cable* forms the second interface between the utility and the PV system supplier's scope-of-work. The Davis and Kerman systems included DAS and SCADA boxes where the PV supplier connected its input and output signals; this is the same device where the utility connected for its input and output signals. The only issue that surfaced in this interface was the mismatch between the PV supplier signals and the utility's specified requirements. During the design stage, a detailed set of drawings and data must be coordinated between the PV supplier and the utility. After construction is completed, a point-to-point signal check should be performed as soon as practical to locate any signal inconsistencies. Calibration of instruments and signals is possible prior to start-up using simulated signals, but may be more difficult to perform.

3. The *grounding cable* is the third electrical interface. The point of interconnection with the utility-provided ac power cable is a convenient location for the ground wire connection between the PV supplier's grounding system and the utility's grounding system.

Utilities normally provide all the necessary equipment to interconnect the PV system with the utility distribution system. This equipment includes the ac power cable, the medium-voltage disconnect device, auxiliary power, emergency power, battery system, telecommunications device, remote control, metering, and protective relays. Aside from the enumerated equipment, the utility also provides the necessary pre-parallel tests to ensure that the equipment and devices required for interconnection are installed and operate properly. PVUSA used utility maintenance personnel and technicians, who are familiar with the electrical interconnection equipment and devices from the onset of the project. The involvement of utility personnel at the start of the project was beneficial in minimizing misinterpretation of the interconnection requirements. Davis and Kerman were governed by the same PG&E interconnection handbook. However, utility personnel at the two geographic locations had varying interpretations and requirements; these were, nonetheless, still consistent with the intent of the utility's interconnection handbook.

As a requirement for interconnecting the PV system to the utility distribution circuit, a three-phase interrupting device—a circuit breaker—is required at the output of the PCU. Fuses do not accomplish three-phase interruption and can cause single-phasing.

Acceptance testing is a utility activity that is instrumental in determining the acceptability of the PV system against specification requirements. For PVUSA, acceptance testing for its US systems ranged from 3 months to 4 years. Field acceptance tests and criteria are developed by PVUSA and agreed upon by the supplier. First-of-a-kind or prototype equipment often has difficulty passing the field acceptance tests, as was the case for the Bluepoint PCU that was installed by SSI for its Davis installation.

COSTS

The PV system price paid by PVUSA does not define an upper bound on the actual PV system cost (**Table 7-1**). For highly visible and research-oriented projects like PVUSA, contract prices may be less than actual costs if suppliers underestimate or intentionally underbid the cost. Available data from the Davis and Kerman system suppliers indicate that, although exceeding contract prices, actual capital costs to the system suppliers were as low as $10/W. About half of the actual capital cost for each system is attributable to the BOS. Although the data are not available, the actual costs to the PV system supplier of some of the more recent installations for SMUD and CSW are believed by PVUSA to be less than $10/W. SMUD and CSW had less stringent interconnection requirements than PG&E.

All of the Davis and Kerman systems can be improved to lower costs with minor design changes that are not expected to diminish system performance or reliability. PVUSA estimated PV system cost reduction potentials of $169,750 ($0.35/W) for APS Davis, $355,350 ($1.81/W) for IPC Davis, $307,000 ($4.58/W based on the 67-kW rating for 50% of the installed array) for SSI Davis, and $462,500 ($0.93/W) for SSI Kerman. These PV system cost reductions may have been realized by eliminating PVUSA's research-related BOS requirements and having the PV system suppliers modify their procedures (e.g., quality control) and system designs based on lessons learned. Cost reductions associated with PV technology breakthroughs, volume purchases of US systems, and supplier-initiated efforts (e.g., production scaleup and automation) are not included but would be significant.

Table 7-1
PVUSA Utility-Scale Systems

System	Technology	Date Accepted	Rating (kWac)[a]	Contract Price ($/W)	Actual Cost to PV System Supplier ($/W)	Utility-Provided BOS Cost ($/W)
APS Davis	Amorphous silicon, fixed tilt, APS PCU	10/92	479[b]	4.18	not available	not evaluated
IPC Davis	Polycrystalline silicon, one-axis active tracking, Omnion PCU	7/93	196	9.37	10.40	not evaluated
SSI Davis	Single-crystal silicon, one-axis passive tracking, Bluepoint PCU	6/94	67[c]	26.94[c]	33.62[c]	not evaluated
SSI Kerman	Single-crystal silicon, one-axis passive tracking, Omnion PCU	6/93	498	9.58	10.19	4.04
SMUD UPG	Single-crystal silicon, one-axis active tracking, Omnion PCU	4/94	213[d]	7.20	not available	4.79
CSW UPG	Single-crystal silicon, one-axis active tracking, Omnion PCU	11/94	100[e]	10	not available	3.60
CSW ENTECH	Single-crystal silicon 21x concentrator, Omnion PCU	1/95	88[f]	13	not available	3.60

[a] Rating based on PVUSA Test Conditions (PTC) and total array area, where PTC are defined as 1,000 W/m^2 plane-of-array irradiance for flat plates and 850 W/m^2 for concentrators, 20° C ambient temperature, and 1 m/s wind speed.

[b] Performance when system was accepted; the rating would be about 400 kW if based on 1994 data.

[c] Based on 50% of the installed array; one of the two PCUs is not operational.

[d] Interim rating by PVUSA.

[e] Based on supplier's estimate (system yet to be rated).

[f] Rating by CSW.

To an electric utility, the purchase price for an installed turnkey PV system is not a complete representation of PV system costs; utilities must also account for owner-provided BOS, which includes site preparation, interconnection, project management, engineering, and procurement. PG&E-provided BOS for the SSI Kerman system cost $4.04/W, for a total system cost to PG&E of $13.62/W. SMUD-provided BOS for the UPG system cost $4.79/W, for a total system cost to SMUD of $11.99/W, but did not involve land siting and acquisition, permitting, fencing, or a grounding grid. CSW-provided BOS for the UPG and ENTECH systems cost $3.60/W, for a total system cost to CSW of $13.60/W and $16.60/W, respectively.

PVUSA, SMUD, and CSW agree that utility-provided BOS costs could be significantly reduced for subsequent, nonresearch installations. In independent evaluations by the respective organizations, utility-provided BOS costs might be as low as $2.30/W for a 500-kW system like PVUSA Kerman, $1.07/W for the three additional SMUD systems totaling 317 kW to be installed at Hedge substation in 1995, and $0.75/W at the CSW Solar Park after the third 100-kW system is installed. The utility-provided BOS cost estimates are notably less for SMUD and CSW than for PVUSA, attributable at least in part to PVUSA's higher estimates for owner home-office ($1.26/W) and owner construction ($0.51/W) costs. As PV systems become standardized and familiar to owners, the costs of owner-provided BOS will tend to decrease, and PV system BOS costs will reflect system design standardization, efficiency, kW rating, and supplier and owner experience.

Failure-related maintenance costs from system acceptance through 1994 have been about 1¢/kWh for the innovative fixed and tracking systems at Davis and 0.6¢/kWh for the second-generation tracking system at Kerman. PCU problems are a key driver for failure-related maintenance costs; non-PCU failure-related maintenance costs from system acceptance through 1994 are 0.3¢/kWh or less for the Davis systems and 0.4¢/kWh for the Kerman system. The annual distribution of failure-related maintenance costs is indicated in **Table 7-2**.

Table 7-2

PVUSA Davis and Kerman Failure-Related Maintenance Data

PV System ac rating at PTC	**APS Davis** **479 kW**	**IPC Davis** **196 kW**	**SSI Davis** **67 kW**	**SSI Kerman** **498 kW**
Failure-related maintenance costs (¢/kWh)[a]	0.4 (10/92-12/92) 1.2 (1993) 1.0 (1994)	6.3 (7/93-12/93) 3.6 (1994)	0.9 (7/94-12/94)	1.3 (8/93-12/93) 0.4 (1994)
Non-PCU failure-related maintenance costs (¢/kWh)[a]	0 (10/92-12/92) 0 (1993) 0.6 (1994)	0 (7/93-12/93) 0.1 (1994)	0 (7/94-12/94)	1.1 (8/93-12/93) 0.2 (1994)
Failure-related maintenance events (number)	12 (10/92-12/92) 24 (1993) 27 (1994)	42 (7/93-12/93) 91 (1994)	34 (7/94-12/94)	12 (8/93-12/93) 44 (1994)
Energy production (MWh)	148 (10/92-12/92) 530 (1993) 651 (1994)	75 (7/93-12/93) 169 (1994)	48 (7/94-12/94)	369 (8/93-12/93) 1,013 (1994)

[a] Assuming fully loaded labor rate of $50/hour.

Section 8
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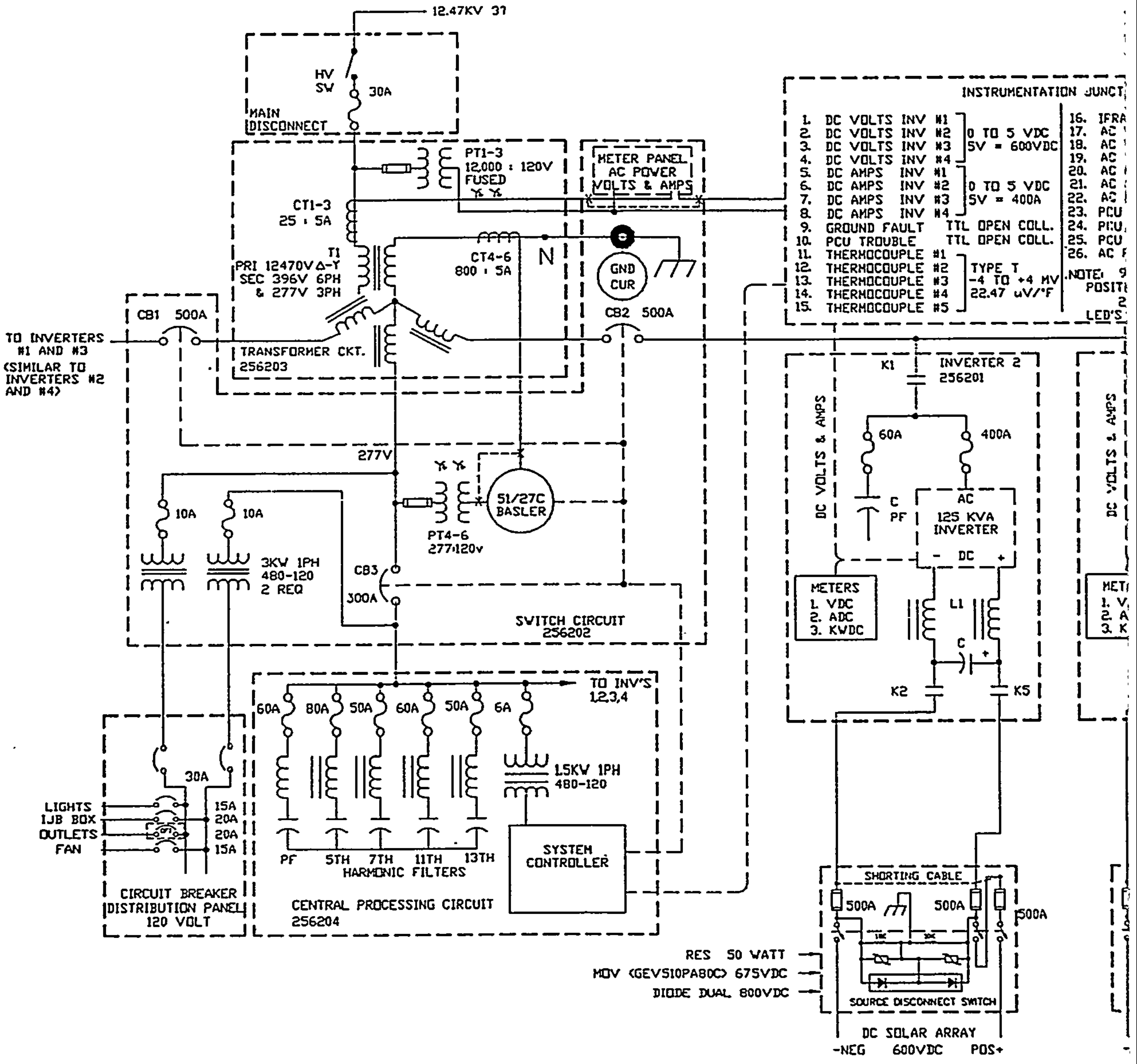
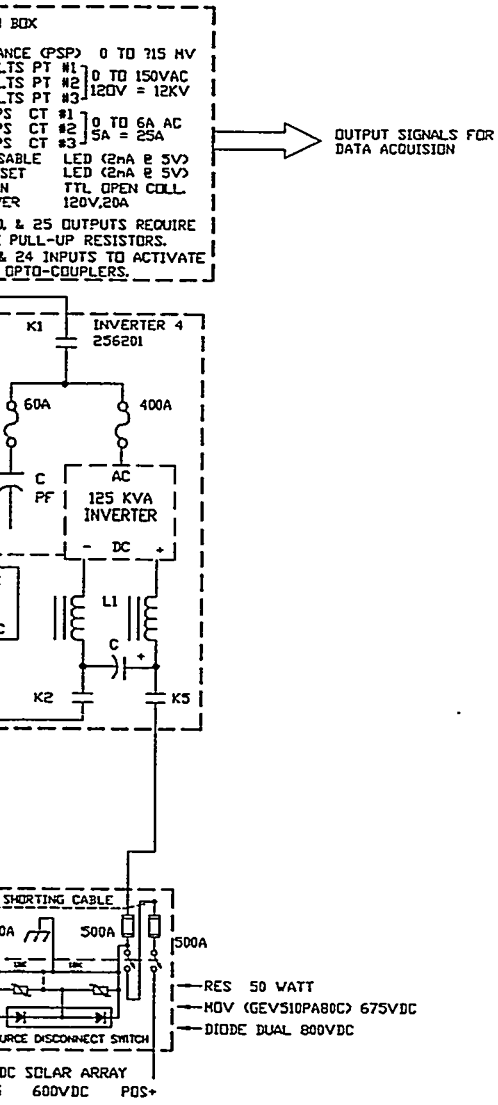
Appendix A
DRAWINGS


12.47KV 3?
HV SW
30A
MAIN DISCONNECT
PT1-3
12,000 : 120V
FUSED
METER PANEL
AC POWER
VOLTS & AMPS
CT1-3
25 : 5A
T1
PRI 12470V∆-Y
SEC 396V 6PH
& 277V 3PH
CT4-6
800 : 5A
N
GND CUR
CB1 500A
CB2 500A
TO INVERTERS #1 AND #3
(SIMILAR TO INVERTERS #2 AND #4)
TRANSFORMER CKT.
256203
277V
51/27C BASLER
PT4-6
277:120v
10A
10A
3KW 1PH
480-120
2 REQ
CB3
300A
SWITCH CIRCUIT
256202
TO INV'S 1,2,3,4
60A
80A
50A
60A
50A
6A
1.5KV 1PH
480-120
PF
5TH
7TH
11TH
13TH
HARMONIC FILTERS
SYSTEM CONTROLLER
CENTRAL PROCESSING CIRCUIT
256204
30A
LIGHTS
IJB BOX
OUTLETS
FAN
15A
20A
20A
15A
CIRCUIT BREAKER DISTRIBUTION PANEL
120 VOLT
INSTRUMENTATION JUNCT
1. DC VOLTS INV #1
2. DC VOLTS INV #2
3. DC VOLTS INV #3
4. DC VOLTS INV #4
0 TO 5 VDC
5V = 600VDC
5. DC AMPS INV #1
6. DC AMPS INV #2
7. DC AMPS INV #3
8. DC AMPS INV #4
0 TO 5 VDC
5V = 400A
9. GROUND FAULT TTL OPEN COLL.
10. PCU TROUBLE TTL OPEN COLL.
11. THERMOCOUPLE #1
12. THERMOCOUPLE #2
13. THERMOCOUPLE #3
14. THERMOCOUPLE #4
15. THERMOCOUPLE #5
TYPE T
-4 TO +4 MV
22.47 uV/°F
16. IFRA
17. AC
18. AC
19. AC
20. AC
21. AC
22. AC
23. PCU
24. PCU
25. PCU
26. AC
NOTE: 9
POSIT
2
LED'S
K1
INVERTER 2
256201
DC VOLTS & AMPS
60A
400A
C
PF
AC
125 KVA INVERTER
- DC +
METERS
1. VDC
2. ADC
3. KWDC
L1
C
K2
K5
DC VOLTS & AMPS
MET
1. V
2. A
3. K
SHORTING CABLE
500A
500A
500A
RES 50 WATT
MOV (GEVS10PA80C) 675VDC
DIODE DUAL 800VDC
SOURCE DISCONNECT SWITCH
DC SOLAR ARRAY
-NEG 600VDC POS+

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED
A	RELEASED FOR PRODUCTION	4/18/91	D.L
B	ADD 10K RES; REVISED TO BECHTEL	7/2/91	D.L
C	12KV WAS 12,000V,277;120V WAS 480,69.3V	8/7/91	D.L
D	REDRAWN AND UPDATED	1/10/92	D.L
E	REVISED AND UPDATED	5/26/92	D.L
F	REVISED AND UPDATED AS BUILT	8/19/92	D.L
G	CORRECT D.C. SWITCH WIRING	10/20/92	D.L
H	SWAP FUSE FOR 7TH AND 13TH HAR.	2/23/93	



PLOT: 2/23/93

ITEM NO.	QTY REQ'D	PART OR IDENT. NO.	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS OR PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMS. IN INCHES OR IN.[MM]
DEC.TOL. XX? XXX?
FRACT.TOL.? ANG.TOL.?
MATERIAL
FINISH

DO NOT SCALE DWG

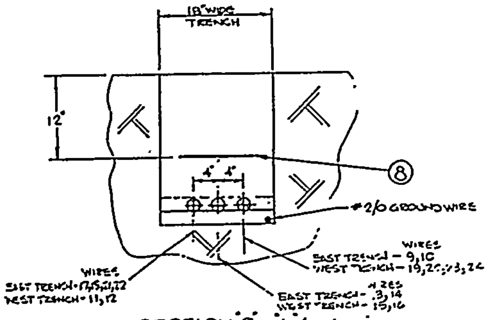
SIGNATURES	DATE
DRN R. LENSKOLD	4/4/9.
DSGN	
CHKD	
CHKD	
CHKD	
APPD	

THIS DRAWING AND SPECIFICATIONS CONTAINED HEREIN IS PROPRIETARY TO APS, INC. AND IS LOANED TO FACILITATE BIDDING, CONSTRUCTION, FABRICATION AND/OR EXECUTION OF REQUIREMENTS STATED AND IS TO BE SURRENDERED UPON REQUEST OR COMPLETION OF SERVICES.

APS ADVANCED PHOTOVOLTAIC SYSTEMS
P.O. BOX 7093
PRINCETON, N.J. 08543-7093

ELECTRICAL CONFIGURATION
ONE LINE DIAGRAM
PVUSA PROJECT, DAVIS CA.

SCALE
SHT 1 OF 1
256216
REV H



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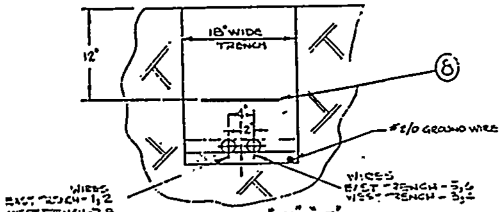

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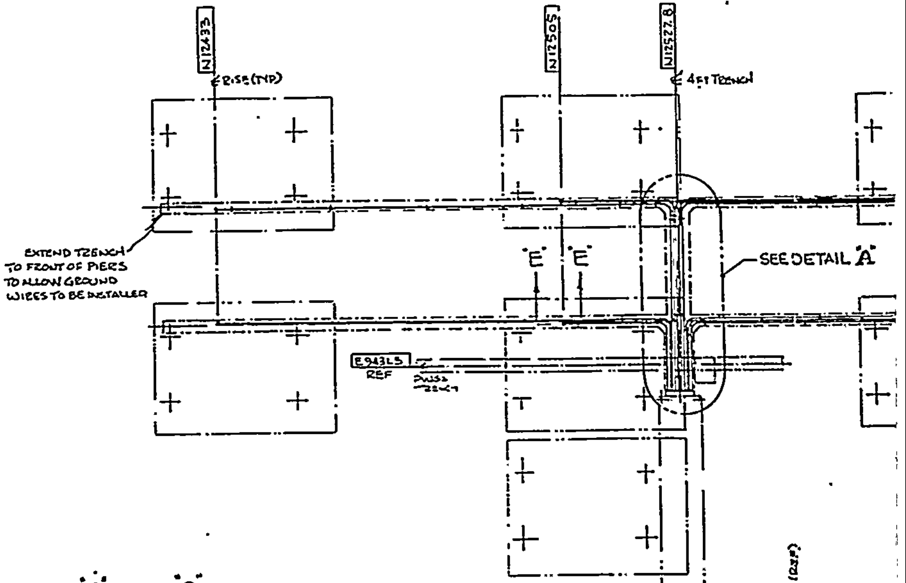

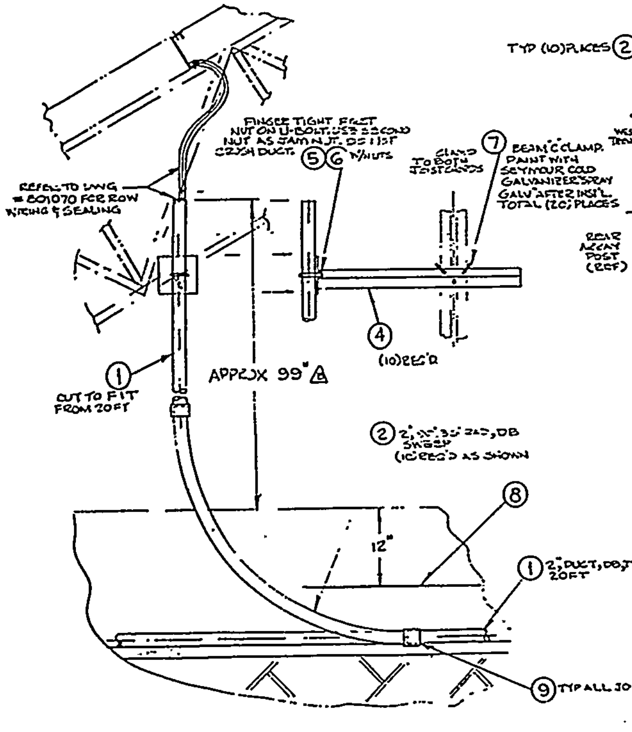

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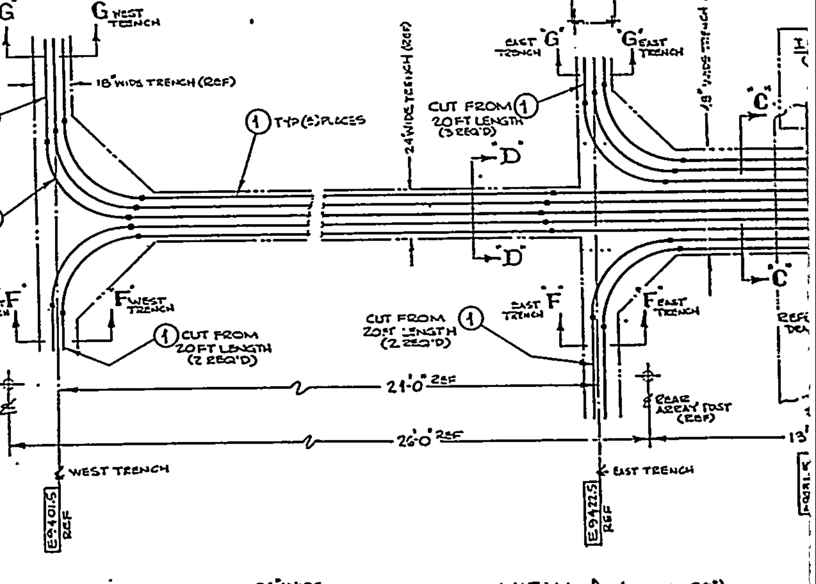
(TYP.)



VIEW A (ROTATED 90° CCW)
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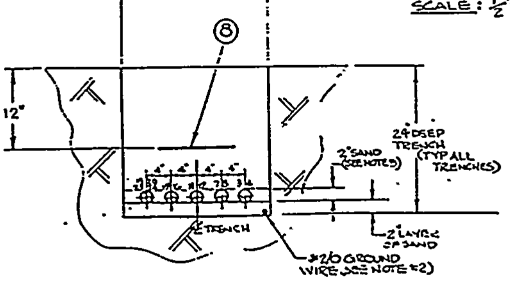

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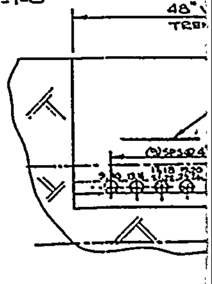
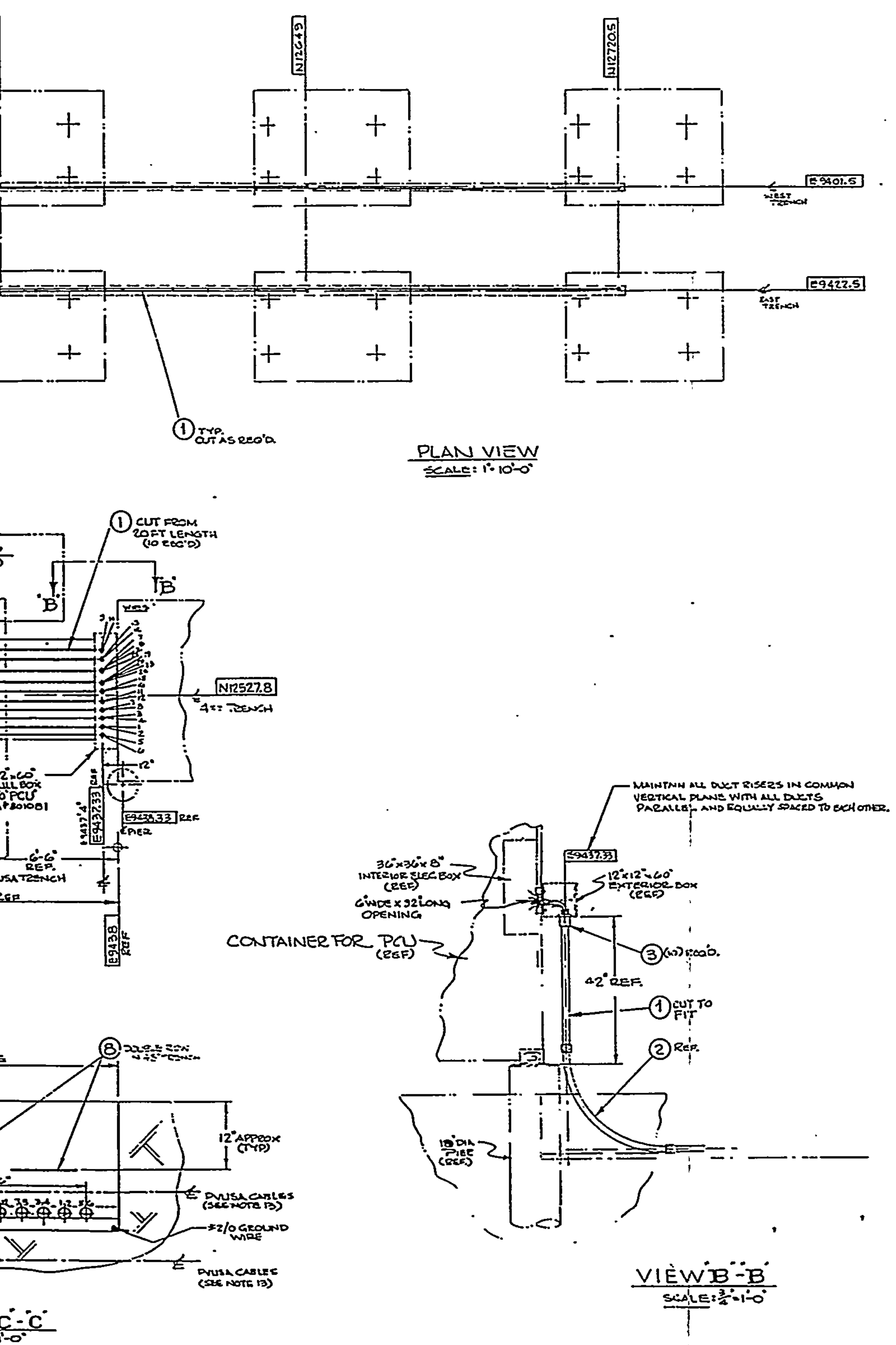


SECTIO
SCALE:



LTR	ECO	DESCRIPTION	DATE	APPR
A	-	RELEASED	6/1/91	[illegible]
B	-	LOCATION OF IDENDOLINE TAPE WAS GIVEN TO TOP OF DUCTS; REVISED NOTE 9; ADDED NOTE 13; [illegible] WAS [illegible]	6/4/91	[illegible]
C	-	ADDED ASTM SPEC # TO NOTE 11	7/24/91	[illegible]
D	-	5¼" Rad WAS 3"	[illegible]	[illegible]
E	-	[illegible]	[illegible]	[illegible]
F	-	ITEM #1 [illegible] WAS [illegible]	9/1/92	

CONSTRUCTION/INSTALLATION NOTES:

TRENCHES

1. TRENCHES SHOULD BE GRADED TRUE AND FREE FROM STONES AND SOFT SPOTS TO A WIDTH AS SHOWN AND TO A DEPTH OF 3[illegible]". TRENCHES TO BE STRAIGHT AND TRUE TO SURVEYOR'S LOCATIONS.

2. LAY-IN GROUND WIRES AND MAKE NECESSARY CONNECTIONS USING CADWELD JOINTS (SEE DWG. #801067).

3. ALL GROUND WIRES AND ALL ROW JUMPER GROUNDS ARE TO BE JOINED TOGETHER USING CADWELDS (SEE DWG. #801067) PRIOR TO AN APPLICATION OF SAND.

4. APPLY A 3" LAYER OF SAND AT BOTTOM OF TRENCHES AND GRADE LEVEL COVERING ALL IN-TRENCH GROUND WIRES.

5. EXPAND TRENCHES AT TURNS FROM CENTER AISLE TO PCU TO ACCOMMODATE RADIUS SWEEPS.

DIRECT BURIAL DUCT INSTALLATION

6. INSTALL DUCT WORK OUTWARD FROM PCU CEMENTING JOINTS USING QUICK-SET, ALL WEATHER SOLVENT (ITEM #9). LAY DUCTS ON TOP OF 3" SAND LAYER, PUSHING GENTLY INTO SAND IF NEEDED.

7. CUT DUCTS AS REQUIRED. CUT MUST BE SQUARE AND SMOOTH.

8. INSTALL SWEEPS MAINTAINING STRAIGHTNESS AND SQUARENESS. CAP ENDS WHERE THEY PROTRUDE FROM GROUND TEMPORARILY TO KEEP DIRT, DEBRIS AND WATER OUT OF DUCTS. MAKE SURE EXITS FROM GROUND ARE TO GIVEN SURVEYOR'S LOCATION PCU.

BACKFILLING

9. APPLY A 3" LAYER OF SAND COVER OVER CONDUITS. BACKFILL 6" OVER SAND WITH SELECTED SOIL (DO NOT TAMP ON TOP OF DUCTS).

10. LAY-IN 12" WIDE IDENDOLITE TAPE (ITEM #8) FULL LENGTH OF ENTIRE TRENCH.

11. FINISH BACKFILLING. BACKFILL SHOULD BE FREE OF STONES AND DEBRIS. START BY BACKFILLING ON SIDES OF DUCTS. TAMP ENTIRE TRENCH TO FINISH GRADE, TO A COMPACTION OF 95% UNDER ROADS AND 90% ELSEWHERE PER ASTM D1557 COMPACTION TEST PROCEDURE. C

12. SYSTEM IS READY FOR WIRE INSTALLATION.

13. COORDINATE REMOVAL AND REPLACEMENT OF PVUSA CABLES/CONDUITS WITH BECHTEL'S SITE CONSTRUCTION PERSONNEL.

14. WIRE PULLING GUIDELINES:
    a) MAXIMUM PULLING TENSION CABLE = 745 lbs.
    b) CLEAN CONDUIT USING AIR BLOW METHOD.
    c) USE CABLE PULLING LUBRICANT; FEED CABLES AT CONDUIT END WITH THE MOST NUMBER OF BENDS. E
    d) MAXIMUM ALLOWABLE TOTAL PULLING TENSION WITH BASKET PULL = 1000 lbs (MULTIPLE CABLES TOTAL) OR 745 lbs (ONE CABLE).
    e) MINIMUM ALLOWABLE AWG 2/0 CABLE BENDING RADIUS = 5¼". D

ITEM NO.	QTY REQ'D	PART OR DOC. NO.	NOMENCLATURE OR DESCRIPTION	REV
9	2-1	COMMERCIAL	QUICK-SET ALL WEATHER CLEAR CEMENT - CARLON #VC9?1?P	
8	[illegible]	COMMERCIAL	12" WIDE IDENDOLINE TAPE BRADY Co TYPE #[illegible] OR EQUAL	
7	20	COMMERCIAL	[illegible]	
6	20	COMMERCIAL	NUT, 3/8-16, HEX, GALV.	
5	10	COMMERCIAL	[illegible]	
4	10	801066	PIPE SUPPORT ASSEMBLY	
3	10	COMMERCIAL	2" MALE ADAPTOR CARLON #E943J	
2	20	COMMERCIAL	2" 90° 36" RAD SWEEP [illegible] TYPE CARLON #[illegible]	
1	7.3	COMMERCIAL	2" DUCT, OD .120 [illegible] 20 FT LG CARLON #[illegible]	

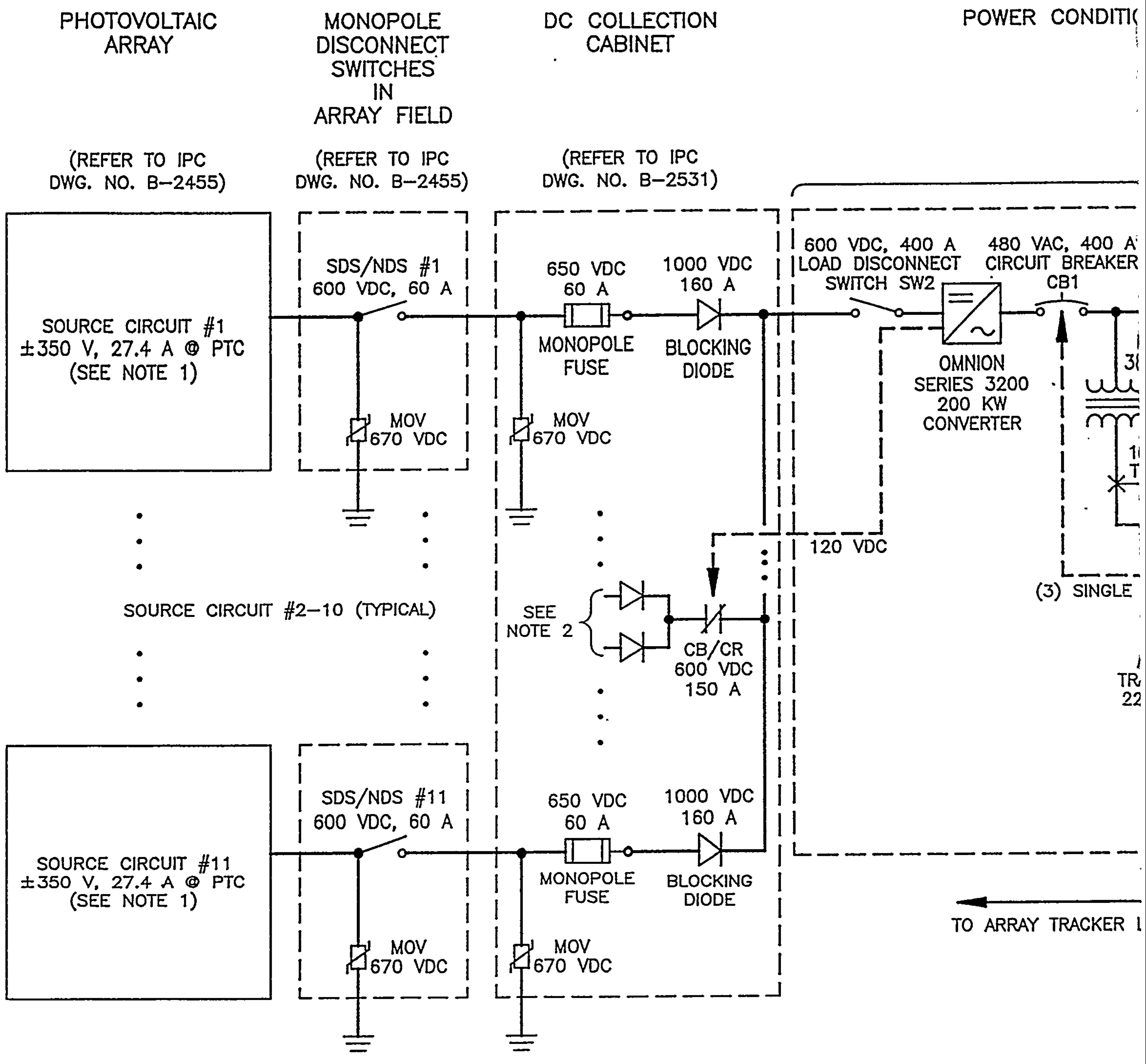
APS ADVANCED PHOTOVOLTAIC SYSTEMS, INC.

DIRECT BURIAL DUCT SYSTEM

DRAWN: J. LAVEDOCK

801065

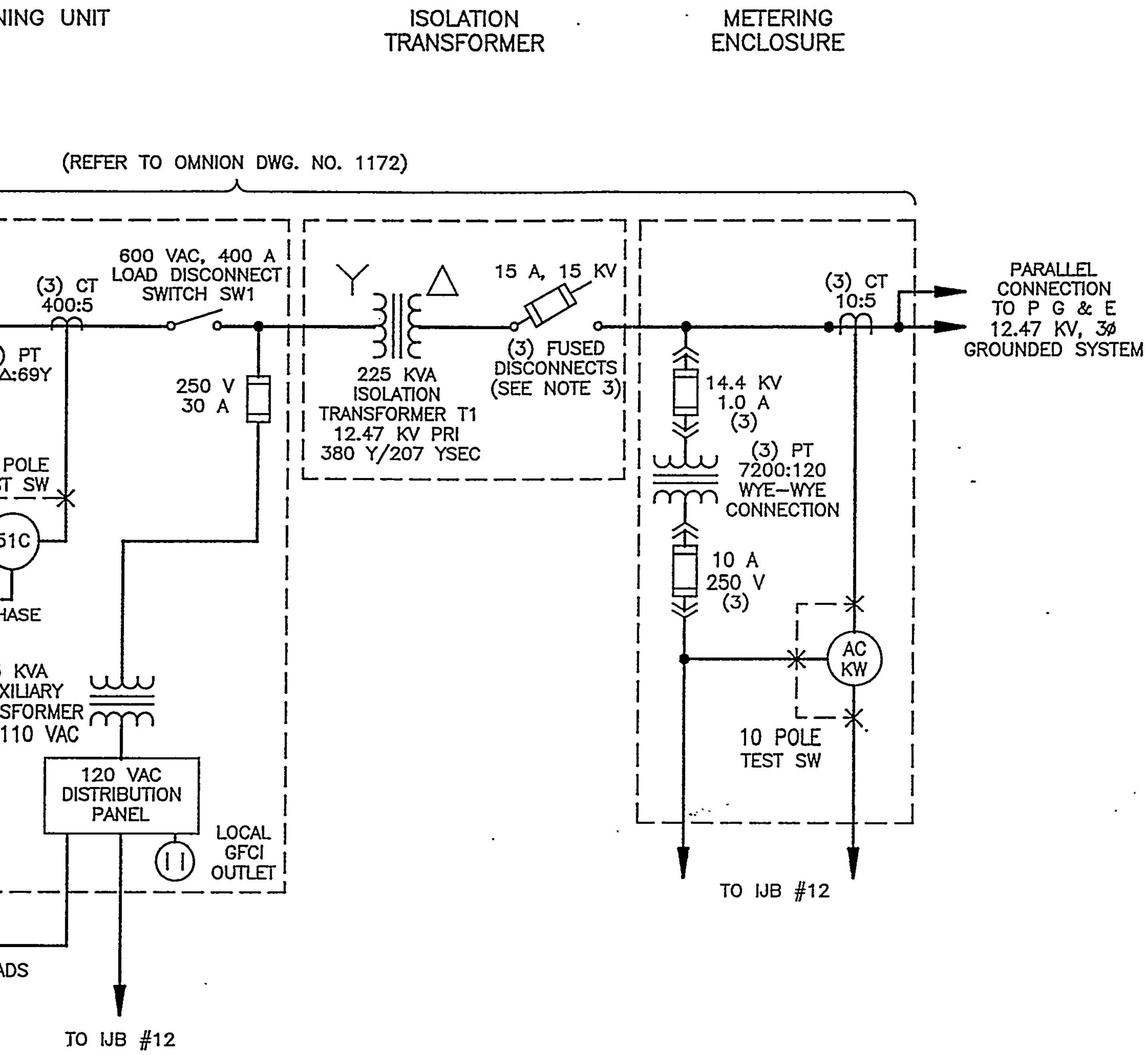
REV F



NOTES:

1. PTC = 1000 W/m^2, 20°C AMBIENT TEMPERATURE, 1 M/SEC WIND SPEED
2. SOURCE CIRCUITS #6 AND #7 ARE SIMILAR TO SOURCE CIRCUIT #1, BUT ARE SWITCHED THROUGH REDUCE POWER CONTACTORS CB AND CR (NORM CLOSED). REFER TO IPC DWG. NO. C–003158.
3. CAUTION: OPEN SW1 PRIOR TO OPENING THE FUSED DISCONNECTS.

THIRD ANGLE PROJECTION



LLY

REVISION DATE
B – 29OCT90
C – 29AUG91

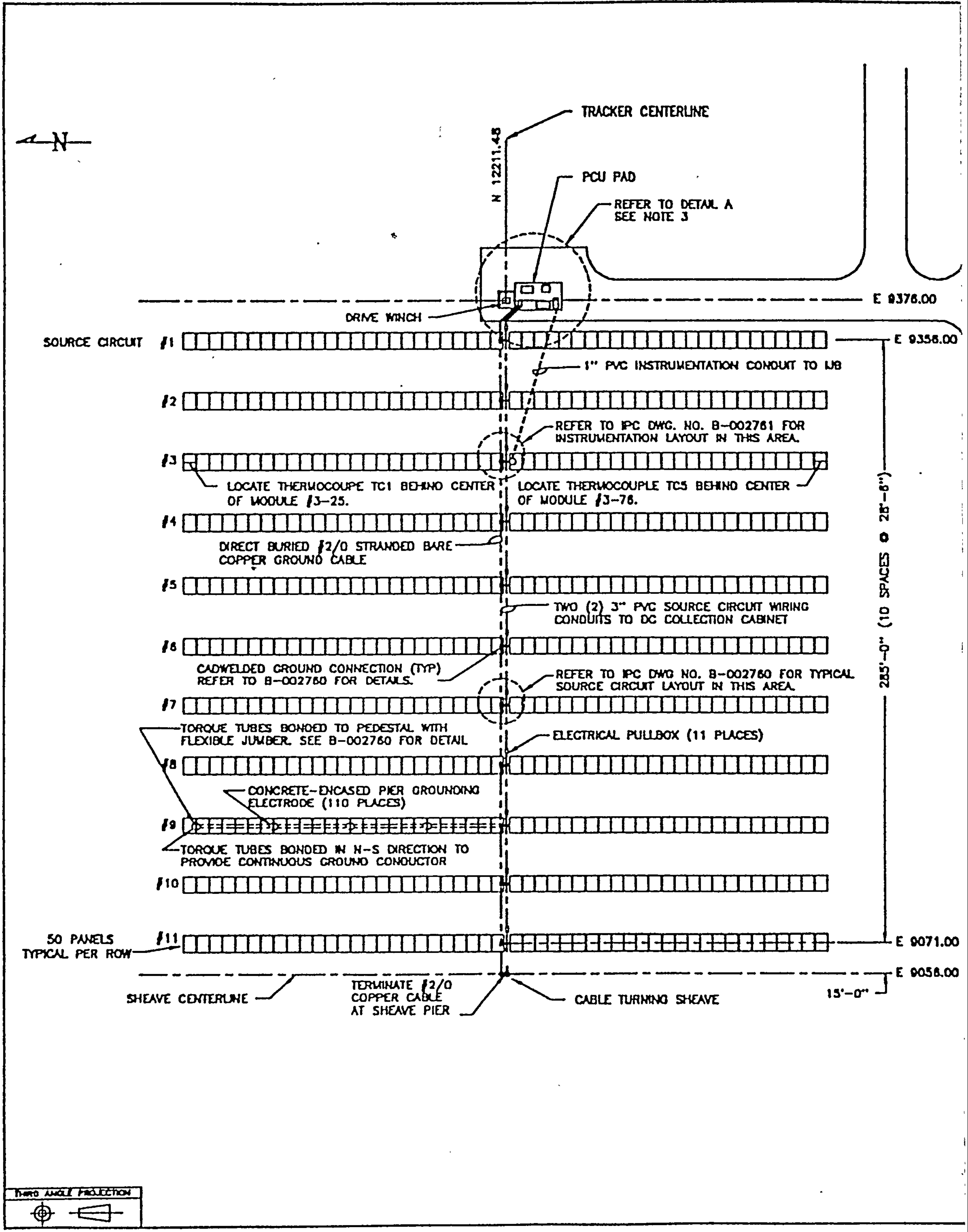
Integrated Power Corporation
ROCKVILLE, MARYLAND USA

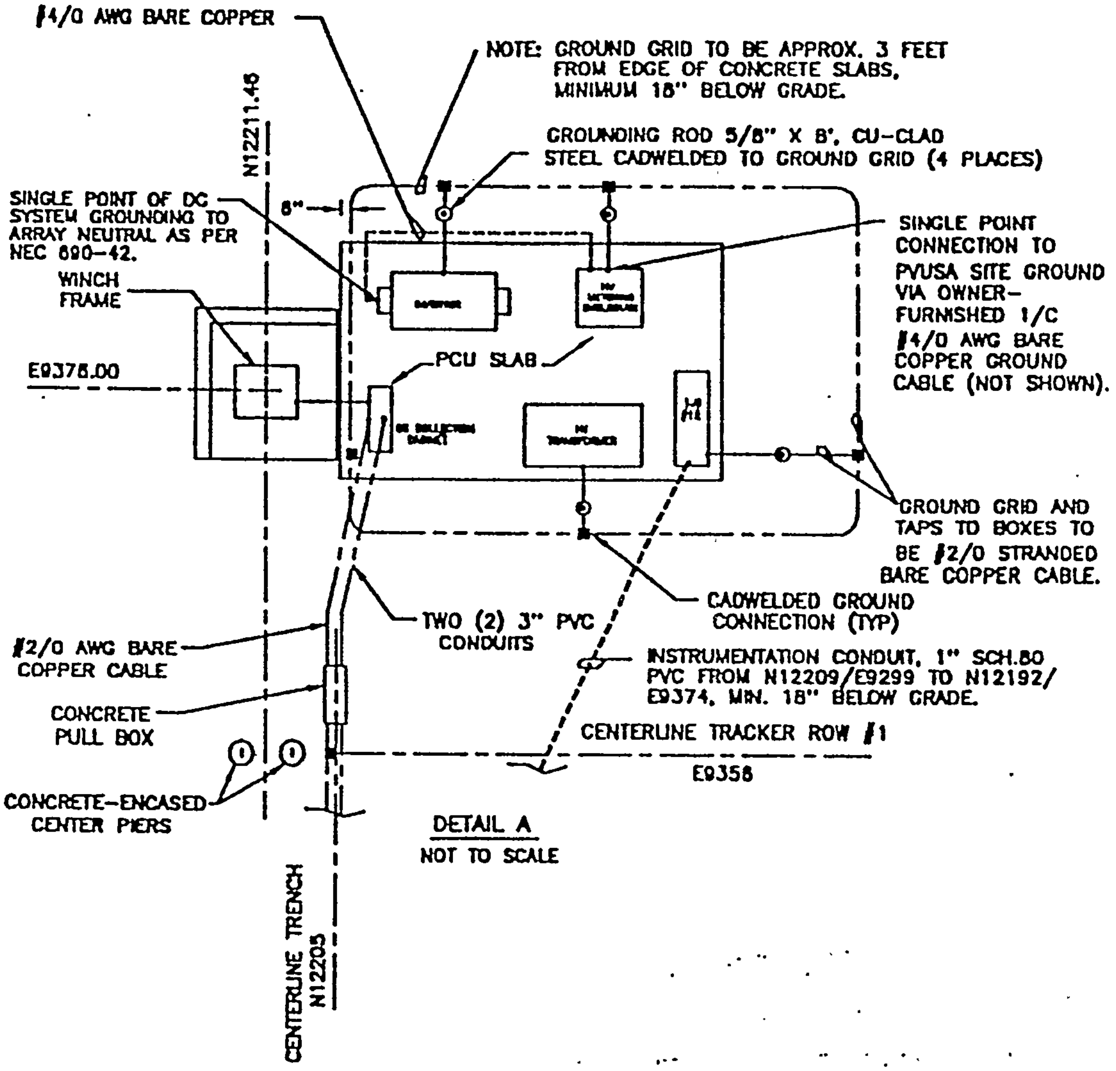
SCALE NTS	APPROVED BY	DRAWN BY GEF	
DATE 10 MAY 90		REV BY CRH	

ONE–LINE DIAGRAM

PVUSA US–1

SIZE	DWG NO.	REV
B	002456	C


N
TRACKER CENTERLINE
N 12211.45
PCU PAD
REFER TO DETAIL A
SEE NOTE 3
E 9376.00
DRIVE WINCH
SOURCE CIRCUIT #1
E 9356.00
1" PVC INSTRUMENTATION CONDUIT TO IJB
#2
REFER TO IPC DWG. NO. B-002761 FOR INSTRUMENTATION LAYOUT IN THIS AREA.
#3
LOCATE THERMOCOUPLE TC1 BEHIND CENTER OF MODULE #3-25.
LOCATE THERMOCOUPLE TC5 BEHIND CENTER OF MODULE #3-76.
#4
DIRECT BURIED #2/0 STRANDED BARE COPPER GROUND CABLE
#5
TWO (2) 3" PVC SOURCE CIRCUIT WIRING CONDUITS TO DC COLLECTION CABINET
#6
CADWELDED GROUND CONNECTION (TYP) REFER TO B-002760 FOR DETAILS.
REFER TO IPC DWG NO. B-002760 FOR TYPICAL SOURCE CIRCUIT LAYOUT IN THIS AREA.
#7
285'-0" (10 SPACES @ 28'-6")
TORQUE TUBES BONDED TO PEDESTAL WITH FLEXIBLE JUMBER. SEE B-002760 FOR DETAIL
ELECTRICAL PULLBOX (11 PLACES)
#8
CONCRETE-ENCASED PIER GROUNDING ELECTRODE (110 PLACES)
#9
TORQUE TUBES BONDED IN N-S DIRECTION TO PROVIDE CONTINUOUS GROUND CONDUCTOR
#10
50 PANELS TYPICAL PER ROW
#11
E 9071.00
E 9056.00
15'-0"
SHEAVE CENTERLINE
TERMINATE #2/0 COPPER CABLE AT SHEAVE PIER
CABLE TURNING SHEAVE
THIRD ANGLE PROJECTION



DETAIL A
NOT TO SCALE

NOTES:
1. REFER TO IPC DWG. NO. C-003155 FOR PCU SLAB EQUIPMENT LAYOUT.
2. REFER TO IPC DWG. NO. D-003156 FOR CONDUIT AND CABLE LAYOUT AND SCHEDULE.
3. REFER TO PVUSA DWG. NO. 478565, DETAIL 3, FOR PVUSA TRENCH DETAILS IN THIS AREA.
4. ALL BURIED GROUND CONNECTIONS TO BE EXOTHERMIC WELD (CADWELD).
5. ALL BOLTED (ABOVE GRADE) GROUND CONNECTIONS SHALL BE MADE TO "BRIGHT" METAL AFTER REMOVAL OF SURFACE COATING. REPAIR SURFACE COATINGS AFTER THE GROUNDING SYSTEM HAS BEEN CHECKED.

AS-BUILT

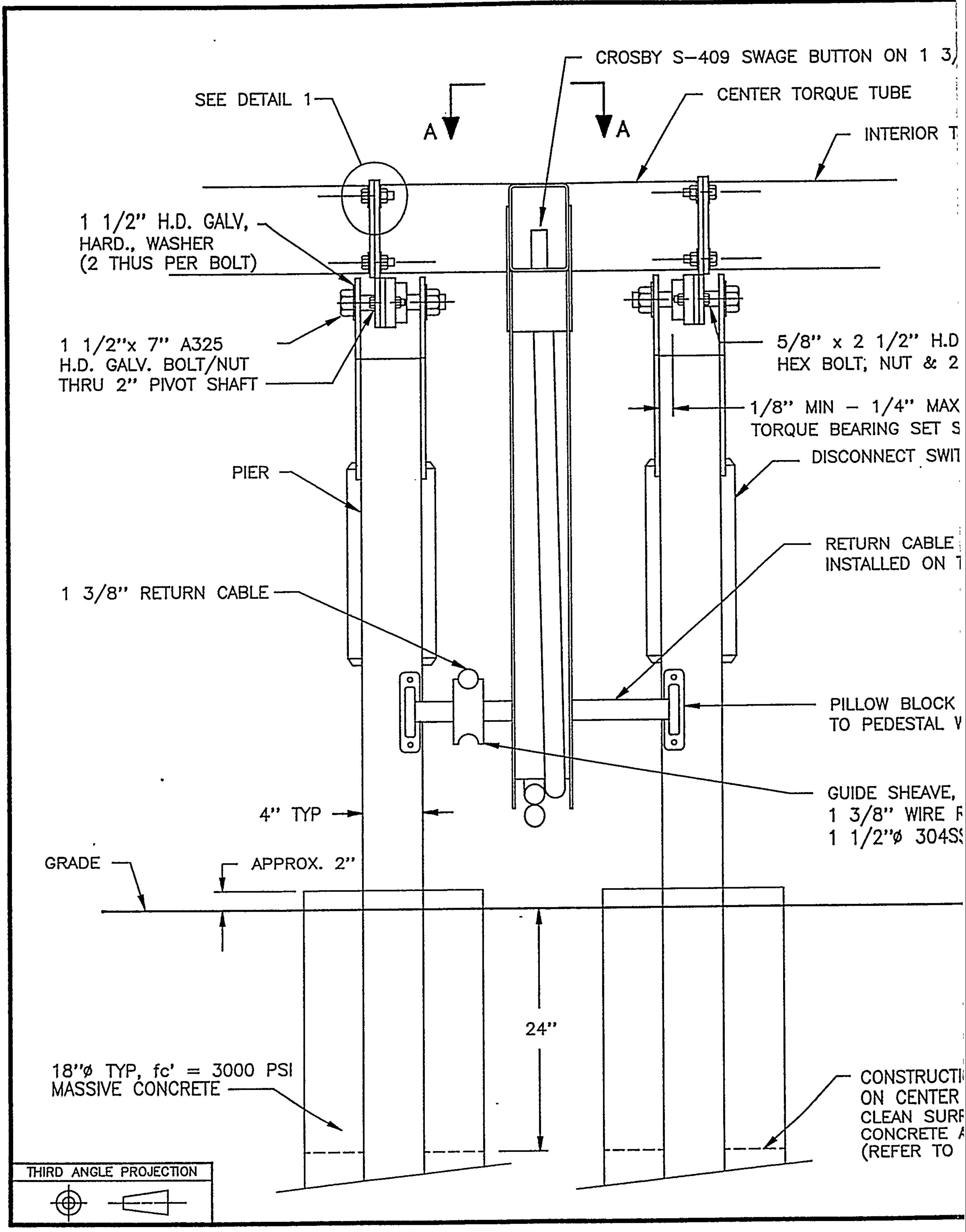
REVISION DATE
B – 25OCT90
C – 29NOV90
D – 09DEC91

Integrated Power Corporation
ROCKVILLE, MARYLAND USA

SCALE NTS
APPROVED BY ACP
DRAWN BY CRH
DATE 25 MAY 90
REV BY CRH

SYSTEM ELECTRICAL PLAN
SITE GROUNDING AND TRENCH LAYOUT

PVUSA US-1
SIZE C
DWG NO. 002774
REV D


CROSBY S-409 SWAGE BUTTON ON 1 3/
SEE DETAIL 1
CENTER TORQUE TUBE
A
A
INTERIOR T
1 1/2" H.D. GALV, HARD., WASHER (2 THUS PER BOLT)
1 1/2"x 7" A325 H.D. GALV. BOLT/NUT THRU 2" PIVOT SHAFT
5/8" x 2 1/2" H.D
HEX BOLT; NUT & 2
1/8" MIN – 1/4" MAX
TORQUE BEARING SET S
PIER
DISCONNECT SWIT
RETURN CABLE
INSTALLED ON T
1 3/8" RETURN CABLE
PILLOW BLOCK
TO PEDESTAL W
GUIDE SHEAVE,
1 3/8" WIRE R
1 1/2"ø 304SS
4" TYP
GRADE
APPROX. 2"
24"
18"ø TYP, fc' = 3000 PSI
MASSIVE CONCRETE
CONSTRUCTI
ON CENTER
CLEAN SURF
CONCRETE A
(REFER TO
THIRD ANGLE PROJECTION

3" CABLE

RQUE TUBE

GALV. A325
HARDENED WASHERS

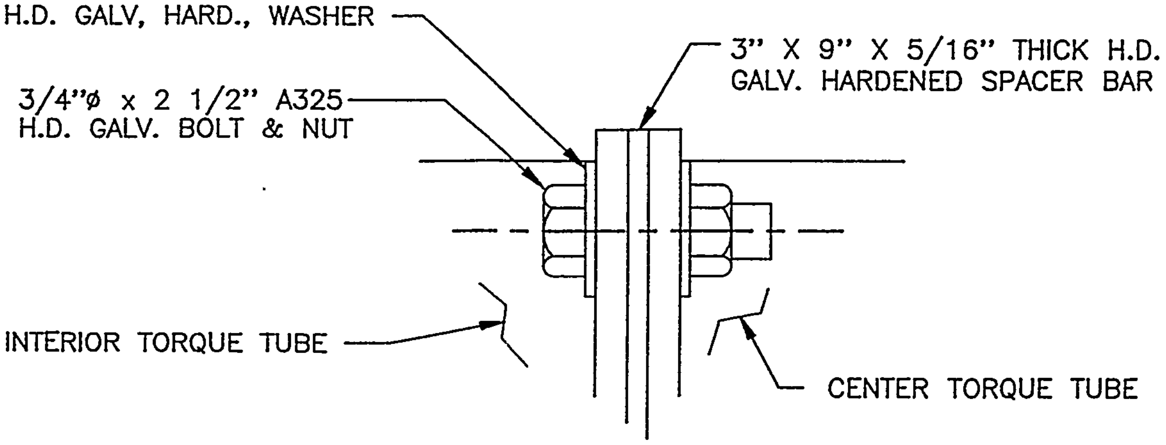
CLEARANCE.
REWS TO 20 IN-LB.
H

UIDE SHEAVE ASSY
ACKER ROWS T1 & T4 ONLY

EARING, UCP208-24 MOUNTED
316SS HARDWARE (2 PER ASSY)

" DIA. 304SS, GROOVED FOR,
PE, PRESS FIT ONTO
SHAFT

E JOINT 24" B.G.
ER ROWS P5 AND P6 ONLY.
CE AND PLACE REMAINING
TER CONDUIT INSTALLATION
-002760).



DETAIL 1 (TYP ALL PIERS)

NTS

SECTION A-A

(TOP VIEW OF CENTER TORQUE RIM ARM)

NOTES:

1. PROVIDE 3" CONCRETE COVER ON STEEL BELOW GRADE
2. PIER VERTICAL TOLERANCE: 1.5 DEG.
3. REFERENCE CONCRETE SPECIFICATIONS:
   ACI 301-89
   ACI 318-89
4. REFER TO B-002496 FOR ELEVATIONS.
5. REFER TO B-002760 FOR ELECTRICAL DETAILS.

AS-BUILT

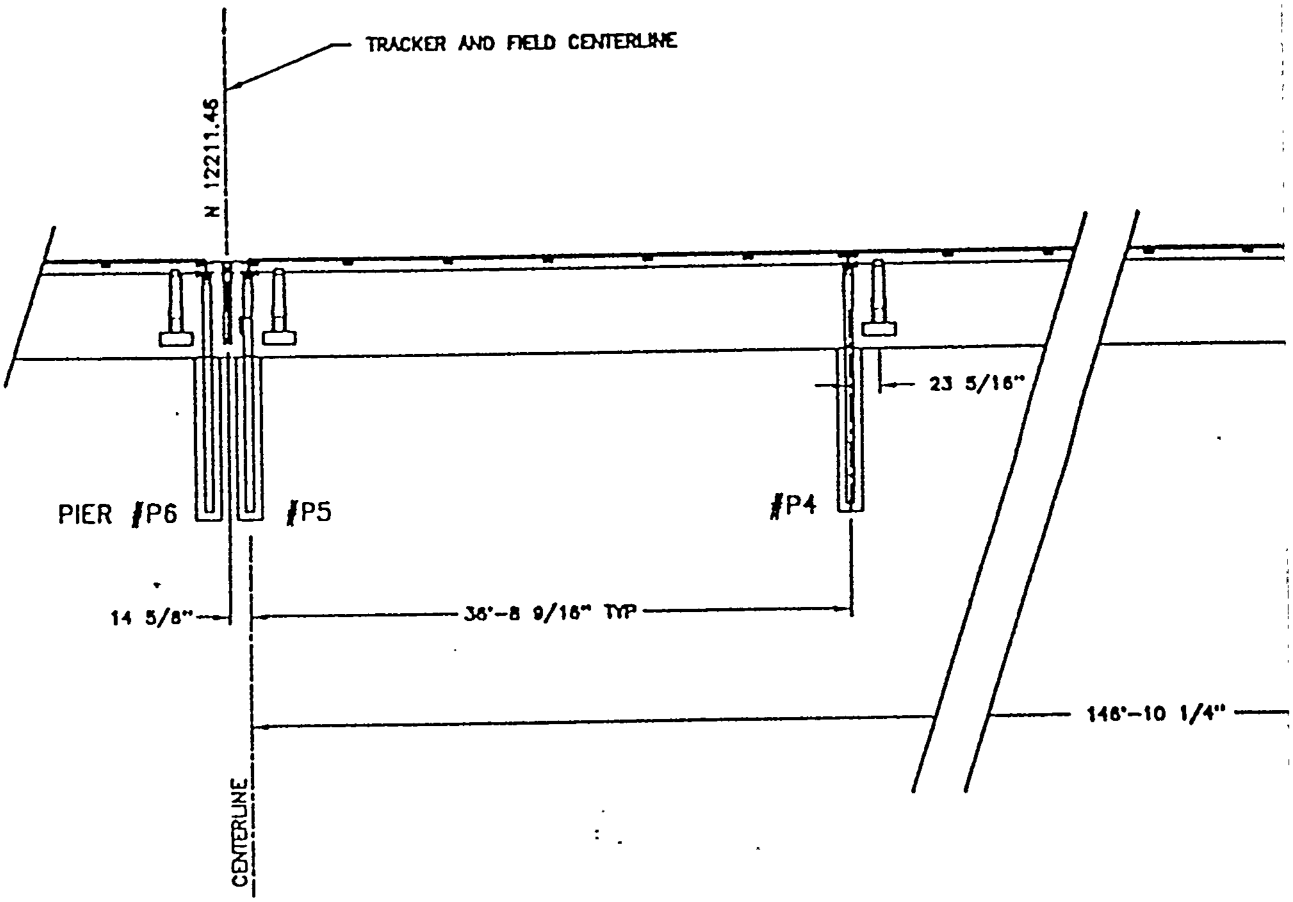
REVISION DATE
B – 18JAN90
C – 15MAR90
D – 16MAY90
E – 02AUG90
F – 09DEC91

Integrated Power Corporation
ROCKVILLE, MARYLAND USA

SCALE NTS
APPROVED BY
DRAWN BY GEF
DATE 27 DEC 89
REV BY CRH

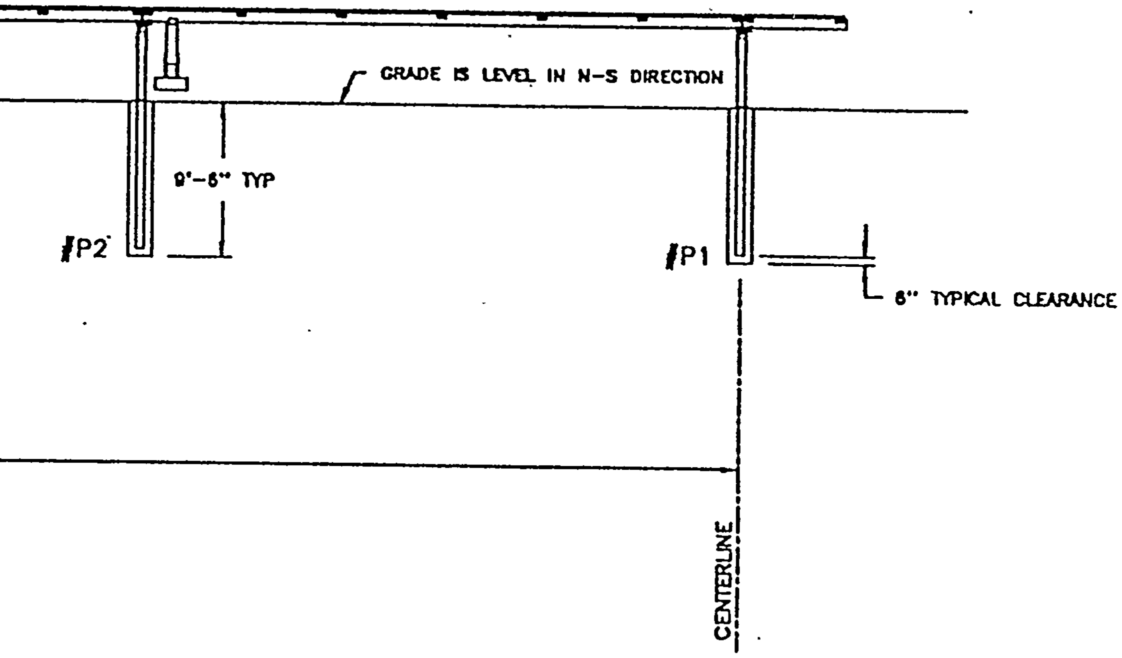
CENTER TORQUE TUBE
WEST ELEVATION

PVUSA US-1
SIZE B
DWG NO. 002497
REV F



NOTES:

1. ALL PIERS IN N-S DIRECTION ARE AT THE SAME ELEVATION
2. REFER TO B-002496 FOR TRACKER ELEVATIONS



NOT TO SCALE

COPY OF ORIGINAL

REVISIONS:
B – 18JAN90
C – 10APR90
D – 18JUL90

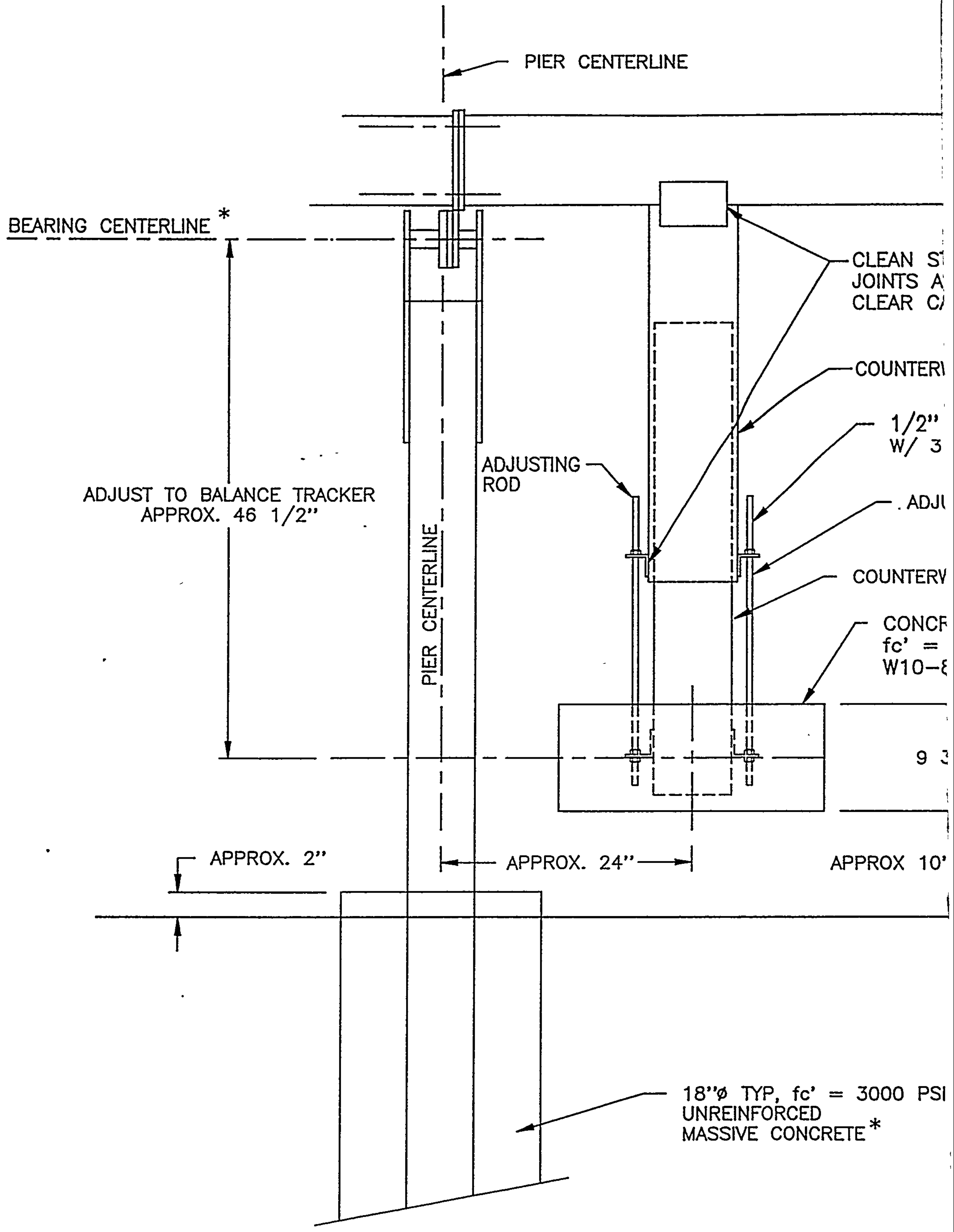
Integrated Power Corporation

SCALE: 1/8"= 1'
DATE: 28 DEC 89
APPROVED BY: D. Parini
DRAWN BY: CEF
REV. BY: CRH

TRACKER – EAST ELEVATION

PVUSA US-1

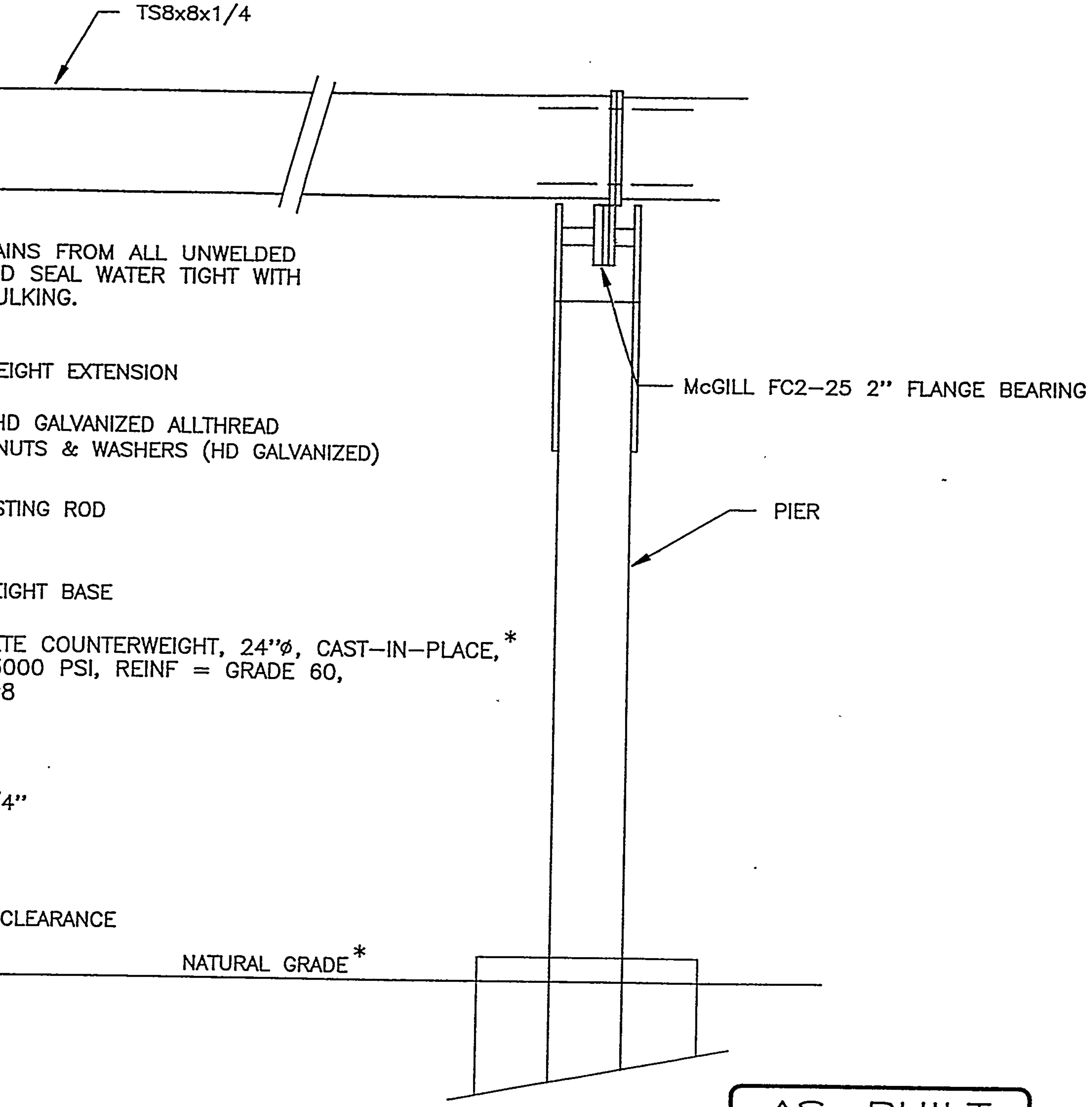
DRAWING NUMBER: C-002441-D



*NOTE:

SEE B–002496 FOR BEARING AND N
SEE B–002497 FOR CONCRETE DETA

THIRD ANGLE PROJECTION



AINS FROM ALL UNWELDED
D SEAL WATER TIGHT WITH
JLKING.

EIGHT EXTENSION

HD GALVANIZED ALLTHREAD
NUTS & WASHERS (HD GALVANIZED)

STING ROD

IGHT BASE

TE COUNTERWEIGHT, 24"ø, CAST–IN–PLACE, *
000 PSI, REINF = GRADE 60,
8

4"

CLEARANCE

URAL GRADE ELEVATIONS.
S

AS–BUILT

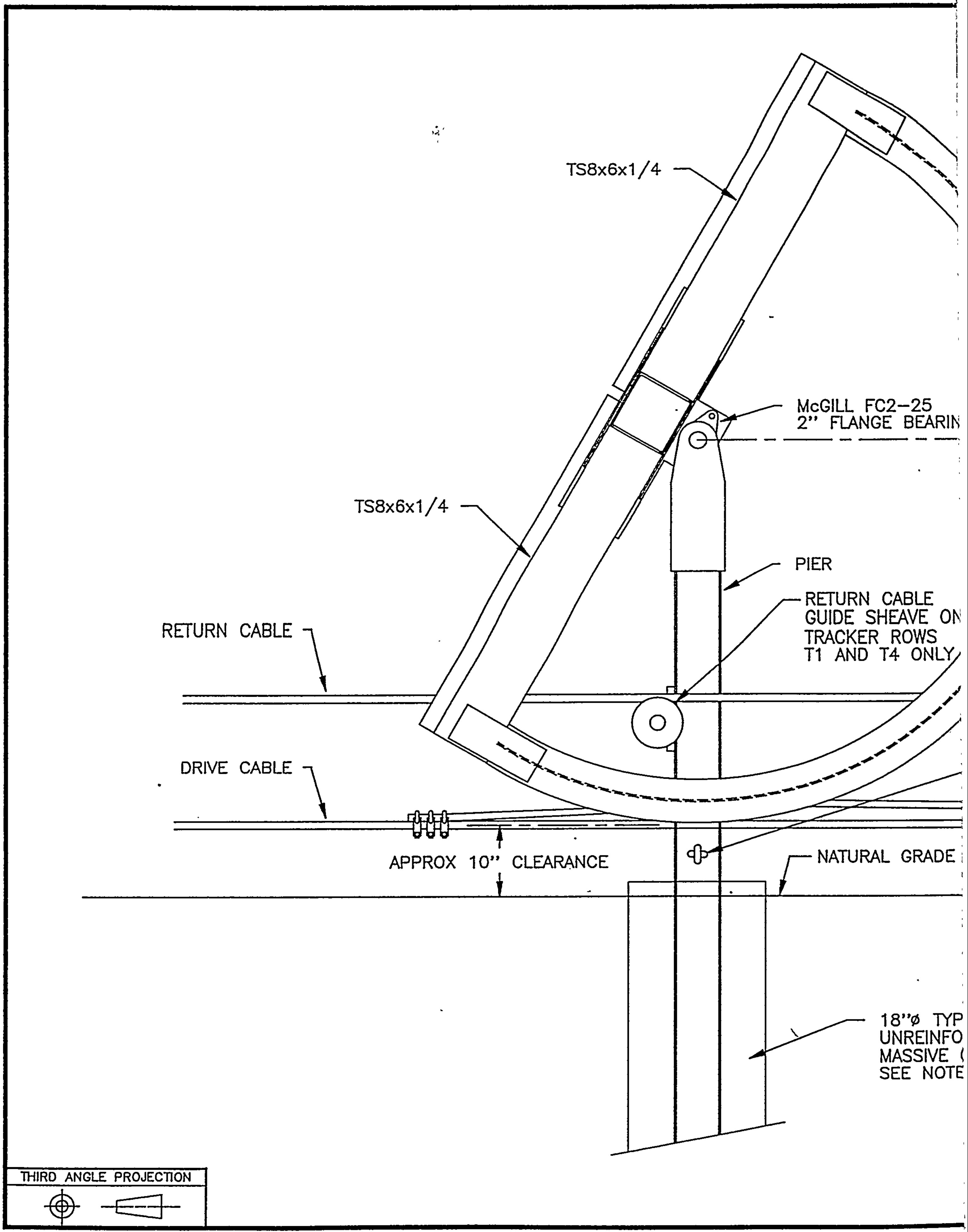
REVISION DATE
B – 18JAN90
C – 04APR90
D – 18JUL90
E – 01AUG90
F – 05DEC91

Integrated Power Corporation
ROCKVILLE, MARYLAND USA

SCALE 1"= 1'– 0"
APPROVED BY Aave Panino
DRAWN BY GEF
DATE 28 DEC 89
REV BY CRH

INTERIOR TORQUE TUBE
EAST ELEVATION

PVUSA US–1
SIZE B
DWG NO. 002442
REV F

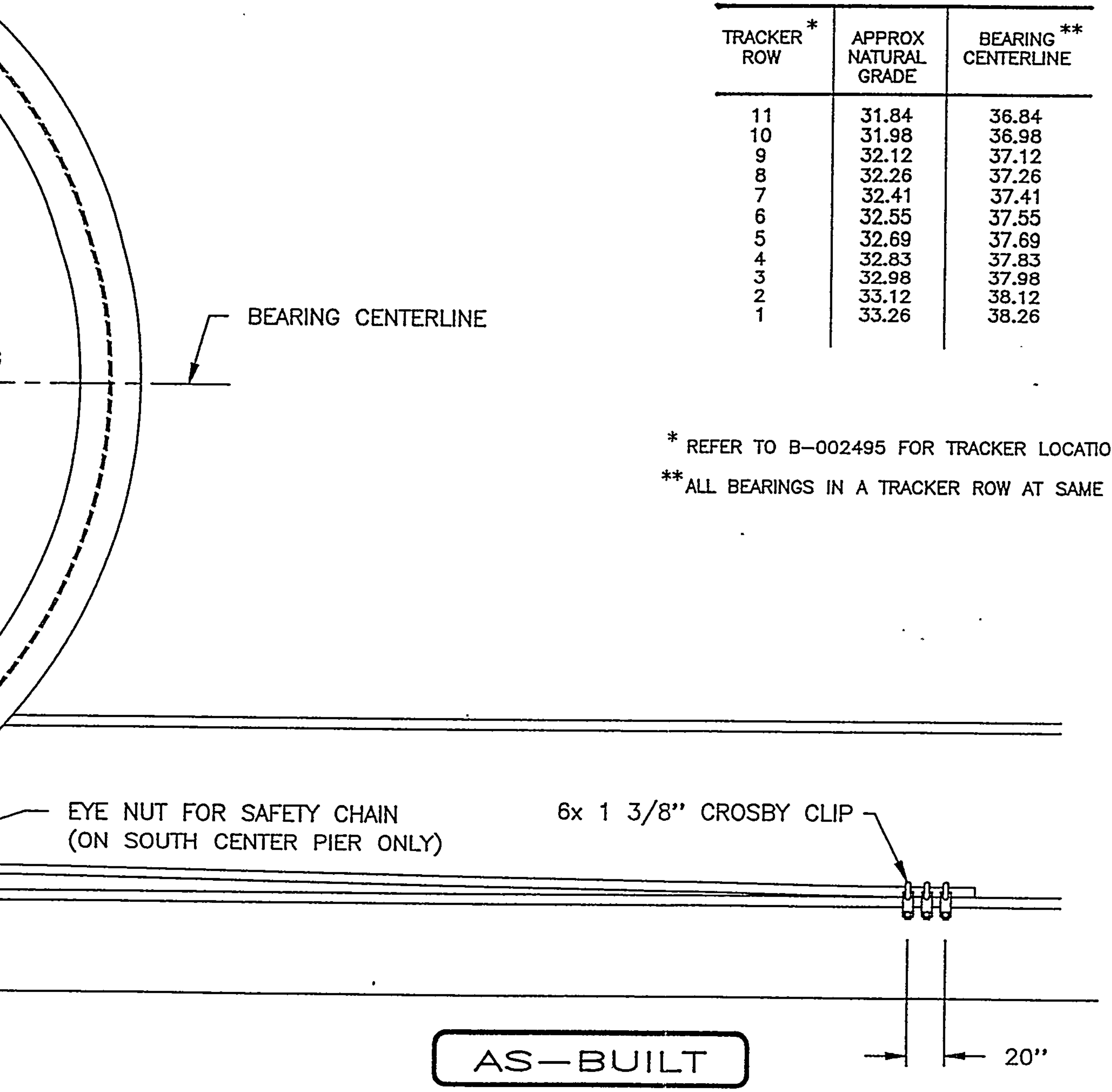

TS8x6x1/4
McGILL FC2–25
2" FLANGE BEARIN
TS8x6x1/4
PIER
RETURN CABLE
GUIDE SHEAVE ON
TRACKER ROWS
T1 AND T4 ONLY
RETURN CABLE
DRIVE CABLE
APPROX 10" CLEARANCE
NATURAL GRADE
18"ø TYP
UNREINFO
MASSIVE (
SEE NOTE
THIRD ANGLE PROJECTION

ELEVATIONS (FT.)

TRACKER ROW *	APPROX NATURAL GRADE	BEARING CENTERLINE **
11	31.84	36.84
10	31.98	36.98
9	32.12	37.12
8	32.26	37.26
7	32.41	37.41
6	32.55	37.55
5	32.69	37.69
4	32.83	37.83
3	32.98	37.98
2	33.12	38.12
1	33.26	38.26

* REFER TO B–002495 FOR TRACKER LOCATIONS.

**ALL BEARINGS IN A TRACKER ROW AT SAME ELEVATION.



AS—BUILT

fc' = 3000 PSI
CED
NCRETE
B–002497

REVISION DATE
B – 09FEB90
C – 04APR90
D – 18JUL90
E – 02AUG90
F – 05DEC91

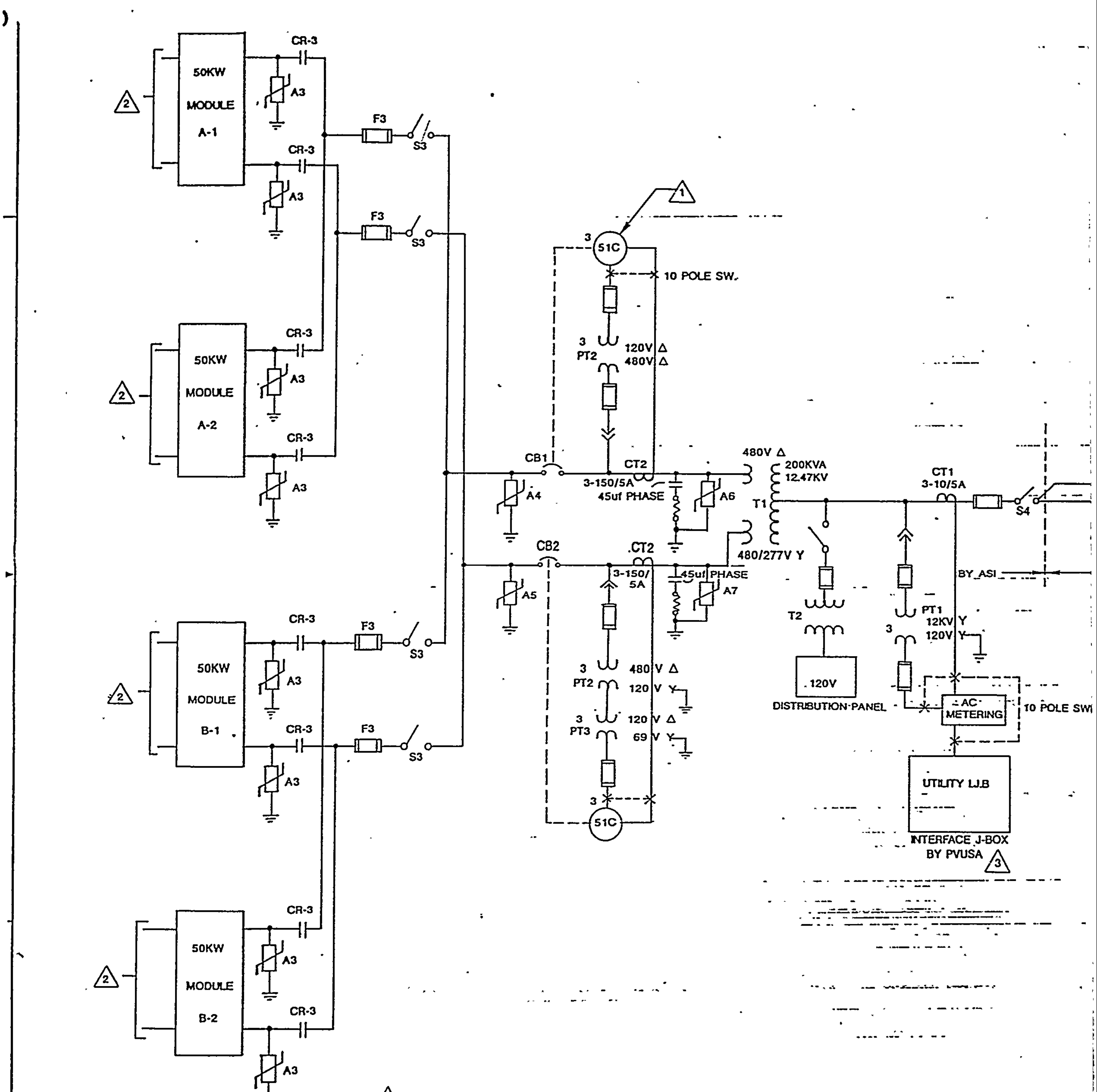
Integrated Power Corporation
ROCKVILLE, MARYLAND USA

SCALE NTS
DATE 27 DEC 89
APPROVED BY Ance Pasic
DRAWN BY GEF
REV BY CRH

CENTER TORQUE TUBE
SOUTH ELEVATION

PVUSA US–1
SIZE B
DWG NO. 002496
REV F

8 7 6 5



4 REFERENCE SIEMENS DWG. NO. 60-01564-060-1B FOR DETAILS.

3 REFERENCE PVUSA DWG. NO. 492694 ELECTRICAL WIRING DIAGRAM INTERFACE J-BOX NO. IJB 11.

2 FOR DC CIRCUITS SEE DWG. NO. 89A3-S-0001 BY BLUEPOINT ASSOCIATES LTD.

1 51 RELAYS BY PVUSA. CT'S AND PT'S BY A.S.I.

NOTES: UNLESS OTHERWISE SPECIFIED →

4 | 3 | 2 | 1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	6	REVISED	12.12. 90	
	7	REVISED	1-14-91	

—TO OTHER US-1 SYSTEM
— TO UTILITY

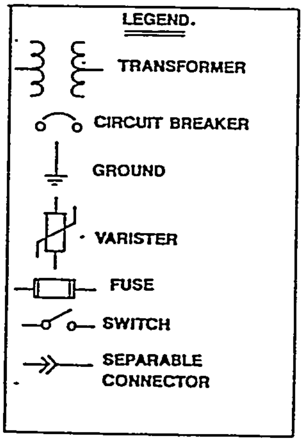
BY PVUSA

H

EQUIPMENT LIST

△4 (CT1, PT1)

QTY.	ITEM	COMPONENT	RATING	VENDOR	PART NO.
12	A3	VARISTOR AC	420V AC 1100 JVz = 620V	SIEMENS	B32K420
3 3	A4 A5	VARISTOR AC	575V AC 2100 J	GENERAL ELECTRIC	V571BA60
3 3	A6 A7	VARISTOR AC	575V AC 2100J	GENERAL ELECTRIC	V571 BA60
4	A1 & A2 B1 & B2	PCU MODULE	50k VA	BLUEPOINT ASSOCIATES	89A3-T-0001
1 1	CB1 CB2	CIRCUIT BREAKER	480V, 150A, 35KAIC	SIEMENS	FD63B150
8	CR3	AC CONTACTOR	600V AC 40A	POTTER BRUMFIELD	P40C42A
3	CT1	CURRENT TRANSFORMER	10/5A ACCURACY CL 0.3	LTJ	CTWH5-110 T200-100
3	PT1	POTENTIAL TRANSFORMER	12KV-120V ACCURACY CL 0.3	LTJ	PT5-110-123F
12	F3	AC FUSE	600V AC 45A	BUSS	JJS-45
4	S3	AC DISCONNECT	600V AC, 60A, 3P	SQUARE D	HU362 RB
1	S4	FUSED DISCONNECT SW.	15KV, 600A, 3P	POWERCON	A62-009-L-A7-B1-R
1	T1	POWER TRANSFORMER	12.47KV-480V 200KVA, 480Y/277	MATRA ELECTRIC	SPECIAL ORDER
1	T2	STATION SERVICE TRANSFORMER	12.47KV-240/120V, 5k VA	GENERAL ELECTRIC	PT 28Y5604
6	PT2	POTENTIAL TRANSFORMER	480V -120V	LTJ	297-151
6	CT2	CURRENT TRANSFORMER	150A - 5A	LTJ	460-480
3	PT3	POTENTIAL TRANSFORMER	120V - 69V	LTJ	460-069



	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS 1/X DECIMALS .X = .XX = .XXX = ANGLES X XX° =
BREAK ALL SHARP EDGES .010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14.5
FINISH

CONTRACT NO.

APPROVALS	DATE
DRAFTSMAN J.BATEMAN	12·12.9
CHECKER	
DESIGNER	
ENGINEER	

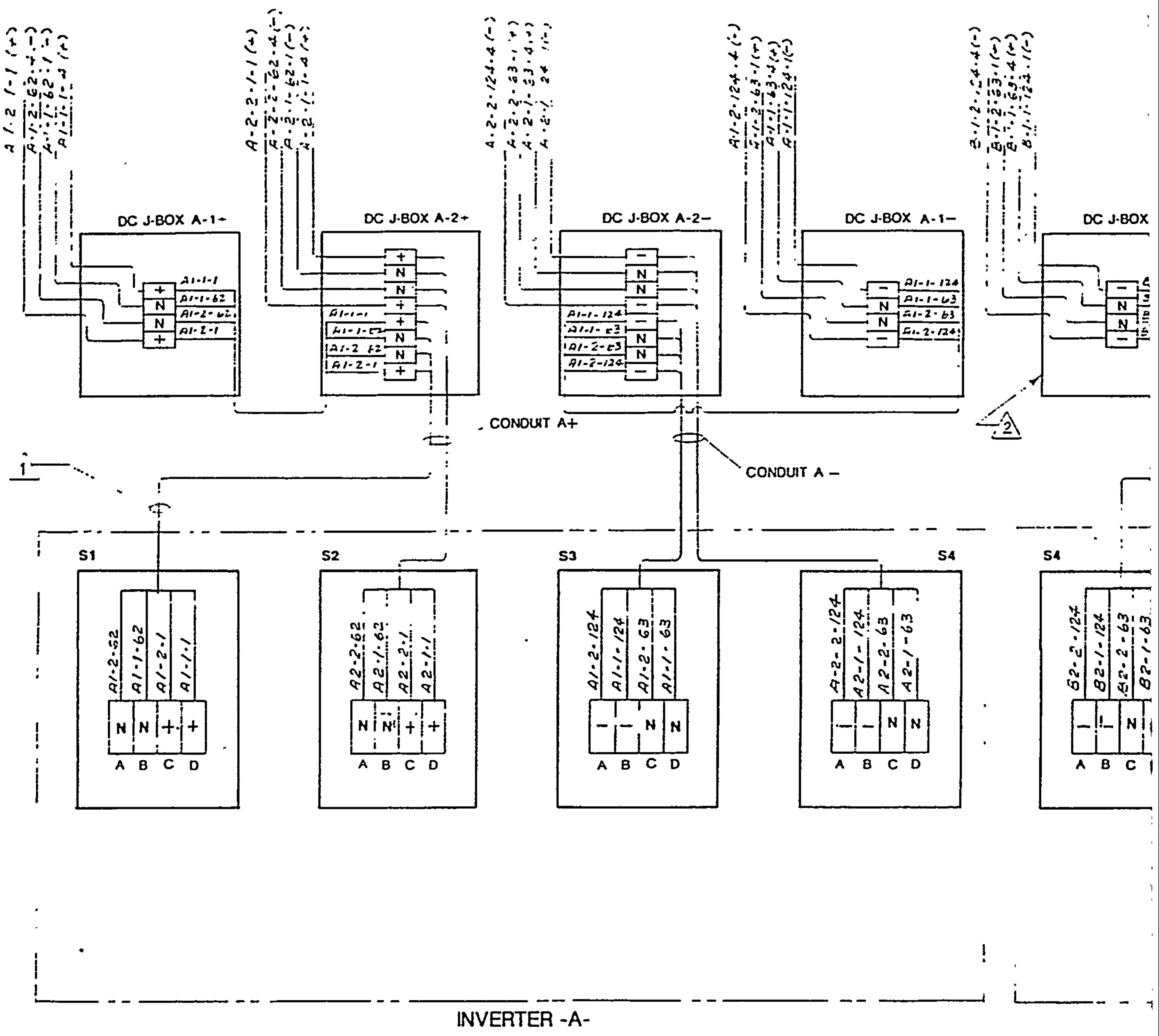
Siemens Solar Industries
P O BOX 6032 Camarillo, CA 93011

ONE LINE ELECTRICAL DIAGRAM

PVUSA US-I

PVUSA US-1

SIZE	FSCM NO.	CODE	DRAWING NO.	REV.

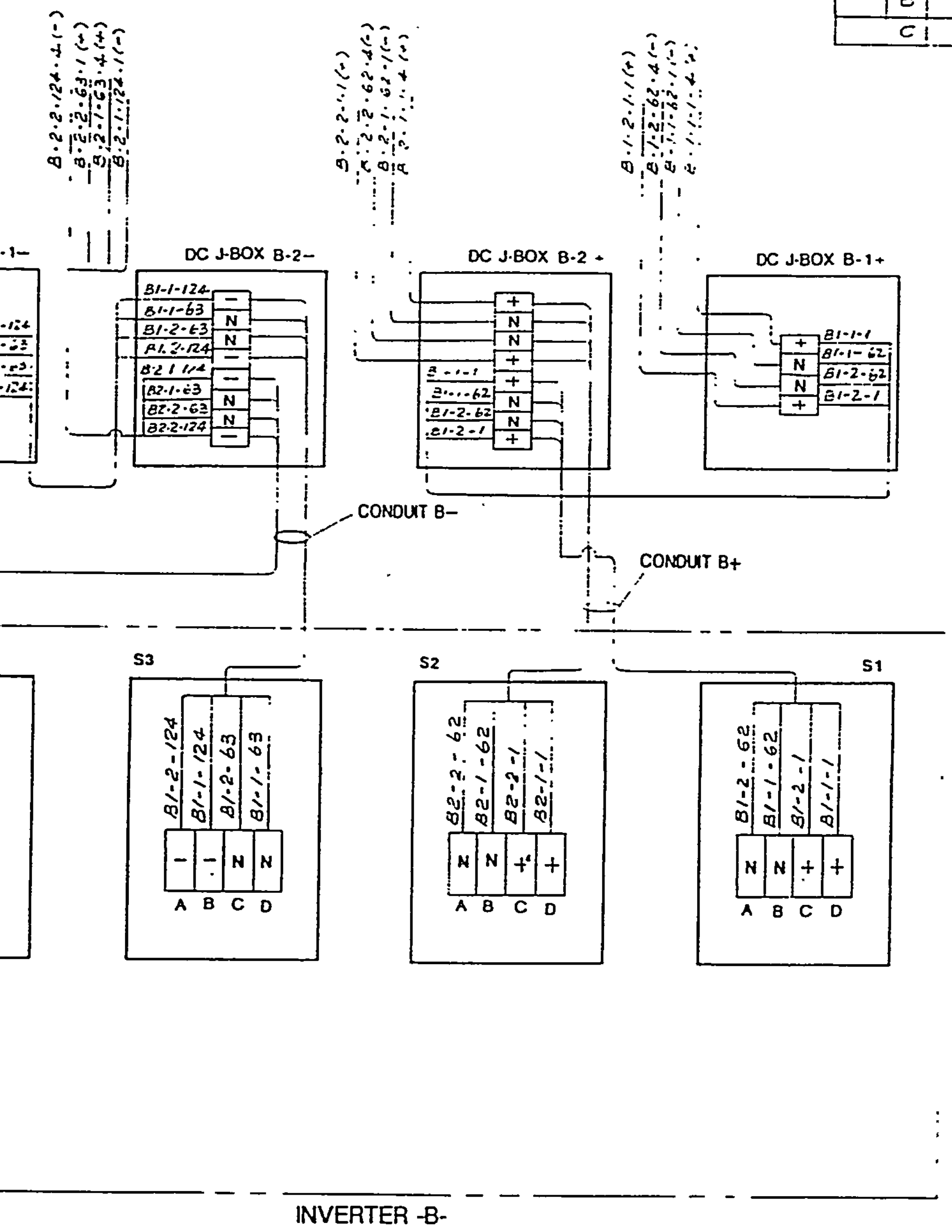


2 REF. DWG. NO. 018036 FOR METERING DEVICES

1 IDENTIFY WIRES WITH WIRE MARKER AT BOTH ENDS OF THE WIRE, TYPICAL.

OTES: UNLESS OTHERWISE SPECIFIED

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
		[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	REVISED	[illegible]	
	A	AS BUILT	1 30 91	[illegible]
	B	REVISED AS BUILT	3 22.91	[illegible]
	C	REVISED AS BUILT	4.22 91	



D

C

B

C

017859

A

	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS 1/X
DECIMALS .X = .XX = .XXX =
ANGLES X XX' =
BREAK ALL SHARP EDGES .010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14.5
FINISH

CONTRACT NO.

APPROVALS		DATE
DRAFTSMAN	J.BATEMAN	5.8.90
CHECKER		
DESIGNER	J.B	5.8.90
ENGINEER		6.14.90
APPROVED		[illegible]

	PVUSA US-1
NEXT ASSY	USED ON

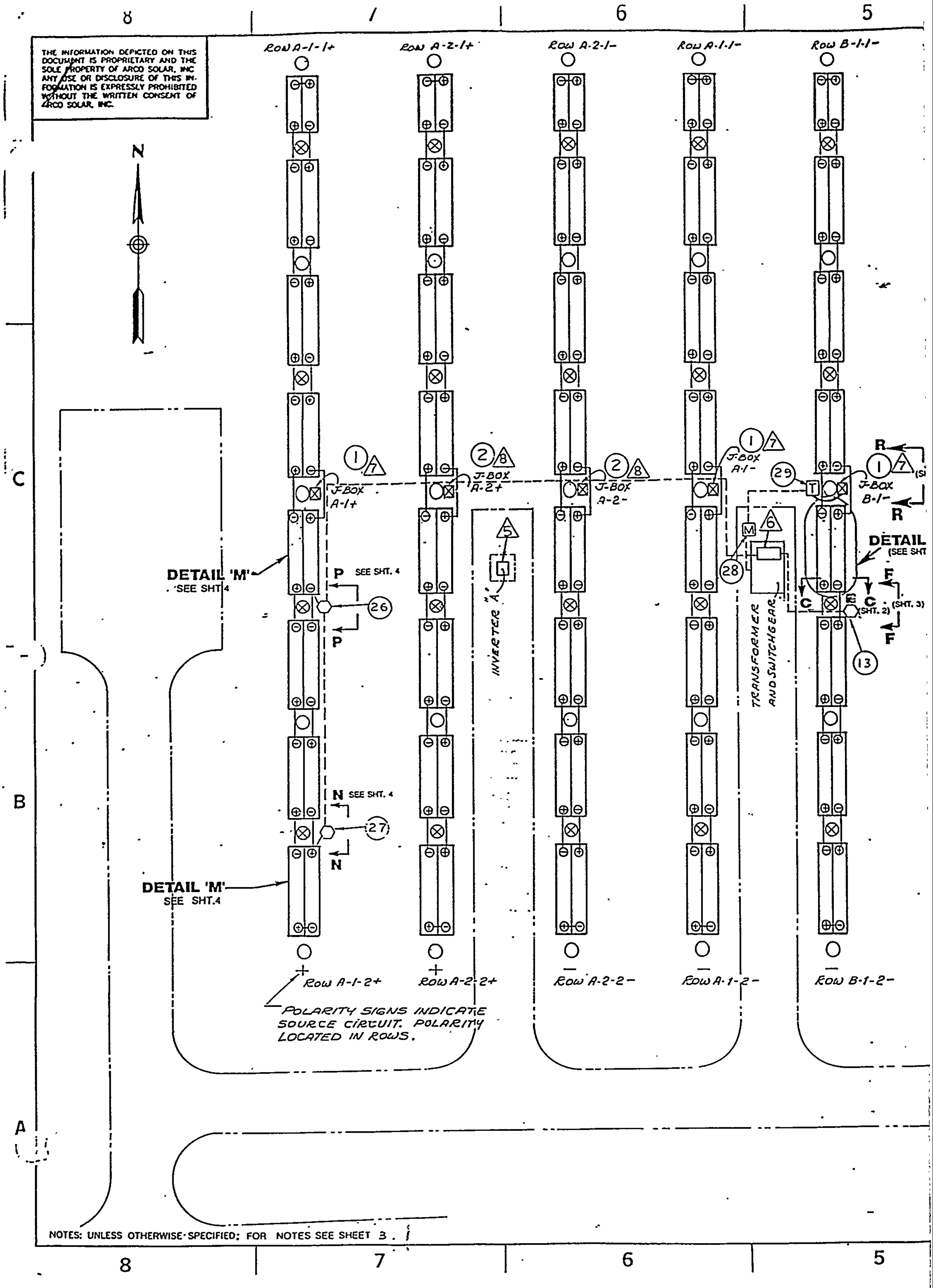
ARCO Solar, Inc.

P.O. Box 6032 Camarillo, CA 93010

DC J-BOX INTERCONNECT DIAGRAM

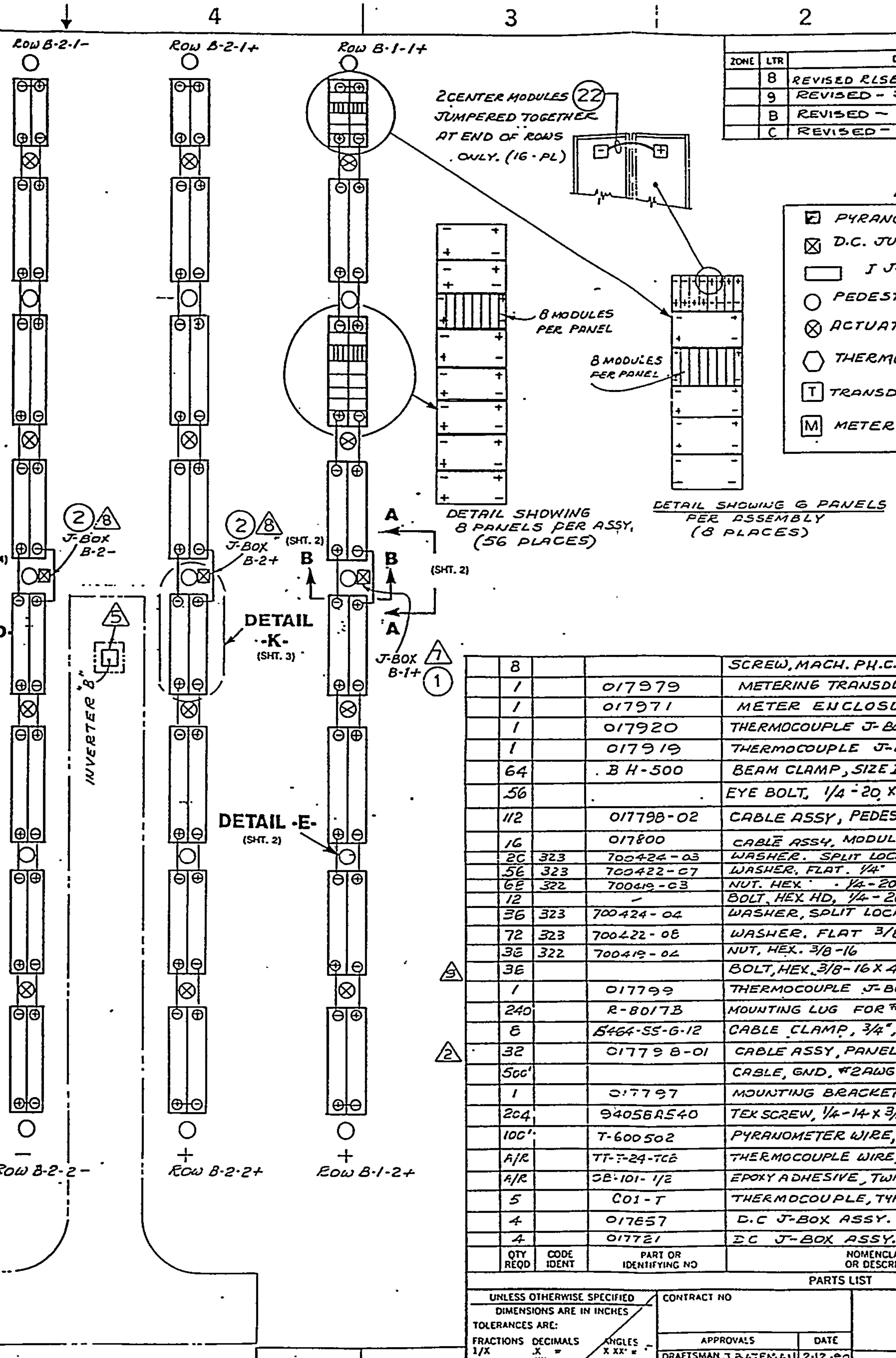
PVUSA US-1

SIZE	FSCM NO.	CODE	DRAWING NO.	REV
D				C



NOTES: UNLESS OTHERWISE SPECIFIED: FOR NOTES SEE SHEET 3.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	8	REVISED RLSE.	11.9.90	
	9	REVISED - SHT. 5 ADDED	1-7-91	
	B	REVISED ~ AS BUILT	2.5.91	
	C	REVISED - AS BUILT	3.15.91	



LEGEND.

- ☒ PYRANOMETER (BY OTHERS
- ☒ D.C. JUNCTION BOX (8 PLACES)
- ▭ I J-BOX II (BY OTHERS)
- ○ PEDESTAL (72 PLACES)
- ⊗ ACTUATOR (32 PLACES)
- ⬡ THERMOCOUPLE JUNCTION BOX
- T TRANSDUCER ENCLOSURE
- M METER ENCLOSURE

	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	REF.	ITEM
	8			SCREW, MACH. PH.C.R 1/4-20 x 1/2" L	18-8 S/S	30
	1		017979	METERING TRANSDUCER ENCLOSURE	A.S.I	29
	1		017971	METER ENCLOSURE	A.S.I	28
	1		017920	THERMOCOUPLE J-BOX 'C' ASSY..	No. 5 THERMOCOUPLE	27
	1		017919	THERMOCOUPLE J-BOX 'B' ASSY	No. 4 THERMOCOUPLE	26
	64		BH-500	BEAM CLAMP, SIZE I" (1/4-20 THD).	APPLETON	25
	56			EYE BOLT, 1/4-20 X 3" LONG	18-8 S/S.	24
	112		017798-02	CABLE ASSY, PEDESTAL/PANEL, INTCONN	ASI	23
	16		017800	CABLE ASSY, MODULE INTERCONNECT	ASI	22
	20	323	700424-03	WASHER. SPLIT LOCK 1/4"	18-8 S/S	21
	56	323	700422-07	WASHER, FLAT. 1/4"	18-8 S/S	20
	68	322	700419-03	NUT. HEX. 1/4-20	18-8 S/S	19
	12		-	BOLT, HEX HD, 1/4-20 x 1 1/2" L	18-8 S/S	18
	36	323	700424-04	WASHER, SPLIT LOCK, 3/8"	18-8 S/S	17
	72	323	700422-08	WASHER, FLAT 3/8"	18-8 S/S	16
	36	322	700419-04	NUT, HEX. 3/8-16	18-8 S/S.	15
9	36			BOLT, HEX. 3/8-16 X 4" L. (1 1/2" THD.) S/S	M & M. FASTENERS	14
	1		017799	THERMOCOUPLE J-BOX 'A' ASSY	1,2,3 Thermocouples	13
	240		R-8017B	MOUNTING LUG FOR #2 AWG. GND WIRE	HOLLINGSWORTH	12
	8		B464-SS-6-12	CABLE CLAMP, 3/4", S/S NEOPRENE.	UMPCO.	11
2	32		017798-01	CABLE ASSY, PANEL INTERCONNECT	A.S.I	10
	500'			CABLE, GND. #2 AWG COPPER, INSULATED	GRAYBAR	9
	1		017797	MOUNTING BRACKET for PYRANOMETER	A.S.I.	8
	204		94056A540	TEK SCREW, 1/4-14 x 3/4" L. SELF DRILL. HEX.	McMASTER-CARR	7
	100'		T-600502	PYRANOMETER WIRE, #20 AWG. SHIELDED	QUALIMETRICS	6
	A/R		TT-T-24-TC2	THERMOCOUPLE WIRE, 24 AWG, 600' REEL	OMEGA	5
	A/R		OB-101-1/2	EPOXY ADHESIVE, TWIN PAK	OMEGA	4
	5		C01-T	THERMOCOUPLE, TYPE T, STYLE 1, SURFACE MOUNT.	OMEGA	3
	4		017657	D.C J-BOX ASSY. 8 TERMINALS	ASI	2
	4		017721	DC J-BOX ASSY. 4 TERMINALS.	A S.I	[illegible]

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS 1/X
DECIMALS .X = .XX = .XXX =
ANGLES X XX° =

BREAK ALL SHARP EDGES .010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14 5

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
	PVUSA US-1

APPLICATION

CONTRACT NO

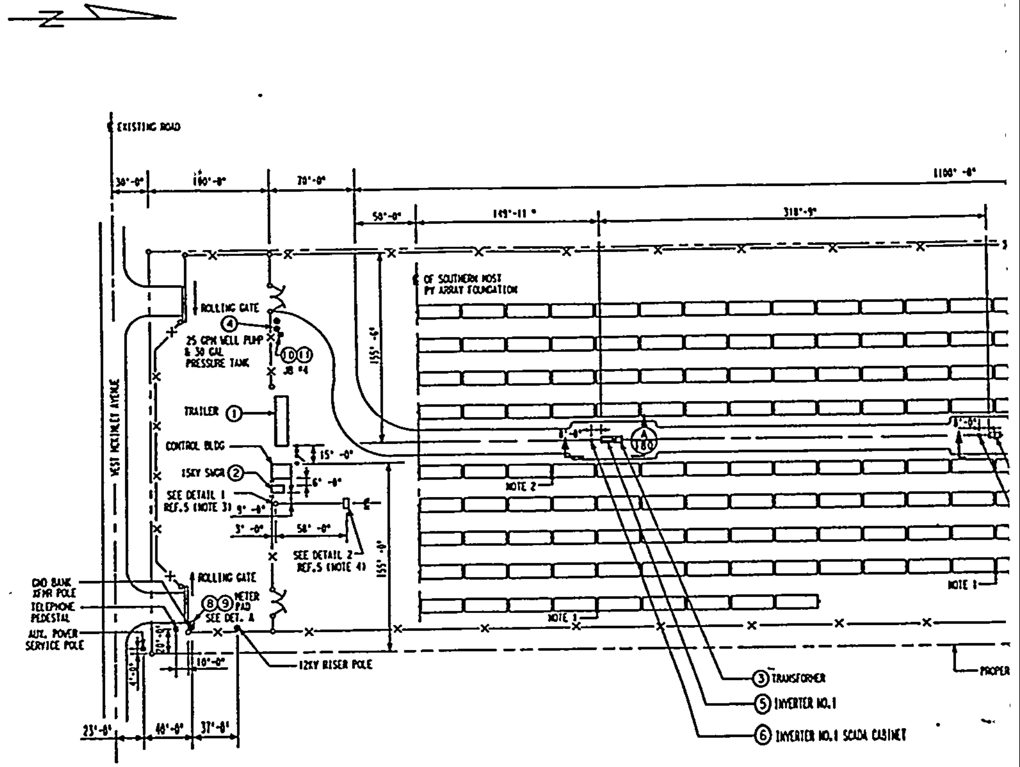
APPROVALS	DATE
DRAFTSMAN J. BATEMAN	2-12-90
CHECKER	
DESIGNER J. Bateman	2.12.90
ENGINEER	6-19-90
APPROVED	6.19.90

ARCO Solar, Inc.
P O Box 6032 Camarillo CA 93010

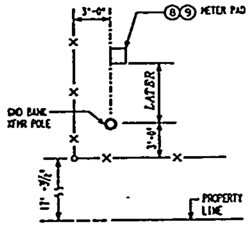
ELECTRICAL DETAILS

PVUSA US-1

SIZE D
FSCM NO
CODE
DRAWING NO 017795
SCALE NONE
WEIGHT —
SHEET 1 OF 5



PLAN
SCALE 1"=50"



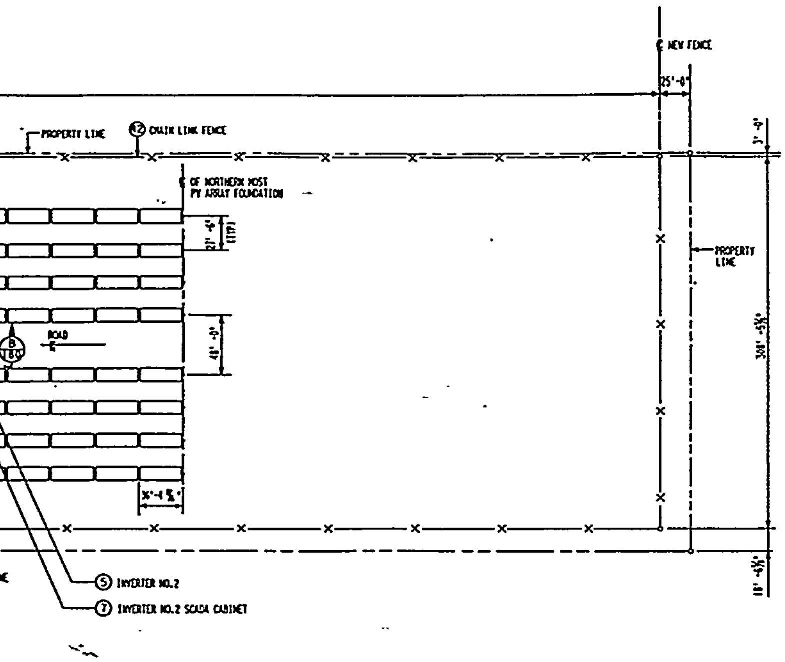
DETAIL A
N.T.S.

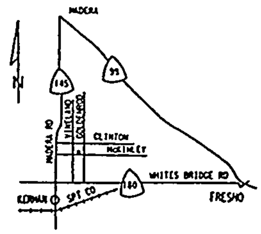
NO.	DATE	DESCRIPTION	DWN/SPEC	DWN	C

REVISIONS

UNIT T8
DSGNR: M.GINES
EXT: 2-
REV. BY: RY
DATE: 10-12-92

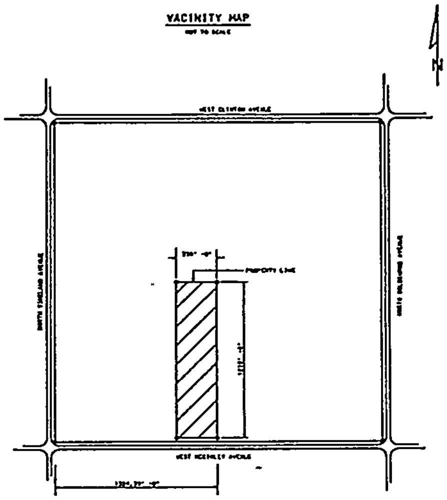
PRF NAME: 4008179B PROJ: KMH





VACINITY MAP

NOT TO SCALE



KEY PLAN

NOTES

1. TWO DC COLLECTION BOXES, ONE POSITIVE AND ONE NEGATIVE, INSTALLED ON ARRAY SUPPORT COLUMN AT THIS LOCATION IN EACH ROW. SEE REF. 6 FOR DETAILS.
2. LOCATION OF PLANE OF ARRAY PYRANOMETER.
3. WOODEN POLE FOR WIND SPEED AND WIND DIRECTION INSTRUMENTS.
4. FOUNDATION FOR SOLAR INSTRUMENTS.

REFERENCES

REFERENCES	DWG. NO.
1. SITE IMPROVEMENTS GRADING PLAN	359638
2. SITE IMPROVEMENTS GRADING SECTIONS & DETAILS	359639
3. SINGLE LINE METER & RELAY DIAGRAM	4008186
4. ARRGT. OF CONDUITS & GROUNDS SH. 1	4008182
5. GENERAL ARRANGEMENT OUTDOOR, SECTIONS & DETAILS SH.2	4008180
6. GENERAL ARRANGEMENT, PV ARRAY FIELD	BECHTEL REC. 19271-SC-0215-30
7. ELECTRICAL ARRANGEMENT, DETAILS AND PV ARRAY FIELD SH.1-3	BECHTEL REC. 19271-SC-0215-52

DWG TYPE	DWG SUBJECT	DRAWING TITLE	UNIT No.
0		GENERAL ARRGT OUTDOORS	

PROJECT LOCATION	INSTALLATION TYPE	DIVISION NAME	MISC	CO CODE	MAN HOURS	CADD	DRAWING SOURCE
KERMAN	L	T		TB		C	

NO.	DATE	DESCRIPTION	GM/SPEC	DWN	CHKD	SUPV	APVD BY
1	10/13/87	APPROVED FOR CONSTRUCTION	6330260	KB/6		RES	

REVISIONS

APPROVED BY	
	GM 6330260
	SUPV R.F.SANTOS
	DSGN VEGA ENG'G
	DWN R.VALLESPIN
	CHKD
	DATE
	SCALES AS SHOWN

ELECTRICAL
GENERAL ARRANGEMENT OUTDOORS
PVUSA KERMAN PHOTOVOLTAIC PLANT

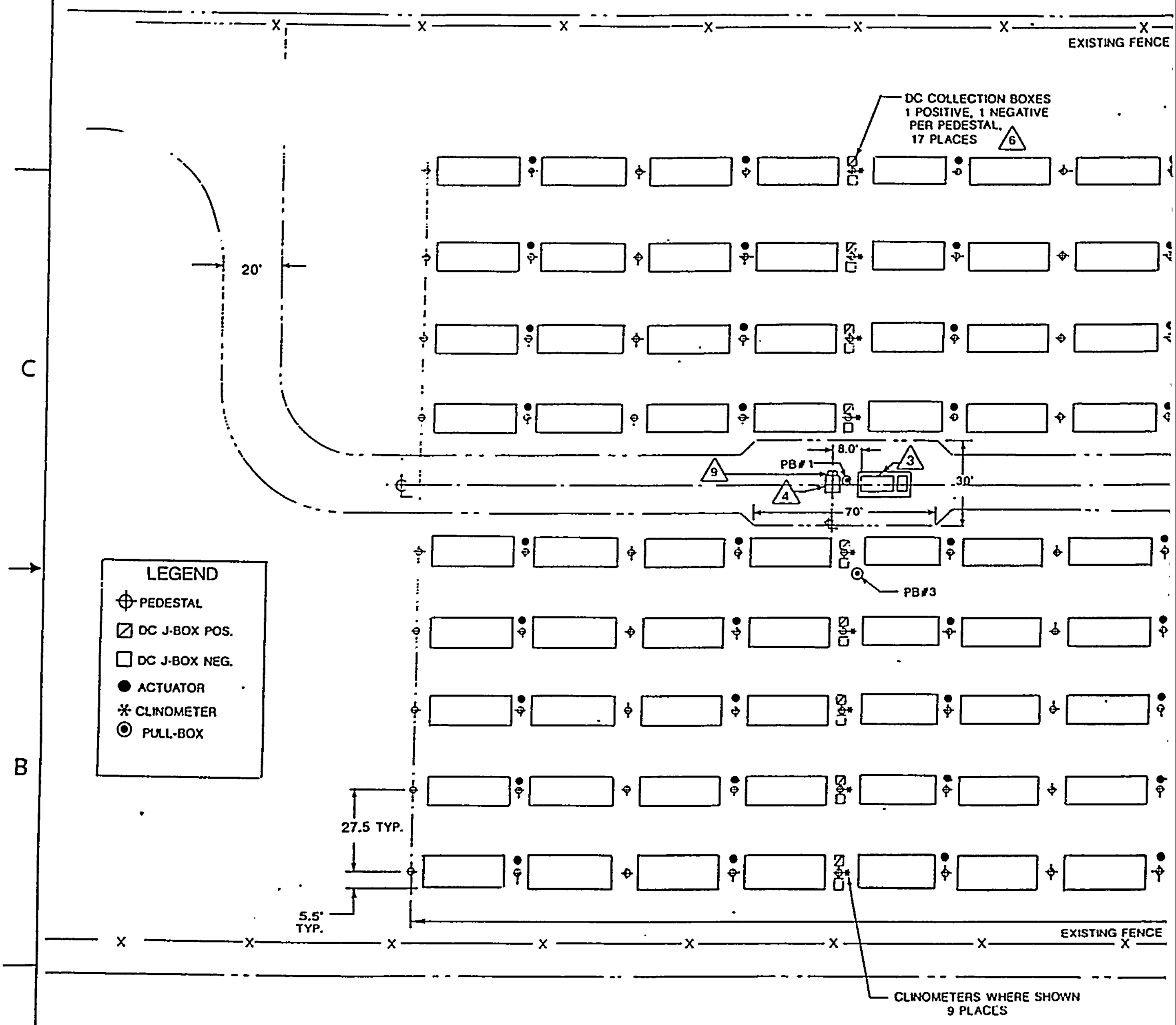
DEPARTMENT OF ENGINEERING
PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

SAN JOAQUIN VALLEY REGION

MICROFILM	
BILL OF MATL	065155
DWG LIST	065154
SUPSDS	
SUPSD BY	
SHEET NO. 1 OF 2	SHEETS

4008179 REV 1

4008179



6. REF. S.S.I DWG. NO. 018356, SHT. 2, VIEW B-B.

5. SCADA BOX #2 (BY PVUSA).

4. SCADA BOX # 1 (BY PVUSA).

3. INVERTER #1 & TRANSFORMER MOUNTED ON 17'-5"L X 5'-9"W X 22"THK. CONCRETE PAD.

2. INVERTER #2 MOUNTED ON 9'-6"L X 3'-10"W X 18"THK CONCRETE PAD.

1. SITE REQUIREMENT 3.8 ACRES.

NOTES: UNLESS OTHERWISE SPECIFIED

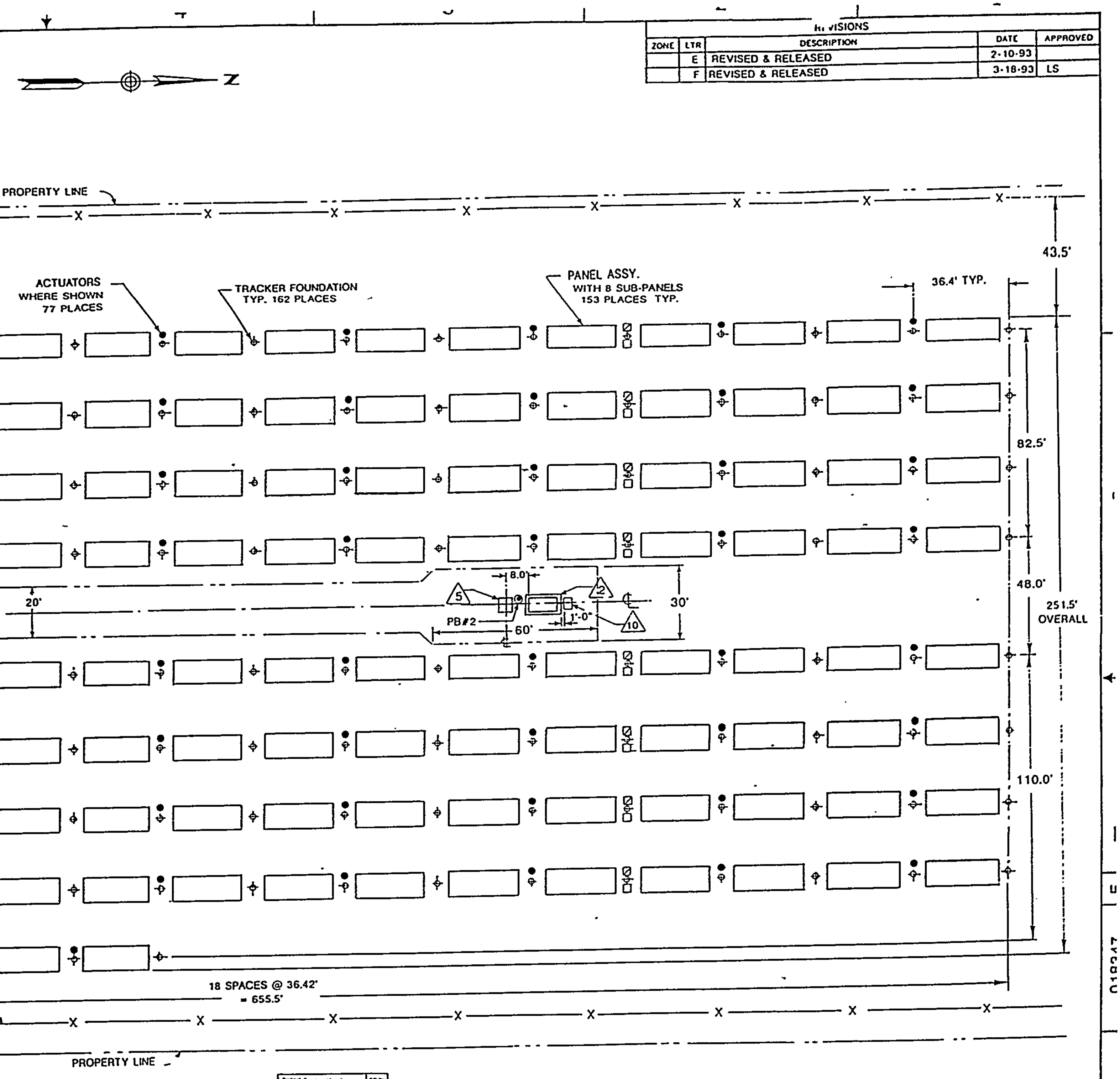
10. ISOLATION TRANSFORMER.
REFERENCE A.S.L DWG. NO. 018242-A (FOUNDATION DETAILS TRANS

9. CLINOMETER BOX, SIGNAL CONDITIONING.
REFERENCE S.S.I DWG. NO. 018499 (INSTRUMENT WIRING DIAGRAM).

8. FOR LOCATION OF SCOURCE CIRCUITS SEE S.S.I. DWG. NO. 018361.

7. REF. A.S.L. DWG. NO. 018241 FOR CORNER POSTS (NORTH & SOUTH) OF ARRAY.

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED
	E	REVISED & RELEASED	2-10-93	
	F	REVISED & RELEASED	3-18-93	LS



ORMER 2).

DIMENSIONS ARE IN FEET

SCALE: 1"= 25'

19271-SC-D215-30(1)-6

	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS 1/X
DECIMALS .X = .XX = .XXX =
ANGLES X XX° =
BREAK ALL SHARP EDGES 010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14.5
FINISH
DO NOT SCALE DRAWING

CONTRACT NO

APPROVALS		DATE
DRAFTSMAN	JB	6-12-92
CHECKER		
DESIGNER		
ENGINEER		6/1/12
APPROVED		2/1/12

NEXT ASSY	USED ON
	PVUSA US-2

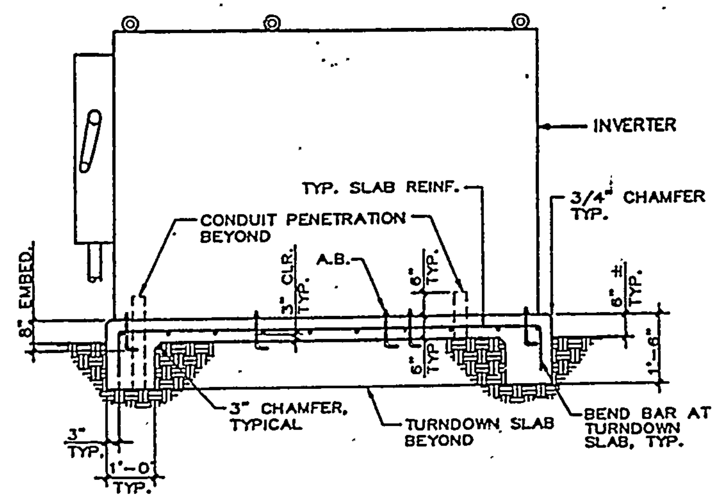
APPLICATION

Siemens Solar Industries
P.O. BOX 6032 Camarillo, CA 93011

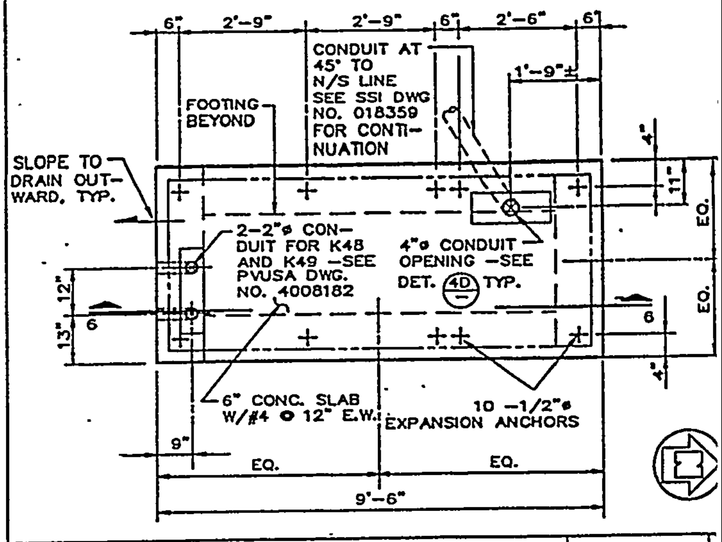
GENERAL ARRANGEMENT
500KW ARRAY
PVUSA US-2

SIZE	FSCM NO.	CODE	DRAWING NO	REV
D			018347	F

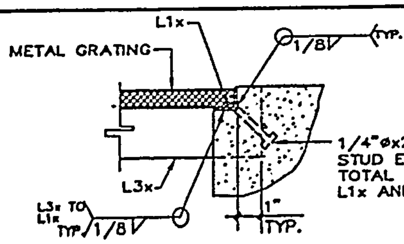
SCALE NOTED | WEIGHT | SHEET 1 OF 1



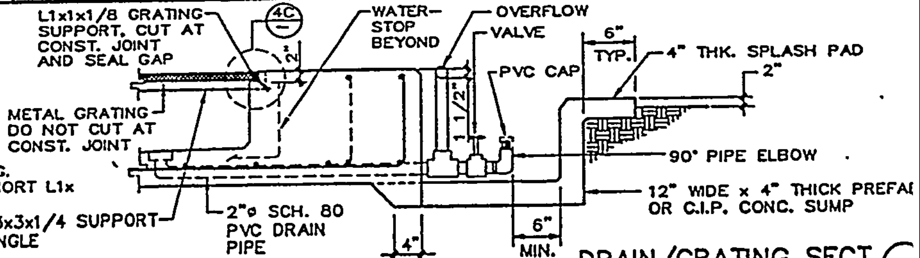
INVERTER SLAB SECTION 1/2"=1'-0" 6



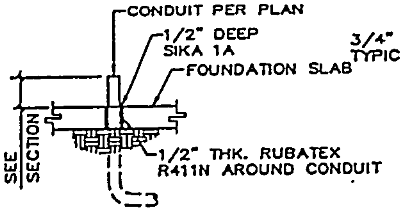
INVERTER SLAB PLAN 1/2"=1'-0"



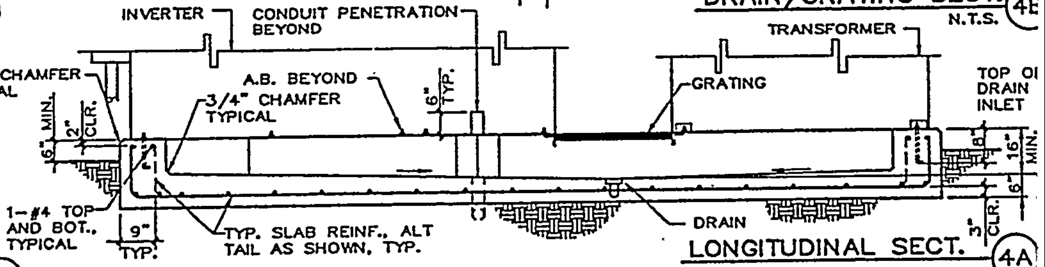
GRATING SUPPORT 4C
N.T.S.



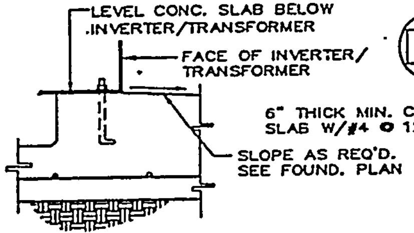
DRAIN/GRATING SECT. 4B
N.T.S.



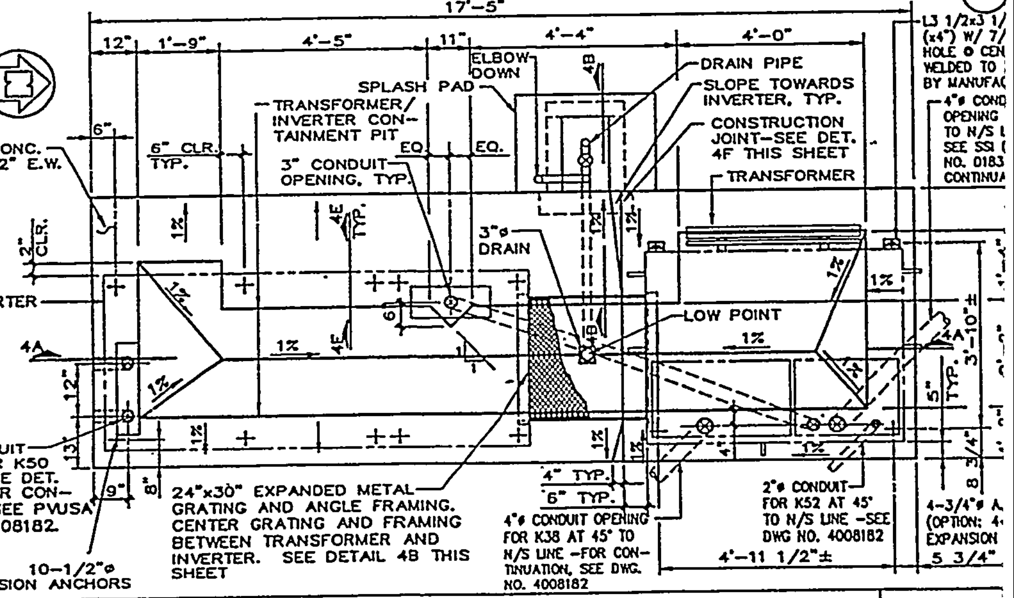
TYP. CONDUIT PENETRATION 4D
N.T.S.

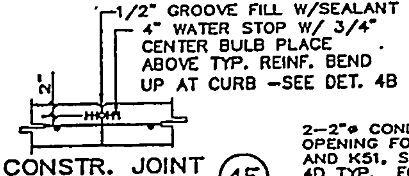


LONGITUDINAL SECT. 4A



TYP. SLAB SECTION 4E
N.T.S.





CONSTR. JOINT 4F

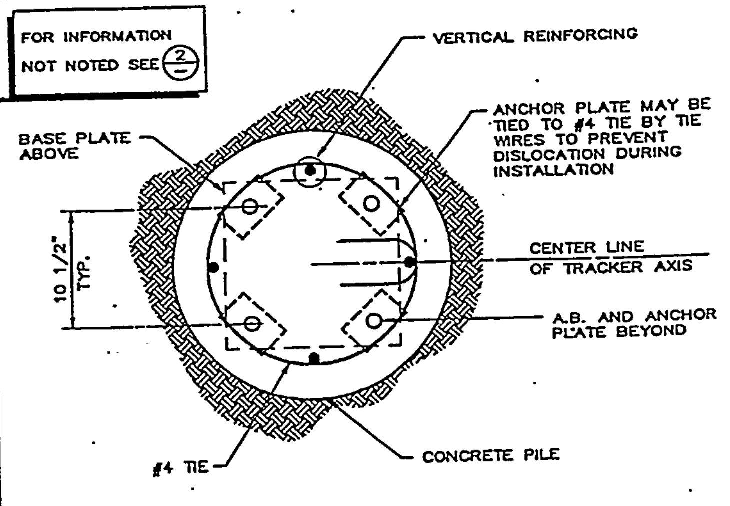
FOR ANCHOR BOLT SPACING FOR INVERTER, SEE DETAIL 5 THIS SHEET.

INVERTER/TRANSFORMER FOUNDATION PLAN AND SECTIONS 1/2"=1'-0"

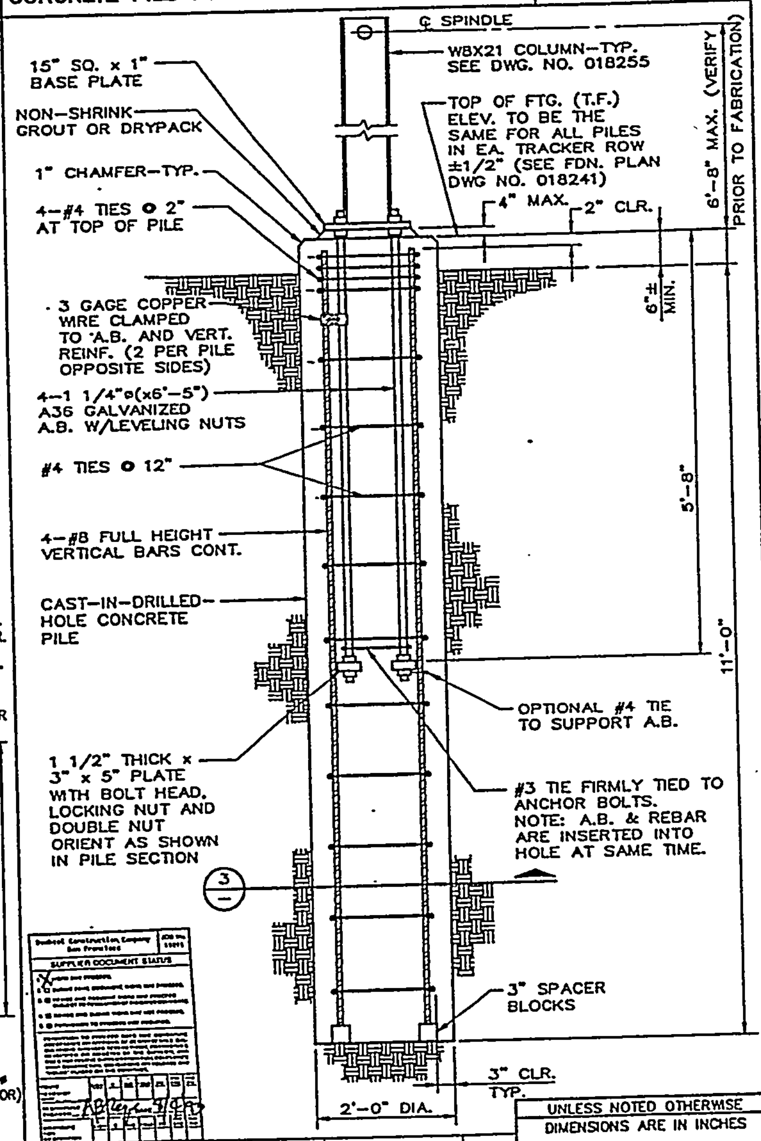
DALE E. WAH
No. 2582
Exp. 3/31/96

ASL Consulting Engineers

DESIGNED BY	VMR	CHECKED BY	V.P.	SCALE AS SHO
DRAWN BY	VMR	DATE	MAY '92	



CONCRETE PILE SECTION 1 1/2"=1'-0" 3



Bechtel Construction Company San Francisco
SUPPLIER DOCUMENT STATUS

CONCRETE PILE ELEVATION 3/4"= 1'-0" 2

GENERAL NOTES

THESE NOTES SHALL APPLY UNLESS SHOWN OTHERWISE ON PLANS

GENERAL

1. ALL MATERIALS AND CONSTRUCTION SHALL CONFORM TO THE 1991 EDITION OF THE UNIFORM BUILDING CODE (U.B.C.).
2. DESIGN IS BASED ON TECHNICAL SPECIFICATION NO. 19271-US-2-K (1/21/92) BY BECHTEL CONSTRUCTION CO. THESE SPECIFICATIONS SHALL BE CONSIDERED A PART OF THESE PLANS.
3. SOIL PROPERTIES, ALLOWABLE DESIGN VALUES, GRADING AND COMPACTION REQUIREMENTS AS PER SOILS REPORT NO. TES 001.1-92.1 SECTION 5 BY PG&E–TECHNICAL AND ECOLOGICAL SERVICES. THIS REPORT SHALL BE CONSIDERED A PART OF THESE PLANS AND SHALL BE KEPT AT THE JOB SITE AT ALL TIMES. LATERAL BEARING VALUE USED FOR PILE DESIGN IS 150 PSF PER UBC TABLE 29-B.
4. CONTRACTOR SHALL VERIFY ALL EXISTING CONDITIONS AND DIMENSIONS BEFORE STARTING WORK. SHOULD CONDITIONS EXIST WHICH ARE CONTRARY TO THOSE SHOWN ON PLANS, THE ENGINEER SHALL BE NOTIFIED BEFORE PROCEEDING WITH WORK.

REINFORCING NOTES

1. REINFORCEMENT FOR CONCRETE SHALL BE DEFORMED BARS CONFORMING TO LATEST A.S.T.M. SPECIFICATIONS A-615. GRADE 60 STEEL SHALL BE USED EXCEPT THE #4 BARS AND SMALLER MAY BE GRADE 40 STEEL.
2. REINFORCEMENT MAY BE SPLICED BY LAPPING BARS 50 BAR DIAMETERS BUT NOT LESS THAN 24" (STAGGER SPLICES).
3. ALL REINFORCEMENT, ANCHOR BOLTS, AND OTHER ANCHORAGES PLACED IN CONCRETE SHALL BE ACCURATELY PLACED AND POSITIVELY SECURED AND SUPPORTED BY CONCRETE BLOCKS, METAL CHAIRS, SPACERS, OR METAL HANGERS, AND SHALL BE IN POSITION BEFORE CONCRETE PLACING IS BEGUN.
4. ALL REINFORCING SHALL BE SUPPORTED IN CONFORMANCE WITH THE ACI "MANUAL OF STANDARD PRACTICE FOR REINFORCED CONCRETE CONSTRUCTION", LATEST EDITION.
5. REINFORCING STEEL SHALL HAVE THE FOLLOWING MINIMUM COVER:
   UNFORMED SURFACES IN CONTACT WITH EARTH. . . . . 3".
   FORMED SURFACES IN CONTACT WITH EARTH OR WEATHER. . . 2".

CONCRETE NOTES

1. ALL CONCRETE SHALL HAVE A MINIMUM COMPRESSIVE STRENGTH OF 2500 PSI AT 28 DAYS. AGGREGATES SHALL CONFORM TO ASTM C-33. CONCRETE MAY HAVE A MAX. SLUMP OF 4".
2. CEMENT FOR CONCRETE SHALL BE TYPE II PORTLAND CEMENT CONFORMING TO A.S.T.M C-150.
3. DRYPACK SHALL BE 1 PART CEMENT AND 3 PARTS SAND (BY VOLUME).
4. NON-SHRINK GROUT SHALL BE "EMBECO", "MASTER FLOW", SIKAGROUT, SIKADUR 42, OR EQUAL.
5. CONDUITS AND CABLES THAT STUB UP AND ARE ROUTED UNDER CONCRETE FOUNDATION SHALL ALL BE IN PLACE AND PROPERLY SUPPORTED PRIOR TO POURING CONCRETE.

STEEL NOTES

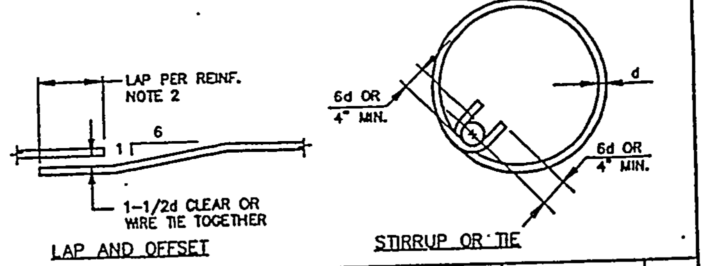
1. STRUCTURAL AND MISCELLANEOUS STEEL SHALL BE A.S.T.M. A-36 UNLESS NOTED OTHERWISE AND SHALL BE FABRICATED IN ACCORDANCE WITH THE LATEST A.I.S.C. SPECIFICATION FOR THE DESIGN, FABRICATION AND ERECTION OF STRUCTURAL STEEL FOR BUILDINGS.
2. BOLTS SHALL CONFORM TO A.S.T.M. A-307 OR BETTER, UNLESS NOTED OTHERWISE.
3. ALL WELDS SHALL BE SHIELDED ARC TYPE AND CONFORM TO AWS A5.1 AND AWS D1.1 STRUCTURAL WELDING CODE.
4. STEEL TUBES SHALL CONFORM TO A.S.T.M. A-500, GRADE B.
5. HOLES FOR BOLTS IN STEEL SHALL BE DRILLED AND OF SAME DIAMETER AS BOLT + 1/16" MAXIMUM, (UNLESS NOTED OTHERWISE ON THE DRAWINGS).
6. ALL STRUCTURAL STEEL SHALL BE HOT-DIP GALVANIZED PER A.S.T.M. A-123 AFTER WELDING. GAGE STEEL SHALL BE GALVANIZED PER ASTM A-525.
7. GALVANIZED WIRE ROPE SHALL CONFORM TO A.S.T.M. A603 WITH CLASS A OR B ZINC COATING. ALL WIRE ROPE SHLL BE 5/8" NOMINAL DIAMETER AND HAVE A MINIMUM BREAKING STRENGTH OF 41 KSI.
8. GAGE STEEL FOR MODULE SUPPORT CHANNELS SHALL CONFORM TO ASTM A446 GRADE A OR BETTER WITH YIELD STRENGTH OF 33 KSI AFTER GALVANIZING.
9. ALL DAMAGED GALVANIZING SHALL BE TOUCHED UP WITH "GALVANOX" OR EQUIVALENT.

EXPANSION ANCHORS

1. ALL EXPANSION ANCHORS SHALL BE STAINLESS STEEL OR GALVANIZED AND SHALL BE MANUFACTURED BY "HILTI", "ITW RAMSET/READ HEAD" OR AN ICBO EQUIVALENT.
2. ALL EXPANSION ANCHORS SHALL BE HILTI "KWIK BOLT II" OR ITW RAMSET/RED HEAD "TRUBOLT WEDGE ANCHOR" AND SHALL BE INSTALLED PER ICBO REPORT NO. 4627 AND 1372 RESPECTIVELY, AND IN ACCORDANCE WITH MANUFACTURER'S RECOMMENDATIONS.
3. 3 1/2"-MINIMUM EMBEDMENT –SEE FOUNDATION PLAN FOR SIZE AND SPACING OF ANCHOR BOLTS.

EXPANDED METAL GRATING

1. ALL EXPANDED METAL GRATING SHALL BE MANUFACTURED BY "McNICHOLS COMPANY" OR AN EQUIVALENT CAPABLE OF SUPPORTING 150 PSF LOAD WITH LESS THAN 1/4" DEFELCTION.
2. EXPANDED METAL GRATING SHALL BE NO. 4 AND SHALL BE HOT DIP GALVANIZED.
3. METAL GRATING SHALL BE CUT, FITTED, AND INSTALLED PER MANUFACTURER'S RECOMMENDATIONS.
4. MINIMUM SPECIFICATIONS:
   STRAND SIZE (WIDTH x THICKNESS): .300" x .215"
   DIAMOND SIZE (SWD x LWD): 1.33" x 5.33"
   OPENING SIZE (SWO x LWO): .83" x 3.30"
   DEPTH: 5/8"
   PERCENT AREA: 62
   WEIGHT: 4.0 PSF



LAP AND OFFSET

STIRRUP OR TIE

TYPICAL BAR BENDS N.T.S. 1

■ ARCADIA	(818) 447-4494
☐ IRVINE	(714) 727-7099
☐ PALM SPRINGS	(619) 320-4220
☐ RANCHO CUCAMONGA	(714) 900-8983
☐ CAMARILLO	(805) 388-2344

FILE NO. 1718.004.2

PVUSA US-2
NEXT ASSY | USED ON
APPLICATION

UNLESS NOTED OTHERWISE DIMENSIONS ARE IN INCHES

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS		DATE
DRAFTSMAN	VMR	9-22-92
CHECKER	V.P.	9-22-92
DESIGNER	VMR	9-22-92
ENGINEER	V.P.	9-22-92
APPROVED		9/25/92

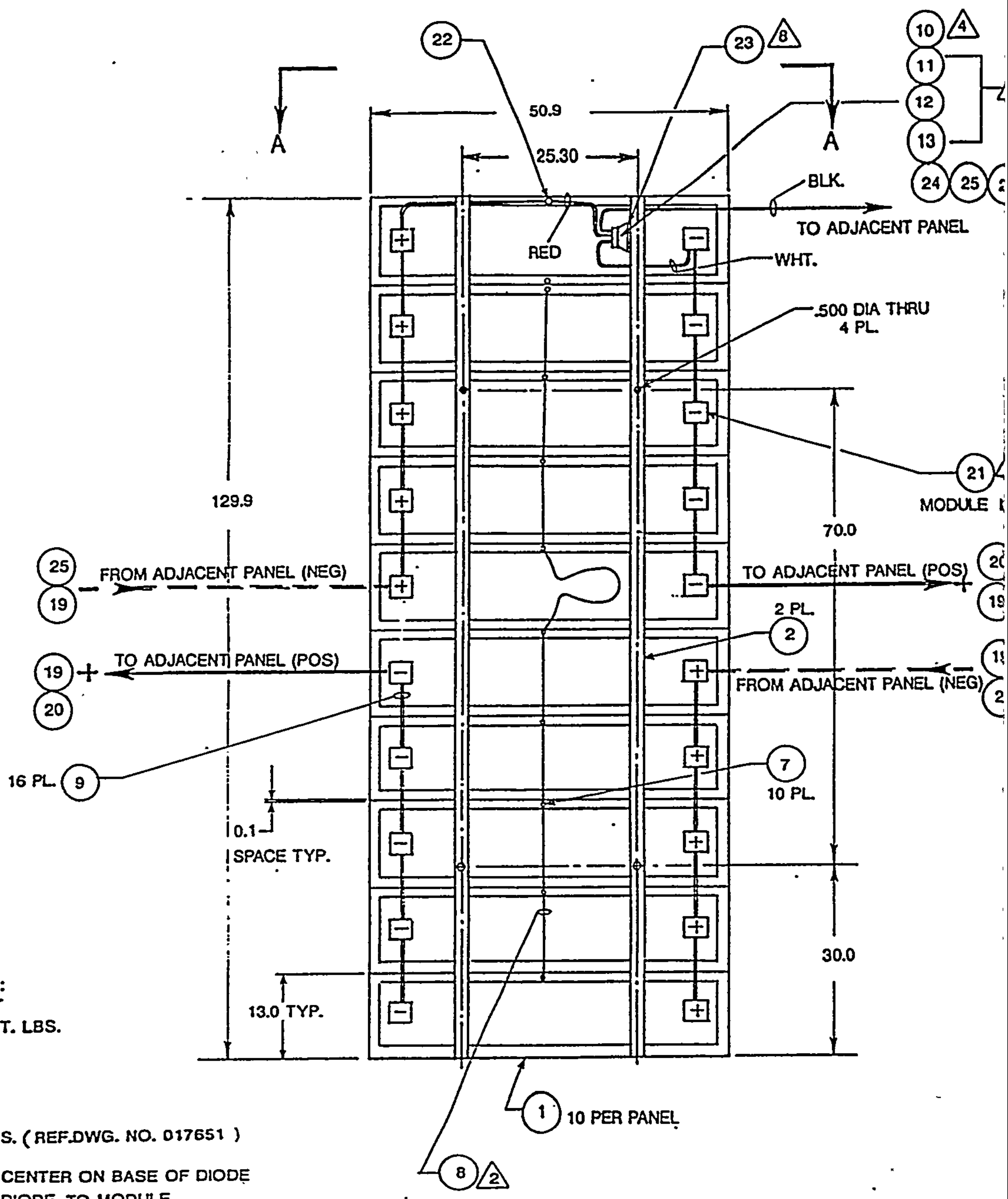
Siemens Solar Industries
P.O. Box 6032 Camarillo, CA 93011

FOUNDATION DETAILS AND
GENERAL STRUCTURAL NOTES
PVUSA US-2

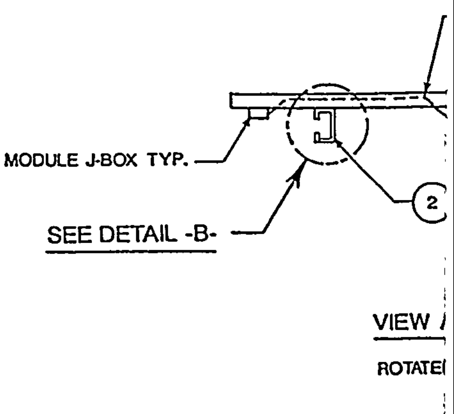
SIZE D | FSCM. NO. | CODE | DRAWING NO. 018242 | REV D
SCALE | WEIGHT | SHEET 1 OF 1

9

19271-SC-D215-44 (1)-4



REAR VIEW



9 FASTENER TORQUE REQUIREMENTS:

MOD. SUPPORT CHANNEL. 1/4-20 =12 FT. LBS.

DIODE. #10-32 = 30 IN. LBS.

J-BOX LID. = 5 IN. LBS.

J-BOX TERMINAL SCREW. 15 IN. LBS. (REF.DWG. NO. 017651)

8 LAYER THERMAL STRIP (ITEM 23) AND CENTER ON BASE OF DIODE WHERE SHOWN, PRIOR TO ATTACHING DIODE TO MODULE SUPPORT CHANNEL.

7 CABLE DESCRIPTION: # 6 AWG, 600V, USE, SUNLIGHT RESISTANT

6. TOTAL NUMBER OF PANELS REQUIRED 1224

5 ALL QUANTITIES SHOWN REFLECTS PARTS NEEDED FOR A SINGLE PANEL (SHOWN) NOT TOTAL QUANTITIES.

4 DIODE MOUNTED ON MODULE SUPPORT CHANNEL (ITEM 2) WHERE SHOWN. ONE DIODE REQUIRED PER PANEL.

3 DIODE LEAD TO BE ROUTED UNDER MODULE CHANNEL AS SHOWN IN DETAIL "B"

2 GROUND CONDUCTOR CONNECTED TO TRACKER STRUCTURE WITH SELF-TAPPING SCREW (ITEM 7).

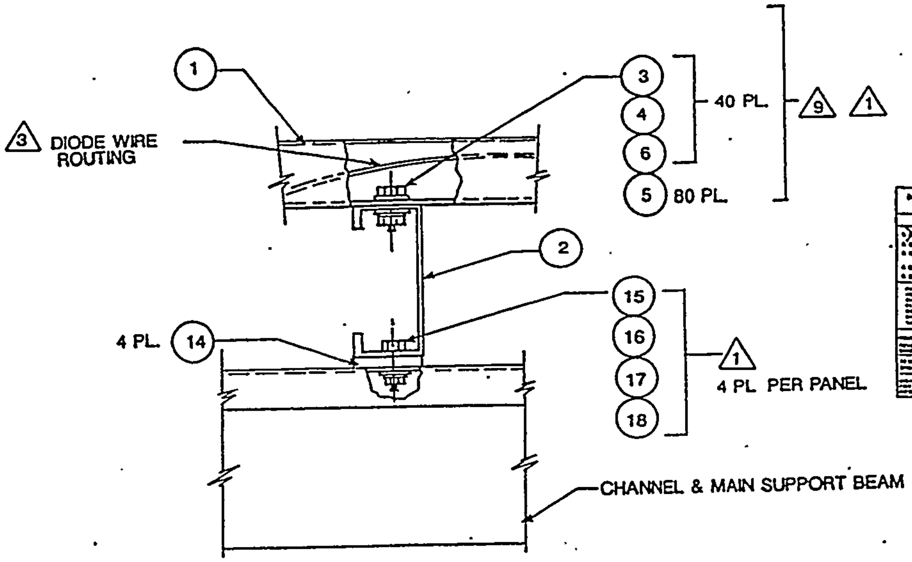
1 ALL HARDWARE TO BE 18-8 SERIES 300 STAINLESS STEEL EXCEPT ITEM NO. 7

NOTES: UNLESS OTHERWISE SPECIFIED

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	E	REVISED AND REDRAWN	2-11-93	

△9 4 PL.

RCONNECT J-BOX TYP.



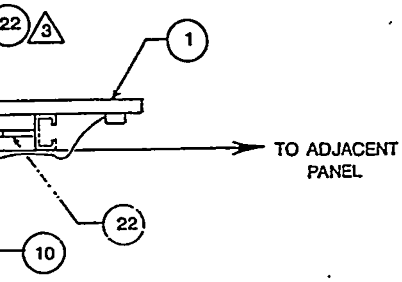
DETAIL -B-
DETAIL ENLARGED FOR CLARITY

19271-SC-D215-32 (1)-3

	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	REFERENCE	ITEM
	39	354	700512-11	SEAL RING, 1/2" NPT CONNECTOR	ALTECH	26
	125	398	018354-02	CABLE ASSY. PEDESTAL/PANEL, I/C	S.S.I	25
	39	398	701381-02	NUT, 1/2" NPT FITTING, #8463	HEYCO	24
	1	398	701359-04	THERMAL FOIL STRIP #AL-364-081	WEST POWER	23
	2	395	700954-21	TIEWRAP, CABLE, BLACK, NYLON 3 1/2" LG.	08404	22
	A/R	399	701381-01	PLUG, 1/2" NPT, #3083	HEYCO	21
	.125	398	018354-01	CABLE ASSY., PEDESTAL/PANEL, INTRCONN.	S.S.I	20
	1.75	398	018353	CABLE ASSY. PANEL INTERCONNECT	S.S.I	19
	4	321	700418-07	BOLT, HEX. HD. 3/8"-16 x 1 3/8 LG. (1/2 THD.)	18-8 S/S	18
	4	322	700419-04	NUT, HEX. 3/8-16	18-8 S/S	17
	4	323	700422-08	WASHER, FLAT, 3/8".	18-8 S/S	16
	4	323	700422-04	WASHER, SPLIT-LOCK 3/8"	18-8 S/S	15
	4	313	016712	SPACER, DELRIN, 1 1/2" x 1 1/2" x .187 THK.	S.S.I	14
	2	322	700420-14	NUT, LOCK, HEX #10-32	18-8 S/S	13
	2	323	700422-19	WASHER, FLAT #10	18-8 S/S	12
	2	320	700407-09	SCREW. PH. CR. #10-32 x 3/4" LG.	18-8 S/S	11
	1	357	018390	DIODE ASSY.		10
	16	398	018352	CABLE ASSY. MODULE INTERCONNECT	S.S.I	9
	130	399	701373-09	GND. STRAP, 3/8" FLAT SHIELDED BRAID	GRAY BAR	8
	10	320	701639-01	SCREW, TAP, TYPE "F", HSWS, #10 x 3/8" LG.	GRES 18-8 S/S	7
	40	320	700424-03	WASHER, SPLIT-LOCK, 1/4"	18-8 S/S	6
	40	323	700422-07	WASHER, FLAT 1/4"	18-8 S/S	5
	40	322	700419-03	HEX, NUT, 1/4-20	18-8 S/S	4
	40	321	700417-03	BOLT, HEX. 1/4-20 x 3/4" L.	18-8 S/S	3
	2	314	018351	MODULE SUPPORT CHANNEL, 6061-T6.	CLEAR ANODIZED	2
	10	004	017647	MODULE ASSY., M55 VJ	S.S.I	1

△7 △7 △7 △5

PARTS LIST 19271-SC-D215-32(1)-3



A

80°

	PVUSA US-2
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS 1/X DECIMALS .X = .XX = .XXX = ANGLES X.XX' =
BREAK ALL SHARP EDGES .010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14.5
FINISH
DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS		DATE
DRAFTSMAN	JB	2-11-93
CHECKER		
DESIGNER		
ENGINEER		
APPROVED		

Siemens Solar Industries
P.O. BOX 6032 Camarillo, CA 93011

PANEL ASSY.
FOR
PVUSA US-2

SIZE	FSCM NO.	CODE	DRAWING NO.	REV.
D			018349	E
SCALE NONE	WEIGHT		SHEET 1 OF 1	

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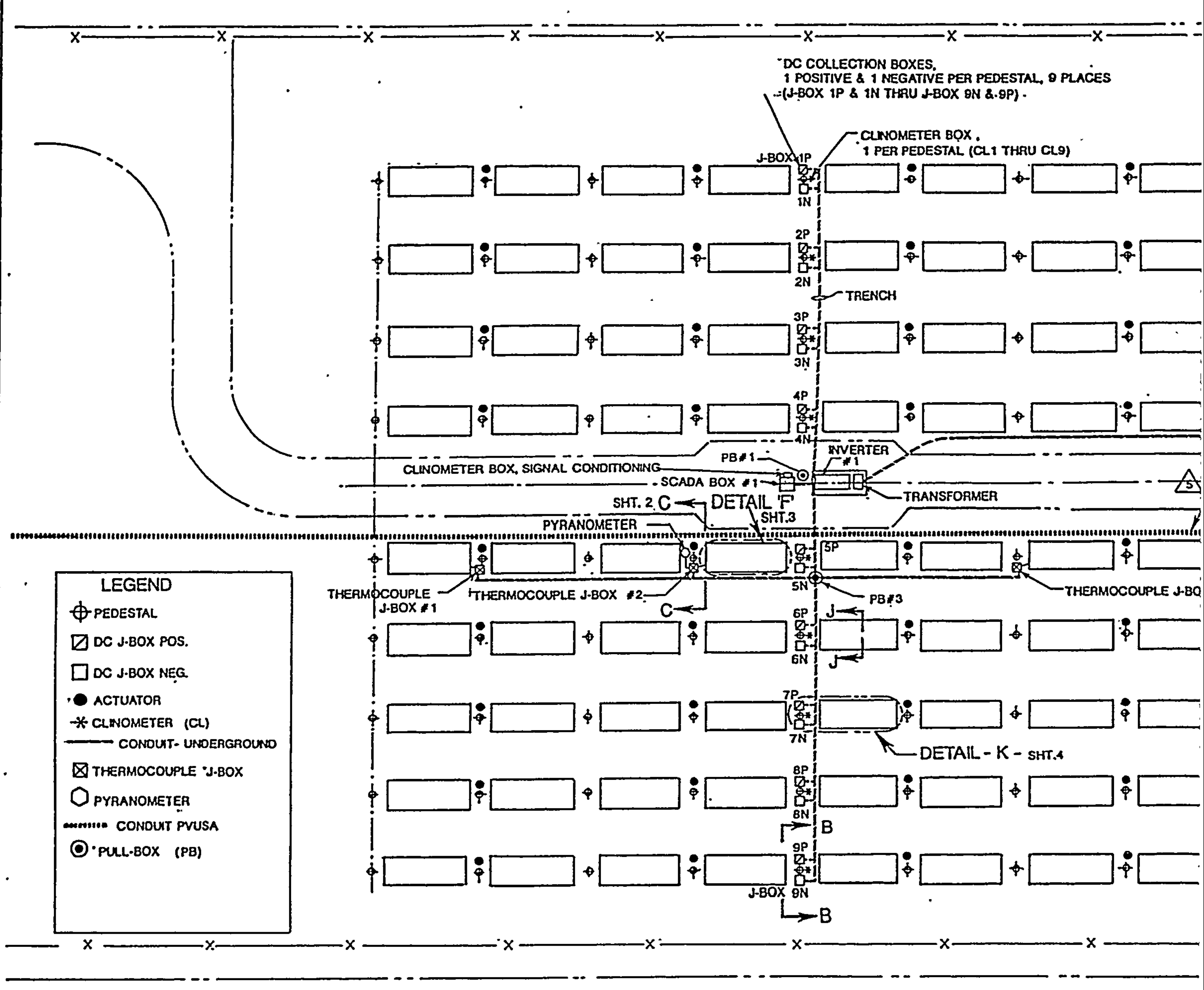


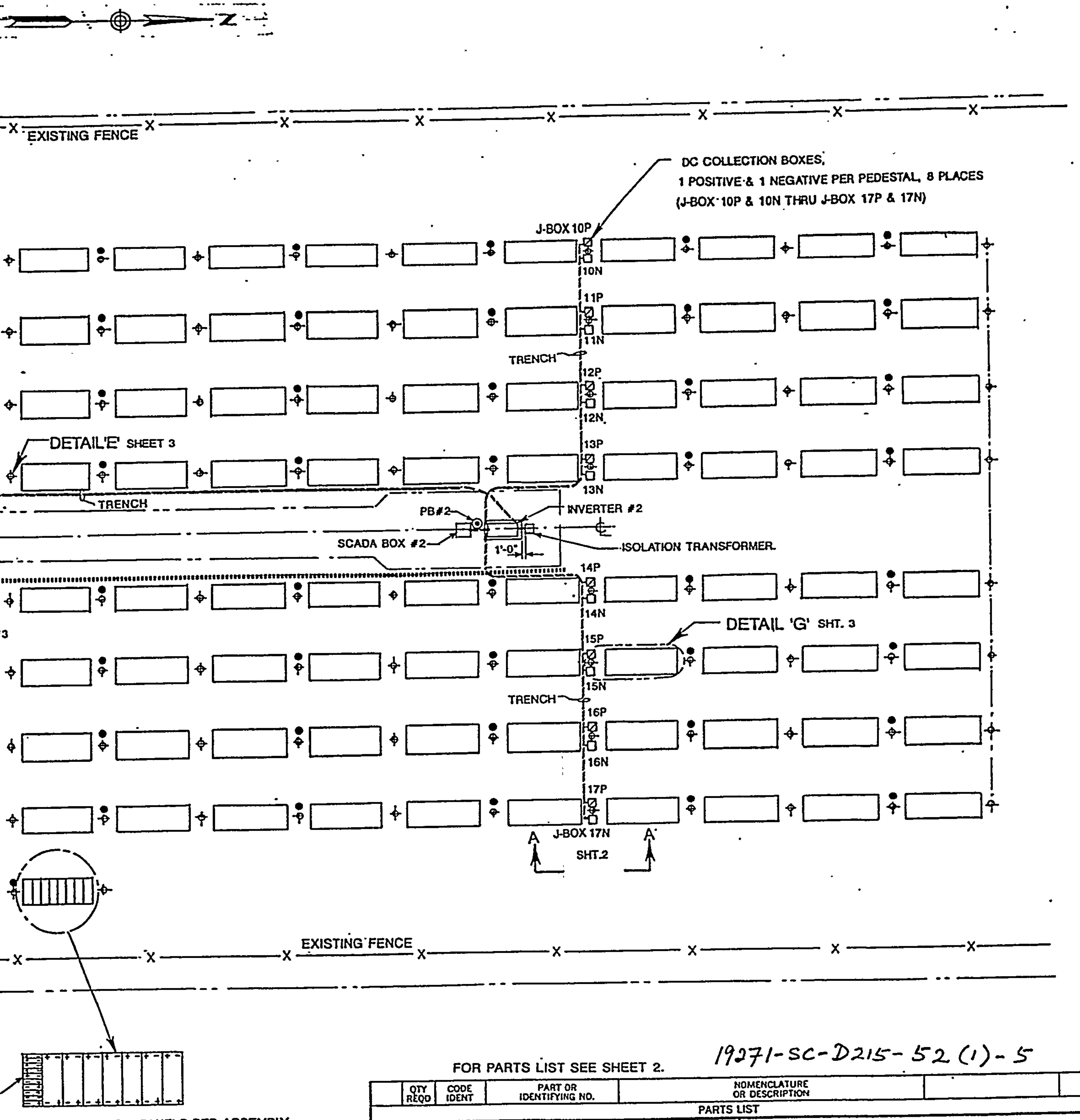
10 MODULES PER PANEL

SCALE: 1" = 25'

DIMENSIONS ARE IN FEET.

NOTES; UNLESS OTHERWISE SPECIFIED SEE SHEET 2.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	E	REVISED & RELEASED	2-8-93	LS
	F	REVISED & RELEASED	3-18-93	LS



DETAIL SHOWING 8 PANELS PER ASSEMBLY

153 PLACES

FOR PARTS LIST SEE SHEET 2.

19271-SC-D215-52 (1)-5

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS 1/X
DECIMALS .X = .XX = .XXX =
ANGLES X XX' =
BREAK ALL SHARP EDGES .010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14.5
FINISH
DO NOT SCALE DRAWING

PVUSA US-2	
NEXT ASSY	USED ON
APPLICATION	

CONTRACT NO.

APPROVALS		DATE
DRAFTSMAN	JB	6-12-92
CHECKER		
DESIGNER		
ENGINEER		6/1/92
APPROVED		6/1/92

Siemens Solar Industries
P.O. BOX 6032 Camarillo, CA 93011

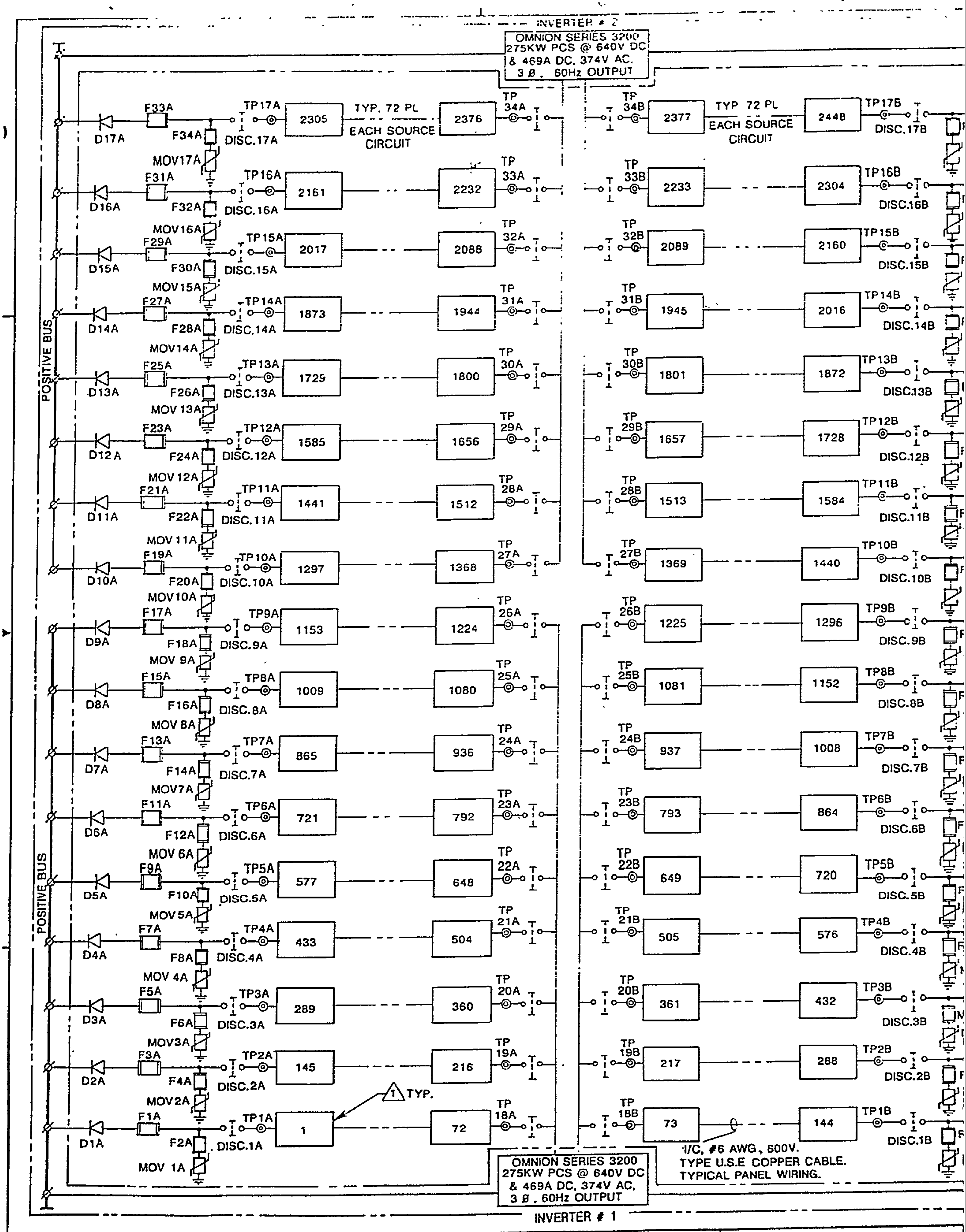
ELECTRICAL DETAILS
PVUSA US-2

SIZE	FSCM NO.	CODE	DRAWING NO.	REV.
D			018356	F

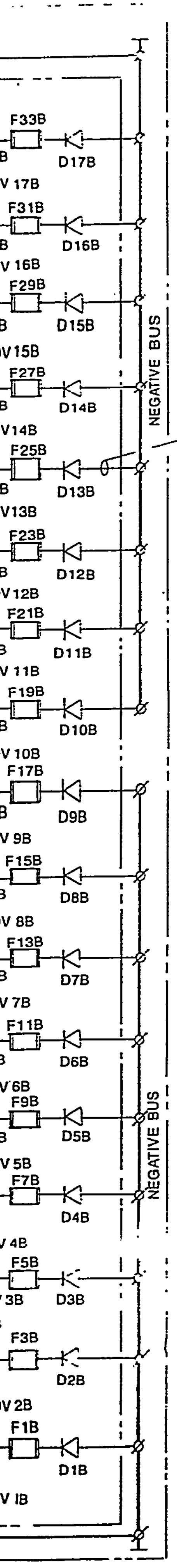
SCALE NOTED | WEIGHT | SHEET 1 OF 4

018356 F

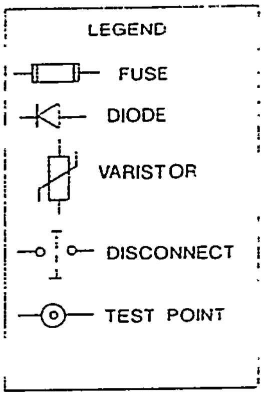
10


INVERTER # 2
OMNION SERIES 3200
275KW PCS @ 640V DC
& 469A DC, 374V AC,
3 Ø , 60Hz OUTPUT
POSITIVE BUS
POSITIVE BUS
D17A
F33A
F34A
MOV17A
TP17A
DISC.17A
2305
TYP. 72 PL
EACH SOURCE CIRCUIT
2376
TP 34A
TP 34B
2377
TYP 72 PL
EACH SOURCE CIRCUIT
2448
TP17B
DISC.17B
D16A
F31A
F32A
MOV16A
TP16A
DISC.16A
2161
2232
TP 33A
TP 33B
2233
2304
TP16B
DISC.16B
D15A
F29A
F30A
MOV15A
TP15A
DISC.15A
2017
2088
TP 32A
TP 32B
2089
2160
TP15B
DISC.15B
D14A
F27A
F28A
MOV14A
TP14A
DISC.14A
1873
1944
TP 31A
TP 31B
1945
2016
TP14B
DISC.14B
D13A
F25A
F26A
MOV 13A
TP13A
DISC.13A
1729
1800
TP 30A
TP 30B
1801
1872
TP13B
DISC.13B
D12 A
F23A
F24A
MOV 12A
TP12A
DISC.12A
1585
1656
TP 29A
TP 29B
1657
1728
TP12B
DISC.12B
D11A
F21A
F22A
MOV 11A
TP11A
DISC.11A
1441
1512
TP 28A
TP 28B
1513
1584
TP11B
DISC.11B
D10A
F19A
F20A
MOV10A
TP10A
DISC.10A
1297
1368
TP 27A
TP 27B
1369
1440
TP10B
DISC.10B
D9A
F17A
F18A
MOV 9A
TP9A
DISC.9A
1153
1224
TP 26A
TP 26B
1225
1296
TP9B
DISC.9B
D8A
F15A
F16A
MOV 8A
TP8A
DISC.8A
1009
1080
TP 25A
TP 25B
1081
1152
TP8B
DISC.8B
D7A
F13A
F14A
MOV7A
TP7A
DISC.7A
865
936
TP 24A
TP 24B
937
1008
TP7B
DISC.7B
D6A
F11A
F12A
MOV 6A
TP6A
DISC.6A
721
792
TP 23A
TP 23B
793
864
TP6B
DISC.6B
D5A
F9A
F10A
MOV5A
TP5A
DISC.5A
577
648
TP 22A
TP 22B
649
720
TP5B
DISC.5B
D4A
F7A
F8A
MOV 4A
TP4A
DISC.4A
433
504
TP 21A
TP 21B
505
576
TP4B
DISC.4B
D3A
F5A
F6A
MOV3A
TP3A
DISC.3A
289
360
TP 20A
TP 20B
361
432
TP3B
DISC.3B
D2A
F3A
F4A
MOV2A
TP2A
DISC.2A
145
216
TP 19A
TP 19B
217
288
TP2B
DISC.2B
D1A
F1A
F2A
MOV 1A
TP1A
DISC.1A
1
1 TYP.
72
TP 18A
TP 18B
73
144
TP1B
DISC.1B
1/C, #6 AWG, 600V.
TYPE U.S.E COPPER CABLE.
TYPICAL PANEL WIRING.
OMNION SERIES 3200
275KW PCS @ 640V DC
& 469A DC, 374V AC,
3 Ø , 60Hz OUTPUT
INVERTER # 1

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	INITIAL RELSE	[illegible] 92	
	B	REVISED & REDRAWN	[illegible] 11 92	



I/C. #4 AWG. 600V.
TYPE XHHW COPPER CABLE.
TYPICAL DC FEEDER WIRING
(BOTH SIDES)



4. PV MONOPOLE 72 (S) X 5 (P) S.S.I M55VJ
   Voc = 523V Isc = 51.7A @ STC
   Voc = 477V Isc = 52.2A @ PTC.

3. FOR WIRE NUMBERS SEE CONDUIT & CABLE SCHEDULE DWG. NO. 018367.

2. FOR COMPONENT RATINGS SEE OMNION DWG. NO. 2117-0 AND 2117-1

△1 PV SUB PANEL 1(S) X 5(P) SSI M55VJ W/BYPASS DIODE
   Voc = 6.62V Isc = 52.2A @ PTC.

NOTES: UNLESS OTHERWISE SPECIFIED.

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION

PARTS LIST

NEXT ASSY	USED ON
	PVUSA US-2

APPLICATION

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS 1/X DECIMALS .X = .XX = .XXX = ANGLES X XX' =
BREAK ALL SHARP EDGES .010 .030
REMOVE ALL BURRS
DIMENSIONS PER USASI Y 14.5
FINISH
DO NOT SCALE DRAWING

CONTRACT NO

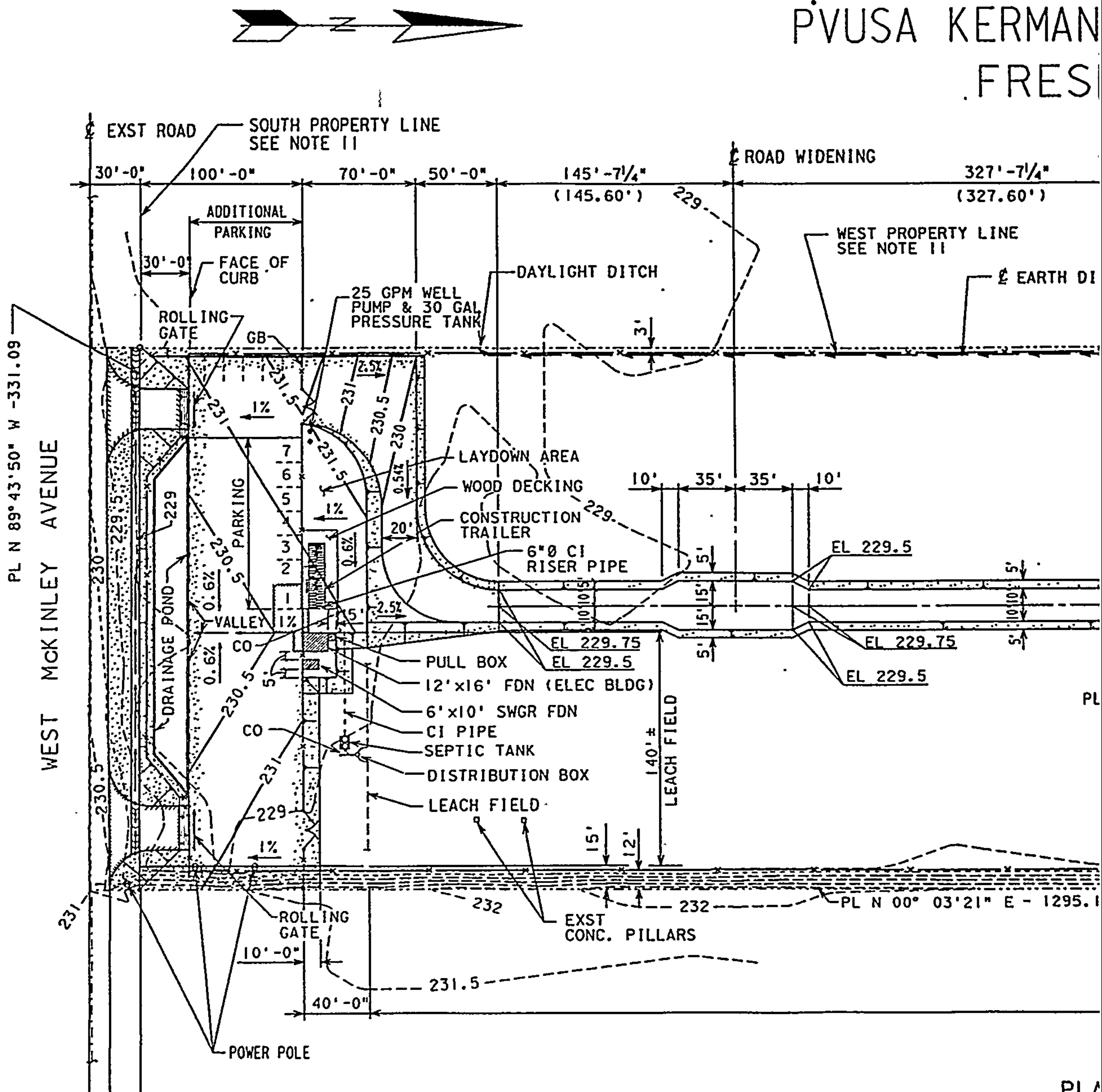
APPROVALS		DATE
DRAFTSMAN	JB	6-1-92
CHECKER		
DESIGNER		
ENGINEER		
APPROVED		

Siemens Solar Industries
P O BOX 6032 Camarillo CA 93011

PV SYSTEM
SCHEMATIC DIAGRAM
PVUSA US-2

SIZE D
FSCM NO
CODE
DRAWING NO 018361
REV B
SCALE NONE
WEIGHT
SHEET 1 OF 1

PVUSA KERMAN
FRES



PLA
SCALE

LEGEND

- • SURVEYOR FOUND ¾" IRON PIPE DESCRIBED AS NOTED
- ○ SURVEYOR SET ¾" X 30" IRON PIPE TAGGED LS 4998
- ▫ EXST 12"X12"X24" CONCRETE PILLAR
- ⊙ EXST 8" DIAM. STAND PIPE
- ⊗ POWER POLE
- T FILL SLOPE
- ▤ 3" HIGH x 5' WIDE AC BERM
- ░ 9" MIN. AGGREGATE BASE
- ▨ 2" AC/6" MIN. AGGREGATE BASE

CO	CLEAN OUT
CI	CAST IRON
EXST	EXISTING
PL	PROPERTY LINE
GB	GRADE BREAK
AC	ASPHALT CONCRETE
AB	AGGREGATE BASE
EL 232	FINISH GRADE ELEVATION
TC 230.5	TOP OF CURB ELEVATION
—230—	FINISH GRADE
--229--	EXST GROUND
← ←	VALLEY

NOTES

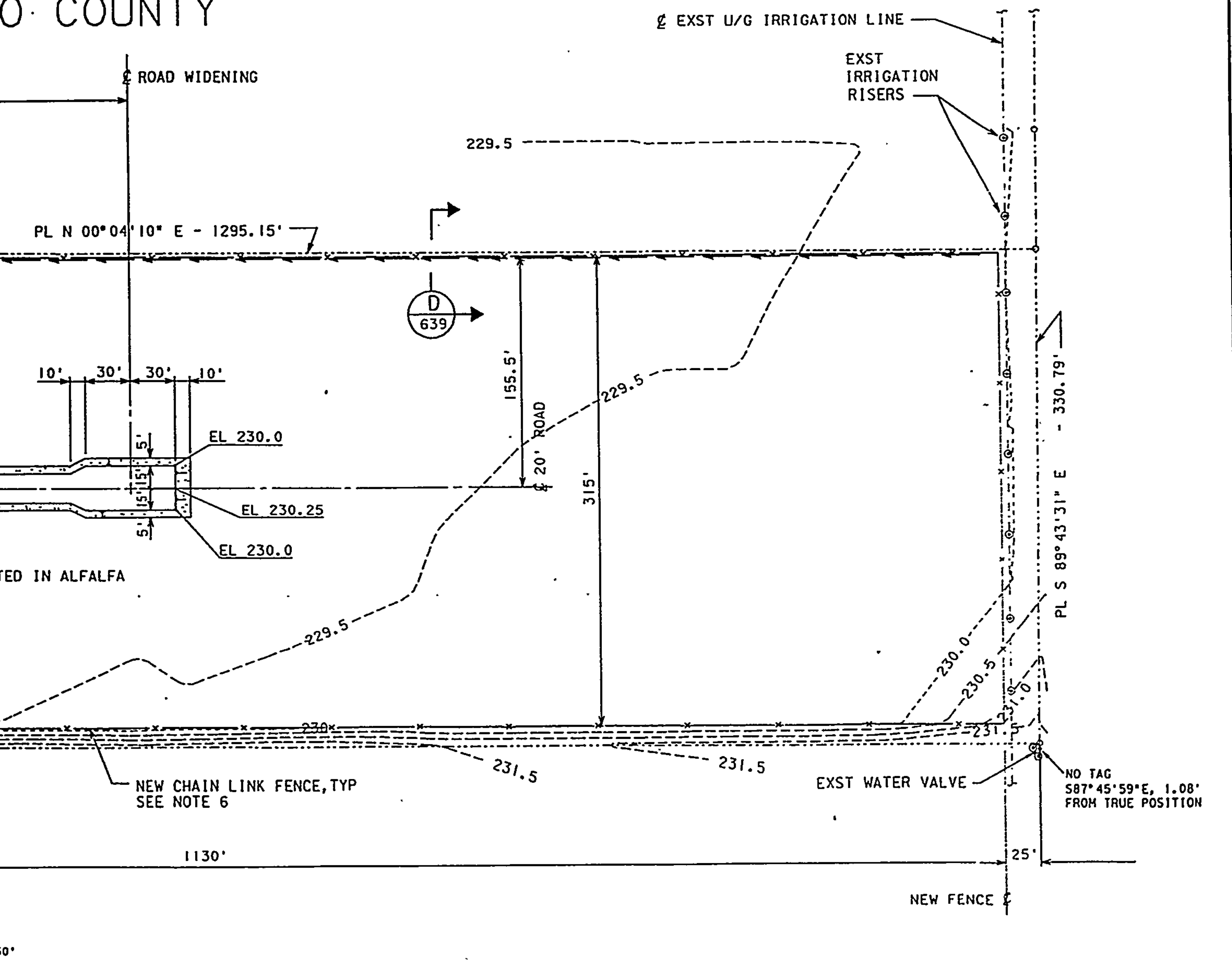
1. BENCH MARK IS BASED ON BRASS
1972" SE CORNER OF McKINLEY A
LATITUDE:36°42' LONGITUDE:1
2. DASHED TOPOGRAPHY CONTOURS AR
FINISHED GRADE CONTOURS ARE S
3. SITE AND ROAD PAVING SHALL BE
BASE ROCK. DRIVEWAY PAVING SH
CLASS II AGGREGATE BASE ROCK,
4. GRADING, PAVING AND DRAINAGE
IN ACCORDANCE WITH FRESNO COU
AND SPECIFICATIONS.
5. SUBBASE OF PAVED AREAS AND EA
WITH HERBICIDE AFTER COMPACTI
AND TYPE OF HERBICIDE SHALL B
SPECIFICATION.

BECHTEL		
MECH.		HBR
ELEC.		ZXB
CIVIL		
ARCH.		
GROUP	DES	ENG
	Chg. No.	

COORDINATED APPROVAL FOR CONSTRUCTION

C 3359638.C01 06-23-92 GRD

G&E
PHOTOVOLTAIC SITE
O COUNTY



0'

STAMPED "AZ MARK
VINEYARD EL 229.55
04'

HOWN AT 0.5' INTERVALS.
N BY SOLID LINES.

MIN OF CLASS II AGGREGATE
BE 2"AC MIN. AND 6"MIN.
E LEGEND.

UIREMENTS SHALL BE
STANDARD DETAILS

DITCH SHALL BE TREATED
IS COMPLETED. APPLICATION
N ACCORDANCE WITH THE

6. ALL FENCE DETAILS IN ACCORDANCE WITH PG&E DRAWING NO. 059659 TO 059662. EXTERIOR FENCE TO BE 7' HIGH CHAIN LINK FENCE PLUS 1' EXTENSION ARMS WITH 3 ROWS OF BARBED WIRE. INTERIOR FENCE TO BE 6' HIGH WITH NO BARBED WIRE.
7. DETAILS OF FOUNDATION, SUPPORT STRUCTURE, STAIRS, AND HANDRAILS SHALL CONFORM TO DETAILS SHOWN ON P2 AND P3.
8. DECKING TO BE 1⅛" THICK PLYWOOD OR REDWOOD 2" x 6".
9. DECKING SHALL BE STAINED WITH BENJAMEN MOORE CLEAR WOOD FINISH 088-00.
10. TOP OF DECK ELEVATION IS 234.08 WHICH IS 3' ± ABOVE FINISH GRADE. THIS WAS ESTABLISHED BY SETTING RAMP AT MAXIMUM GRADE WHICH IS 1 VERTICAL TO 12 HORIZONTAL OR 8.33%. FINAL TOP OF DECK ELEVATION TO BE SET IN FIELD SUCH THAT IT MATCHES BOTTOM OF TRAILER DOOR THRESHOLD.
11. CONSTRUCTION MEASUREMENTS SHALL BE TAKEN FROM THE SOUTH AND THE WEST PROPERTY LINES SINCE ALL PROPERTY LINES ON THIS PARCEL OF LAND ARE NOT PARALLEL.

KENT S. FERRE
C 034629

REV	DATE	DESCRIPTION	JOB NO	DSG/DWN	CHKD	SUPV	APVD
01	3-11-92	ISSUED FOR PERMIT					
1	6-23-92	APPROVED FOR CONSTRUCTION		J.R.			KF

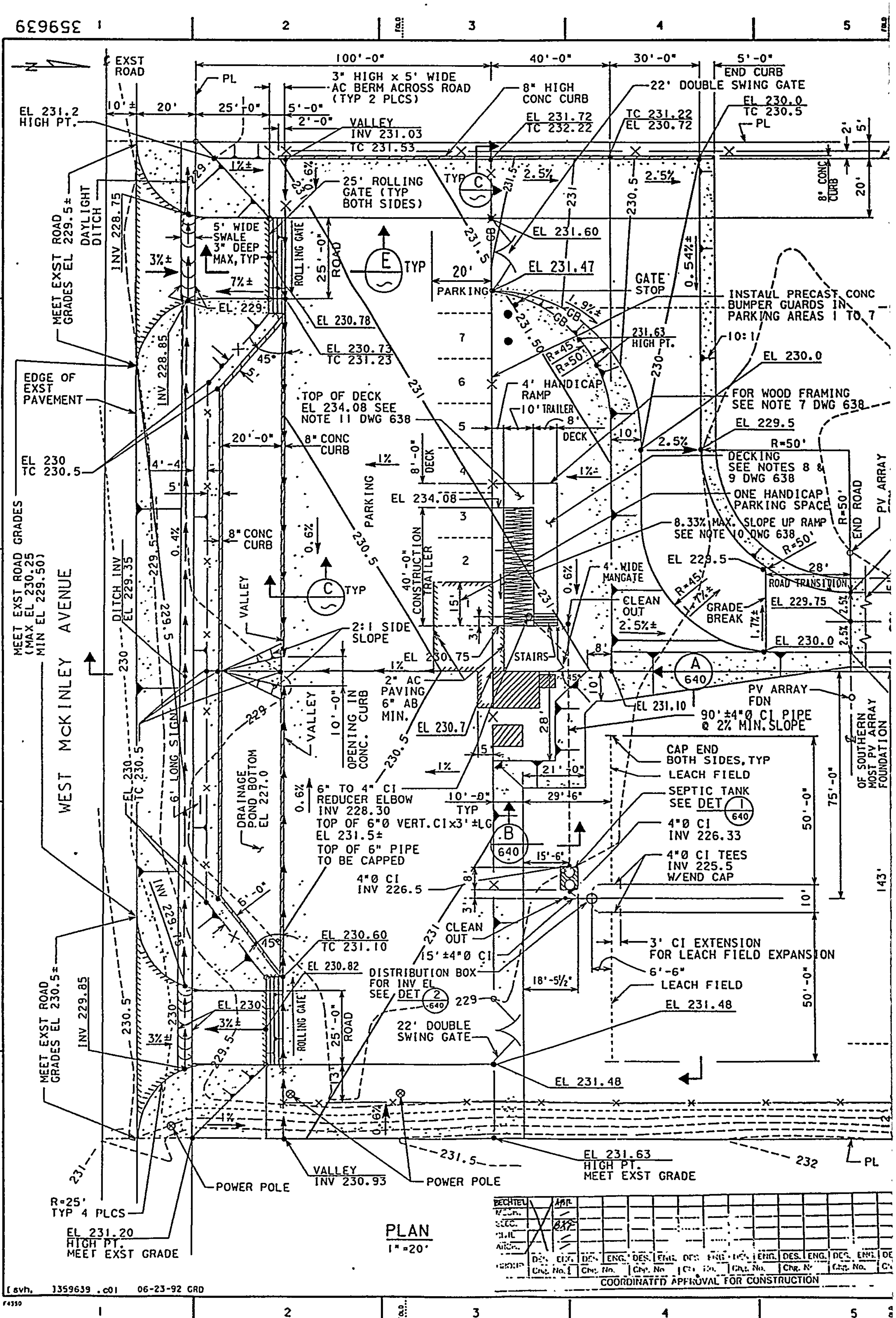
REVISION 1.
DSG J RZONCA
DWN S HOPKINS
CHKD
SUPV M CHAIO
APVD Karl Ferre
APVD
DATE 6/23/92

CIVIL
SITE IMPROVEMENTS
GRADING PLAN
PVUSA KERMAN PHOTOVOLTAIC SITE

DEPARTMENT OF ENGINEERING

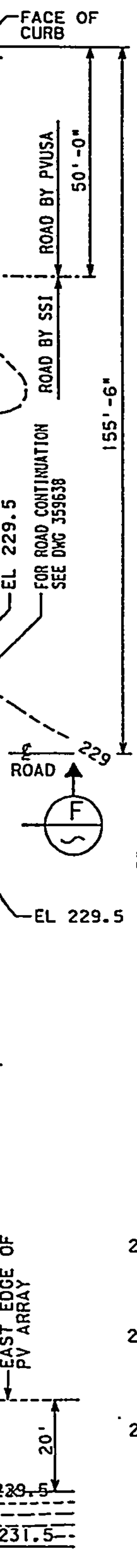
PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

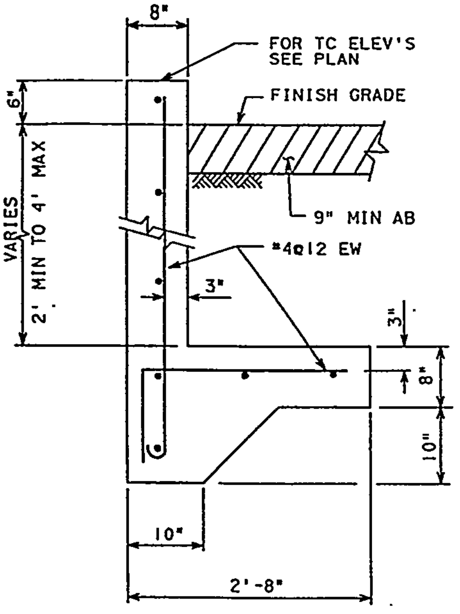
MICROFILM
BILL OF MATL
DWG LIST 063119
SUPSDS
SUPSD BY
SHEET NO
SHEETS
359638
REV 1



PLAN
1"=20'

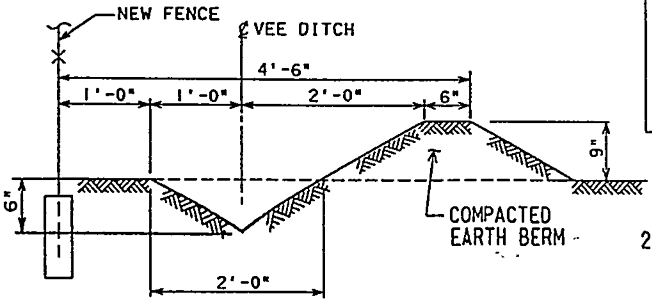
PRF 359639.c0
UNIT cd EXT 3-3499
ADDRESS 1641b ,1 cd
NAME s. hopkins





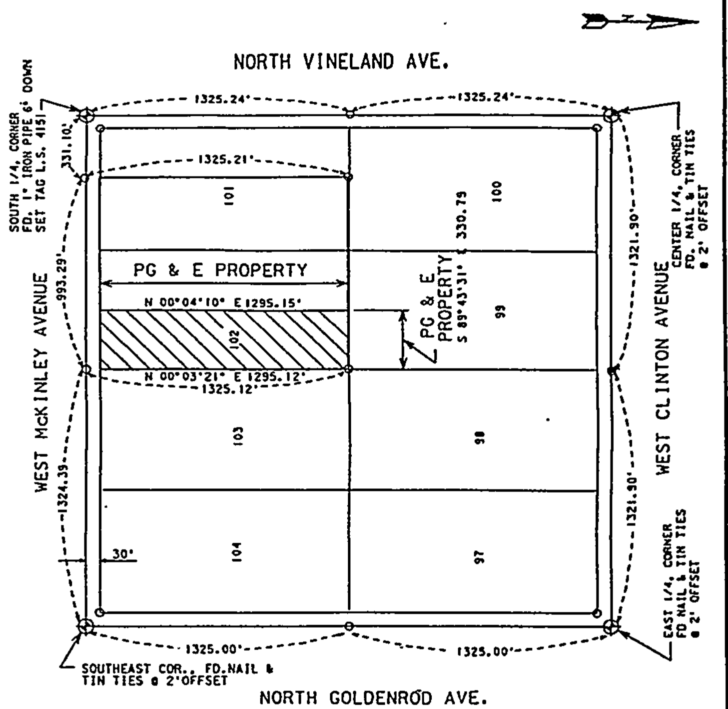
SECTION C

1"=1'-0"



SECTION D 638/639

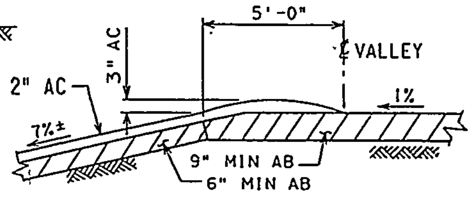
1"=1'-0"



LOCATION PLAN

SCALE: 1"=500'

MAP OF SURVEY
BY R.W. GREENWOOD ASSOCIATES, INC.
OF THE EAST ½ OF LOT 101 AND ALL OF
LOT 102 IN SECTION 30, TOWNSHIP 13
SOUTH, RANGE 18 EAST, M.D.B.&M.,
BANK OF CALIFORNIA TRACT, BOOK 5,
PAGE 13 OF PLATS, FRESNO COUNTY
RECORDS.

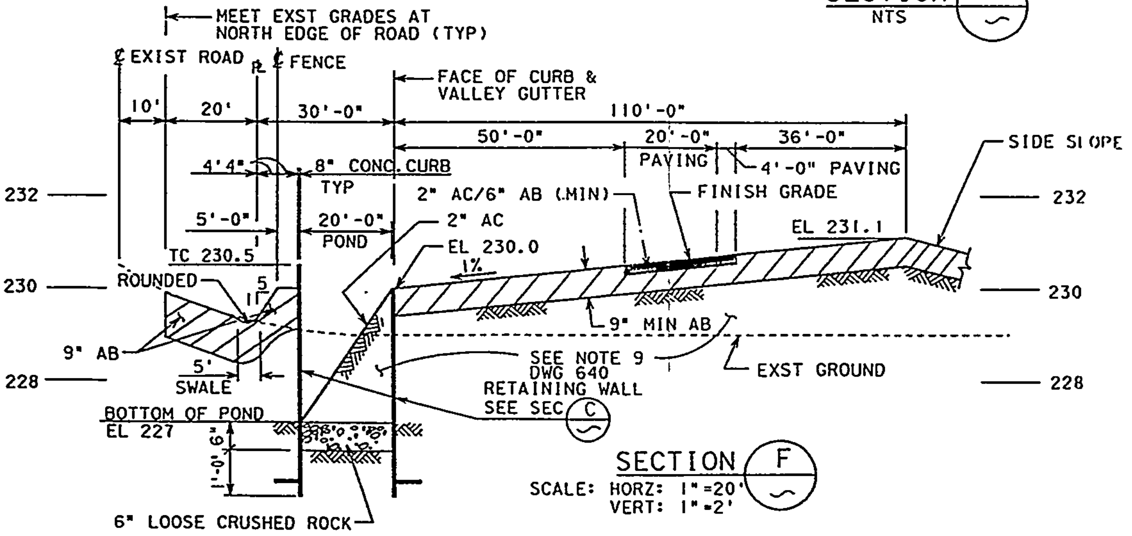


SECTION E

NTS

NOTES

1. FOR GENERAL NOTES SEE DWG 359638 AND DWG 359640
2. FOR REFERENCES AND LEGEND SEE DWG 359638.



SECTION F

SCALE: HORZ: 1"=20'
VERT: 1"=2'

C 034629
EXP. 9-30-95

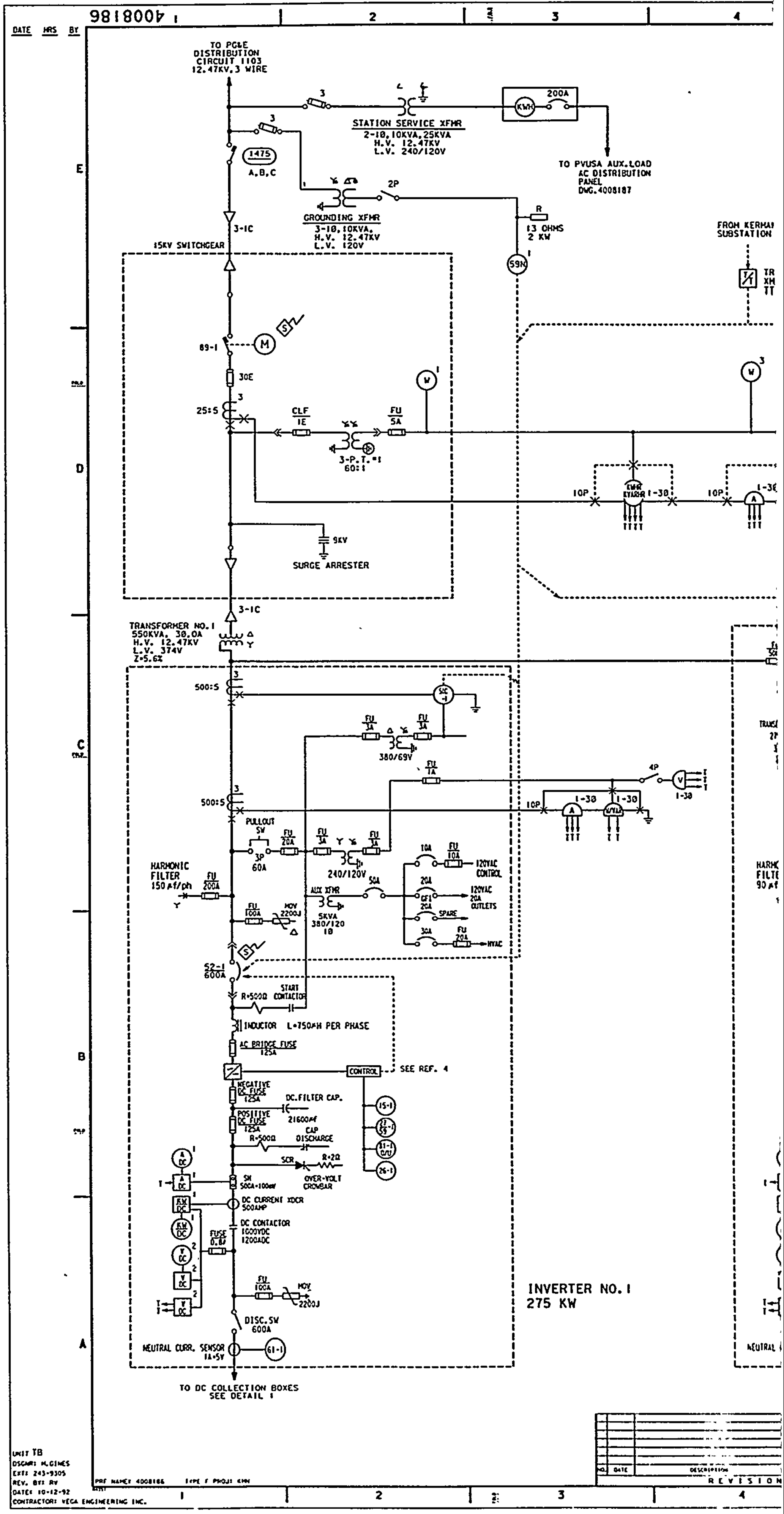
REV	DATE	DESCRIPTION	JOB NO	DSG/DWN	CHKD	SUPV	APVD
01	3/11/92	ISSUED FOR PERMIT					
1	6-23-92	APPROVED FOR CONSTRUCTION		J.R.			KSF

REVISION 1	
DSG	J. RZONCA
DWN	S. HOPKINS
CHKD	
SUPV	
APVD	Kent Ferre
APVD	
DATE	6-23-92

CIVIL
SITE IMPROVEMENTS
GRADING SECTIONS AND DETAILS
PVUSA KERMAN PHOTOVOLTAIC SITE

DEPARTMENT OF ENGINEERING
PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

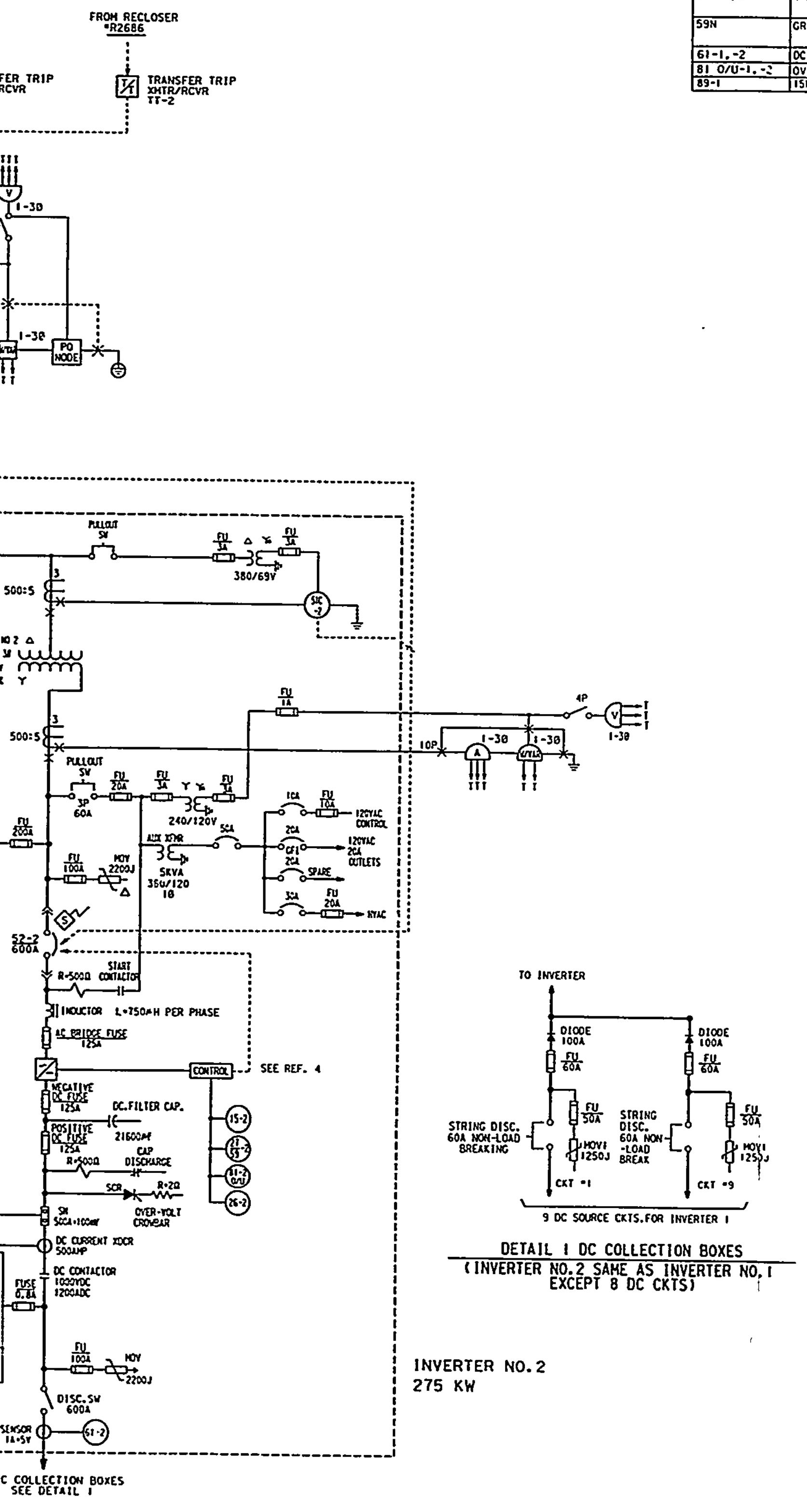
MICROFILM	
BILL OF MATL	
DWG LIST	063119
SUPSDS	
SUPSD BY	
SHEET NO	SHEETS
359639	REV 1



UNIT TB
DSGNR: M.GINES
EXT: 243-9305
REV. BY: RV
DATE: 10-12-92
CONTRACTOR: VEGA ENGINEERING INC.

TABLE OF DEVICES

DEVICE NO.	FUNCTION	RATING	MFR	TYPE	CATALOG OR REF DWG	REMARKS
AMMETER	12KV AND 380 VOLT SYSTEM AMPS	5 AMP	BITRONICS	DIGITAL	ATAIEI	
PQ NODE	POWER QUALITY/DISTURBANCE ANALYZER	120VOLT	BMI			
TT-1	TRANSFER TRIP EQPT, TRANSMIT/RECEIVE		RFL	6745		
TT-2	TRANSFER TRIP EQPT. TRANSMIT/RECEIVE		RFL	6745		
VOLTMETTER	12KV AND 380 VOLT SYSTEM VOLTS	120VOL.	BITRONICS	DIGITAL	VTAIEI	
WATT/VAR METER	380 VOLT SYSTEM	5A, 120V	BITRONICS	DIGITAL	OTWIEI	-1 TO +1 MA OUTPUT
WATT/VAR TRANS	12KV WATTS & VARS	5A, 120V	SQUARE D	8410	CLE-2080045	3 ELEM, -1 TO +1 MA OUT
KWHR/KVAR HR ME	12KV WHR/VAR HR METER		SCI Col	JEM-1	603P-J	3 ELEM, W/EXJ REG
15-1, -2	FREQUENCY MATCHING DEVICE					SEE NOTE 1
27/59-1, -2	UNDERVOLTAGE/OVERVOLTAGE RELAY					SEE NOTE 1
51C-1,2	OVERCURRENT WITH VOLTAGE CONTROL RELAY		BASLER	BEI	BEI-51/27C-LIE-Z10-BONOF	
59N	GROUND FAULT OVERVOLTAGE RELAY		BASLER	BEI	BEI-59N-A5E-EIK-C052F	SET @ 20V, 0.4SEC
61-1, -2	DC GROUND FAULT RELAY					SEE NOTE 2
81 O/U-1, -2	OVER/UNDER FREQUENCY RELAY					SEE NOTE 1
89-1	15KV METAL ENCLOSED INTERRUPTOR	600A	SQUARE D	HVL	REF. 7	95KV BIL, 40KA ASYMM



DETAIL 1 DC COLLECTION BOXES
(INVERTER NO. 2 SAME AS INVERTER NO. 1 EXCEPT 8 DC CKTS)

LEGEND

DRAWOUT OR RACKOUT DEVICE

MOTOR OPERATED DISCONNECT SWITCH WITH LOAD BREAK FEATURE

DIGITAL METER, THREE PHASE, 3 ANALOG OUTPUT
A - CURRENT
V - VOLTAGE
W/VAR - WATT/VAR

REVENUE METER WITH RE-TRANSMIT
(FOUR CHANNEL SHOWN)

TRANSDUCER, THREE PHASE, 3 ANALOG OUTPUT
W/VAR - WATT/VAR

10P TEST SWITCH, 10 POLE

INDICATING WHITE LIGHT

INVERTER (SELF COMMUTATED, PULSE WIDTH MODULATED USING 6 BRIDGES OF INSULATED GATE BIPOLAR TRANSISTORS(IGBT))

SCADA CONTROLLED EQUIPMENT

GROUNDED AT SWITCHBOARD

POTHEAD TERMINAL

NOTES

1. THESE PROTECTIVE FEATURES ARE INTEGRATED INTO THE CONTROLS OF THE UNIT. VOLTAGE & FREQUENCY FUNCTIONS HAVE TEST FEATURES TO ALLOW TESTING & CALIBRATION.
2. FOR DEVICE TYPE, RATING & CAT. NO. OF INVERTER PROTECTION SYSTEM SEE OMNION SERIES 3200 O&M MANUAL, REF 8

REFERENCES

	DWG. NO.
1. SINGLE LINE DIAGRAM STATION SERVICE	4008187
2. ELEMENTARY DIAG. -12KV MOTOR OPERATED FUSED DISC. SW	4008188
3. ELEMENTARY DIAG. -PHOTOVOLTAIC DC SYSTEM	BECHTEL REC. 19271-SC-0215-41
4. SINGLE LINE DIAGRAM-PHOTOVOLTAIC INVERTER	BECHTEL REC. 19271-SC-0215-45
5. ARRANGEMENT OF SWITCHRACKS	4008185
6. GENERAL ARRANGEMENT-OUTDOORS	4008179
7. 15KV SWITCHGEAR INSTRUCTION MANUAL	BECHTEL REC. 19271-K-E-01-1
8. INVERTER OPERATION AND MAINT. MANUAL (OMNION)	BECHTEL REC. 19271-SC-0215-81

P.G.&E. SYSTEM PHASE SEQUENCE A-C-B

DWG TYPE I
DRAWING TITLE S/L METER & RELAY DIAG
PROJECT LOCATION F I H M A N
INSTALLATION TYPE L
REVISION NAME I
DO CODE T B
CADD C

NO.	DATE	DESCRIPTION	GM/SPEC	DWN	CHKD	SUPV	APVD BY
2	10-29-93	ADDED XFMR #2 AND HARMONIC FILTERS, REV PER AS-BUILT, & MISC CORRECTIONS	6330260	LCF		RFS	
1	10/15/92	APPROVED FOR CONSTRUCTION	6330260		MSS	RFS	

REVISIONS

GM 6330260
SUPT R.F. SANTOS
DSGN VEGA ENG'G
DWN R. VALLESPIN
CHKD MSS
OK RFS
DATE 10/15/92
SCALES NONE

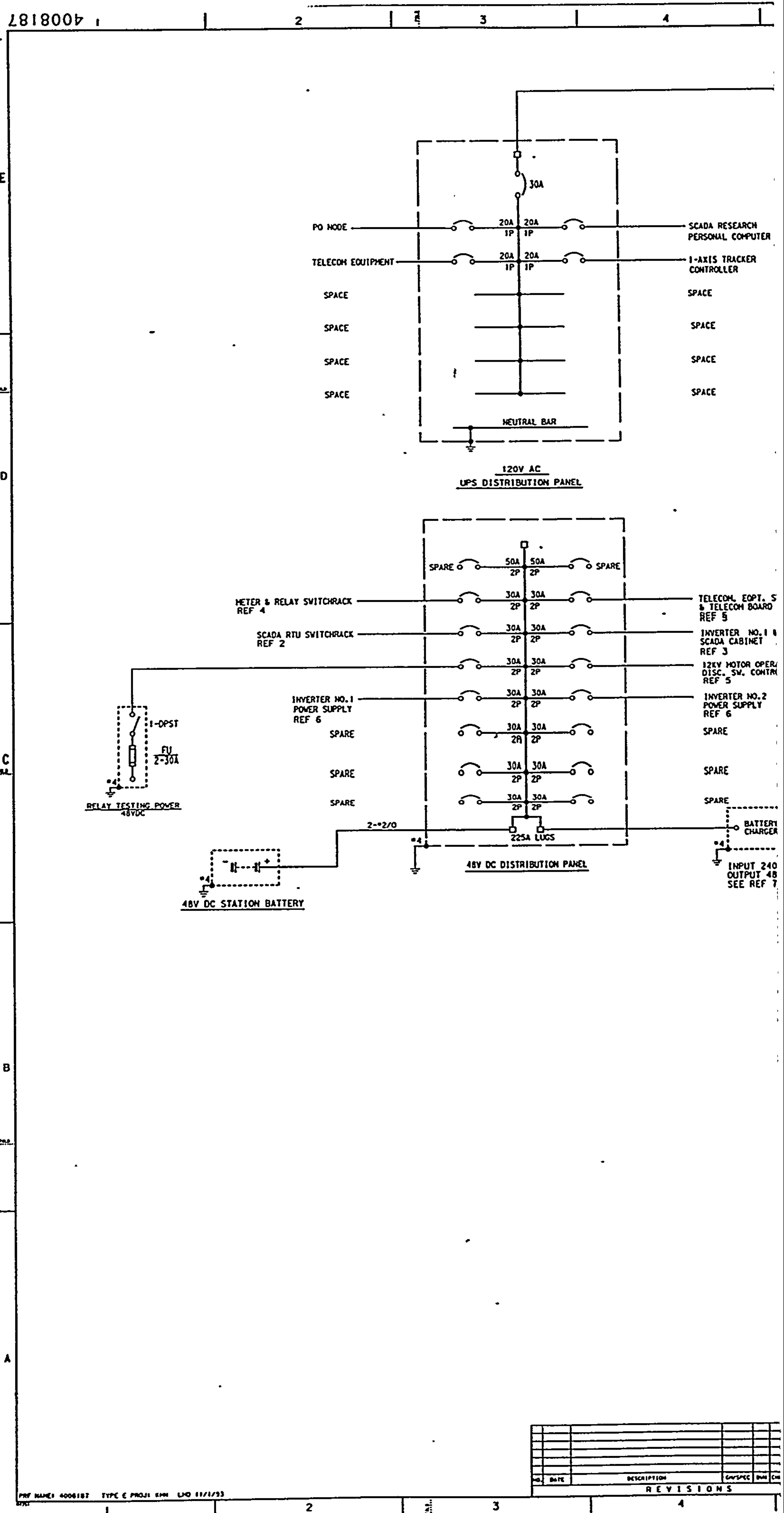
ELECTRICAL - SINGLE LINE
METER & RELAY DIAGRAM
PVUSA KERMAN PHOTOVOLTAIC PLANT

DEPARTMENT OF ENGINEERING
PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

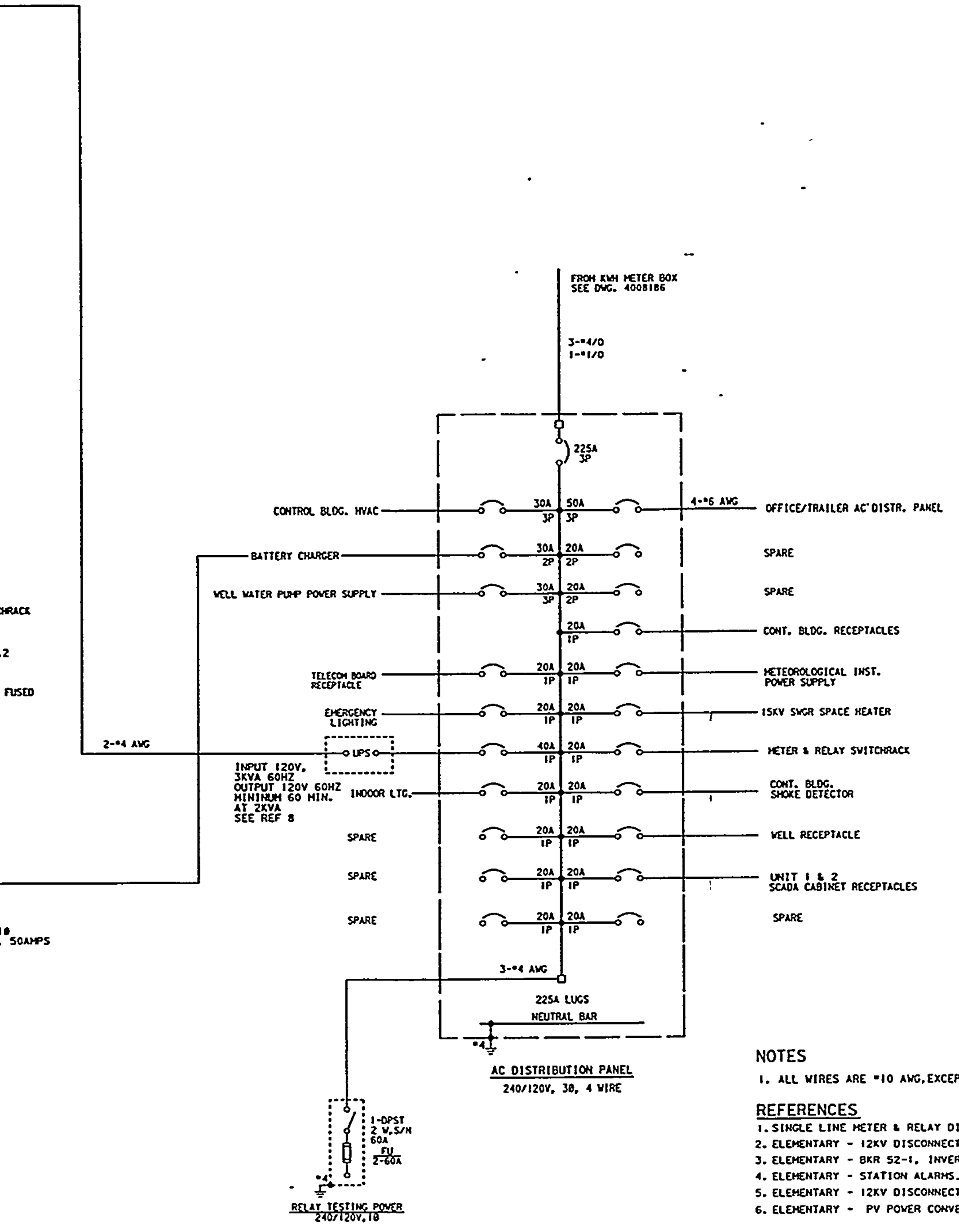
SAN JOAQUIN VALLEY REGION
MICROFILM 2
BILL OF MATL
DWG LIST 065750
SUPSDS
SUPSD BY
SHEET NO. SHEETS
4008186 REV 2

4008187

DATE HRS BY



UNIT T8
DSGNR: M.GINES
EXT: 243-9305
REV. BY: RV
DATE: 11-06-92
CONTRACTOR: VEGA ENGINEERING INC.

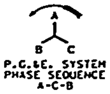


NOTES

1. ALL WIRES ARE #10 AWG,EXCEPT AS NOTED.

REFERENCES

REFERENCES	DWG.NO.
1. SINGLE LINE METER & RELAY DIAGRAM	4008186
2. ELEMENTARY - 12KV DISCONNECT SCADA CKTS	4008189
3. ELEMENTARY - BKR 52-1, INVERTER #1 & SCADA CKTS	4008190
4. ELEMENTARY - STATION ALARMS	4008192
5. ELEMENTARY - 12KV DISCONNECT & TRANSFER TRIP SCHEME	4008200
6. ELEMENTARY - PV POWER CONVERSION SYSTEM, SH 3 BECHTEL REC	19271-SC -0215-59
7. INSTRUCTION MANUAL - BATTERY CHARGER,BECHTEL REC NO	19271-SC -K-E-08-5
8. INSTRUCTION MANUAL - UPS, BECHTEL REC NO	19271-SC -K-E-011-1



P.G.&E. SYSTEM
PHASE SEQUENCE
A-C-B

DWG TYPE S | DWG SUBJECT | DRAWING TITLE SINGLE LINE DIAG STA SERVICE | UNIT NO.
PROJECT LOCATION KERMAN | INSTALLATION TYPE L | DIVISION NAME T | MISC | DD CODE TB | MAN HOURS | CADD C | DRAWING SOURCE

NO.	DATE	DESCRIPTION	CN/SPEC	DWN	CHKD	SUPV	APVD BY
2	4-29-93	REV PER FIELD AS-BUILT	6330260	CCF	–		
1	11/18/92	APPROVED FOR CONSTRUCTION	6330260		MSS	RFS	K.R.

REVISIONS

APPROVED BY K.R.
CN 6330260
SUPV R.F. SANTOS
DSGN VEGA ENG'G
DWN R.P. ATRAN
CHKD MSS
OK RFS
DATE 11/18/92
SCALES NONE

ELECTRICAL - SINGLE LINE DIAGRAM
STATION SERVICE
PVUSA KERMAN PHOTOVOLTAIC PLANT

DEPARTMENT OF ENGINEERING
PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

SAN JOAQUIN VALLEY REGION
MICROFILM 2
BILL OF MATL
DWG LIST 865754
SUPSDS
SUPSD BY
SHEET NO. SHEETS
4008187 REV 2

REVISIONS

NO.	DATE	DESCRIPTION	SPVR	GM	BY	CHKD.	APPVD.
1	10/19/92	APPROVED FOR CONSTRUCTION	RFS	6330260	VEGA/MG	GD	KJL
2	10-29-93	REV SHT'S 3 THRU 6, 8 & 9 - AS BUILT	[illegible]	5330260	CCF	/	BKF

REMOTE TERMINAL UNIT

NUMBER	MAKE (MANUFACTURER)	MODEL NUMBER
1	WESTRONIC INC.	WESDAC D20

GM:6330260

APVD. KJL

SUPV. R.F. SANTOS
DSGN. M. GINES
DWN.
CHKD. L. POLONSKY
O.K. R Santos
DATE 10-19-92

REFERENCES: SCADA DIAGRAMS: 4008189 THRU 4008191 & 4008193

SUPERVISORY CONTROL AND DATA ACQUISITION
INPUT / OUTPUT POINT ASSIGNMENT LIST
PVUSA KERMAN PHOTOVOLTAIC PLANT

DEPARTMENT OF ENGINEERING
PACIFIC GAS & ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

SUPSDS.

SUPSD. BY

SHEET 1 OF 9 SHEETS

DRAWING NUMBER	REVISION
065761	2

35 M/M NEG	2

TABLE OF CONTENTS

12 KV	DEVICE NUMBER	SHEET NO.	ELEMENTARY DIAGRAMS SCADA CONTROL	A C CIRCUITS	D C CIRCUITS
89-1		7	4008189	4008188	4008200
CONT. BLDG.		8	4008193	------	------
WEATHER STA.		9	4008193	------	------

380 V	DEVICE NUMBER	SHEET NO.	ELEMENTARY DIAGRAMS SCADA CONTROL	A C CIRCUITS	D C CIRCUITS
CB 52-1 & T1		3 & 4	4008190	------	------
CB 52-2		5 & 6	4008191	------	------

SHEET 2 OF SHTS

P G & E C O.

DRAWING NUMBER 065761

REVISION 1

PVUSA KERMAN PHOTOVOLTAIC PLANT

REVISION

MICROFILM

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
		ELEMENTARY									
CB # 52-1 & TRANSFORMER 1 INVERTER # 1	DEVICE NUMBER	SYMBOL NUMBER	DRAWING NUMBER	SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
AMPS A - PHASE	--------	1A	4008190		BITRONICS	SCADA CAB.#1	SCADA CAB.#1	D20C1-1	1	64,15	+AMP A-1, COM-A1
AMPS B - PHASE	--------	2A	"		"	"	"	"	2	16,66	+AMP B-1,
AMPS C - PHASE	--------	3A	"		"	"	"	"	3	17,67	+AMP C-1,
WATTS 3 - PHASE	--------	4A	"		"	"	"	"	4	68,19	+WATT 3ϕ-1, COM-W/V1
VARS 3 - PHASE	--------	5A	"		"	"	"	"	5	69,20	+VAR 3ϕ-1,
VOLTS A - PHASE	--------	6A	"		"	"	"	"	6	21,71	+VOLT A-1, COM-V1
VOLTS B - PHASE	--------	7A	"		"	"	"	"	7	22,72	+VOLT B-1,
VOLTS C - PHASE	--------	8A	"		"	"	"	"	8	73,24	+VOLT C-1,
DC VOLTS POSITIVE	--------	9A	"		------	PCU	"	"	9	74,25	+PDCV, -PDCV
DC VOLTS NEGATIVE	--------	10A	"		------	"	"	"	10	26,76	+NDCV, -NDCV
DC AMPS POSITIVE MONOPOLE	--------	11A	"		------	"	"	"	11	27,77	+PDCA, -PDCA
~~INVERTER ENCLOSURE TEMPERATURE~~		~~12A~~	~~"~~			~~"~~	~~"~~	~~"~~	~~12~~	~~78,29~~	~~+ITEMP, -ITEMP~~
MODULE BACK TEMPERATURE - 1 △2	--------	13A	"		------	"	"	"	13	79,30	+MTEMP-1, -MTEMP-1
MODULE BACK TEMPERATURE - 2	--------	14A	"		------	"	"	"	14	31,81	+MTEMP-2, -MTEMP-2
MODULE BACK TEMPERATURE - 3	--------	15A	"		------	"	"	"	15	32,82	+MTEMP-3, -MTEMP-3
		16A							16	83,34	
TRACK ANGLE ROW 1	--------	17A	4008190		------	SCADA CAB.#1	"	D20C2-1	1	64,15	+TAROW-1, ~~-TAROW-1~~ SC
TRACK ANGLE ROW 2	--------	18A	"		------	"	"	"	2	16,66	+TAROW-2, ~~-TAROW-2~~ SC
TRACK ANGLE ROW 3	--------	19A	"		------	"	"	"	3	17,67	+TAROW-3, ~~-TAROW-3~~ SC
TRACK ANGLE ROW 4	--------	20A	"		------	"	"	"	4	68,19	+TAROW-4, ~~-TAROW-4~~ SC
PLANE OF ARRAY IRRADIANCE	--------	21A	"		------	"	"	"	5	69,20	+POA, -POA
TRACK ANGLE ROW 5	------	22A	"		----	"	"	"	9	74,25	+TAROW-5, SC
" " " 6	------	23A	"		-----	"	"	"	10	26,76	" 6, SC
" " " 7	-----	24A	"		-----	"	"	"	11	27,77	" 7, SC
" " " 8	-----	25A	"		-----	"	"	"	12	78,29	" 8, SC
△2 " " " 9	----	26A	"		------	"	"	"	13	79,30	" 9, SC
INVERTER CONTROL - DISABLE		3C	"		I/O MOD.	"	"	D20C1-1	3	6,55	RD1-1, RD2-1
INVERTER CONTROL - RESET		4C	"		"	"	"	"	4	57,7	RR1-1, RR2-1
INVERTER CONTROL - RESTART		5C	"		"	"	"	"	5	9,58	RS1-1, RS2-1
BKR CONTROL SW (OPEN)	RE52CS-1	1C	"		CSK	SCADA CAB.#1	"	"	1	3,52	PRE-1, POP-1
" " (CLOSE)	RE52CS-1	2C	"		CSR	"	"	"	2	4	RCL-1

SHEET 3 OF SHEETS

P G & E C O

DRAWING NUMBER 0 6 5 7 6 1

REVISION 2

P V U S A K E R M A N P H O T O V O L T A I C P L A N T

MICROFILM

REVISION 2

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
CB # 52-1 & TRANSFORMER 1 INVERTER # 1	DEVICE NUMBER	ELEMENTARY SYMBOL NUMBER	ELEMENTARY DRAWING NUMBER	ELEMENTARY SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
BREAKER STATUS (OPEN)	52X-1	1S	4008190		AUX. RLY	PCU	SCADA CAB.#1	D20C1-1	1	84,35	KSCOM-11,KOP-1
LOCAL/REMOTE SW STATUS (LOCAL)	43LR-1	2S	"		ELECTRO.SW	"	"	"	2	36	KLR-1
PCS ON		3S	"		PCS	"	"	"	3	37	K1-1
PCS STANDBY/READY		4S	"		"	"	"	"	4	38	K2-1
PCS STANDBY/FAULT		5S	"		"	"	"	"	5	39	K3-1
PCS SHUTDOWN		6S	"		"	"	"	"	6	40	K4-1
PCS OVER-TEMPERATURE-		7S	"		"	"	"	"	7	41	K5-1
DC GROUND FAULT		8S	"		"	"	"	"	8	42	K6-1
SMOKE DETECTED		9S	"		"	"	"	"	9	43	KSCOM-12,K7-1
PCS FAULT		10S	"		"	"	"	"	10	44	K8-1
SYNC FAILURE- PCS IN SCADA /AUTO		11S	"		"	"	"	"	11	45	K9-1
		12S	"		"	"	"	"	12	46	K10-1
MAIN TRANSFORMER 1 HIGH TEMP	49-T1	13S	"		---	XFMR CAB	"	"	13	47	KHT-T1
PCS FAN FAILURE WARNING.		14S	"		PCS	PCU	"	"	14	48	K11-1

SHEET 4 OF SHEETS	DRAWING NUMBER	REVISION		REVISION
P G & E CO	0 6 5 7 6 1	2	PVUSA KERMAN PHOTOVOLTAIC PLANT	MICROFILM 2

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
CB # 52-2 INVERTER # 2	DEVICE NUMBER	ELEMENTARY SYMBOL NUMBER	ELEMENTARY DRAWING NUMBER	ELEMENTARY SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
AMPS A - PHASE	--------	1A	4008191		BITRONICS	SCADA CAB.#2	SCADA CAB.#2	D20C1-2	1	64,15	+AMP A-2, COM-A2
AMPS -B - PHASE	--------	2A	"		"	"	"	"	2	16,66	+AMP B-2,
AMPS C - PHASE	--------	3A	"		"	"	"	"	3	17,67	+AMP C-2,
WATTS 3 - PHASE	--------	4A	"		"	"	"	"	4	68,19	+WATT 3ϕ-2, COM-W/V2
VARS 3 - PHASE	--------	5A	"		"	"	"	"	5	69,20	+VAR 3ϕ-2,
VOLTS A - PHASE	--------	6A	"		"	"	"	"	6	21,71	+VOLT A-2, COM-V2
VOLTS B - PHASE	--------	7A	"		"	"	"	"	7	22,72	+VOLT B-2,
VOLTS C - PHASE	--------	8A	"		"	"	"	"	8	73,24	+VOLT C-2,
DC VOLTS POSITIVE	--------	9A	"		------	PCU	"	"	9	74,25	+PDCV, -PDCV
DC VOLTS NEGATIVE	--------	10A	"		------	"	"	"	10	26,76	+NDCV, -NDCV
DC AMPS POSITIVE MONOPOLE -	--------	11A	"		------	"	"	"	11	27,77	+PDCA, -PDCA
~~INVERTER ENCLOSURE TEMPERATURE~~	~~--------~~	~~12A~~	~~"~~		~~------~~	~~"~~	~~"~~	~~"~~	~~12~~	~~78,29~~	~~+ITEMP, -ITEMP~~
2		13A							13	79,30	
		14A							14	31,81	
		15A							15	32,82	
		16A							16	83,34	
~~TRACK ANGLE ROW 5~~	~~--------~~	~~17A~~	~~4008191~~			~~PCU~~	~~"~~	~~D20C2-2~~	~~1~~	~~64,15~~	~~+TAROW-5, -TAROW-5~~
~~TRACK ANGLE ROW 6~~		~~18A~~	~~"~~			~~"~~	~~"~~	~~"~~	~~2~~	~~16,66~~	~~+TAROW-6, -TAROW-6~~
~~TRACK ANGLE ROW 7~~		~~19A~~	~~"~~			~~"~~	~~"~~	~~"~~	~~3~~	~~17,67~~	~~+TAROW-7, -TAROW-7~~
~~TRACK ANGLE ROW 8~~		~~19A~~	~~"~~			~~"~~	~~"~~	~~"~~	~~4~~	~~68,19~~	~~+TAROW-8, -TAROW-8~~
~~TRACK ANGLE ROW 9~~		~~19A~~	~~"~~			~~"~~	~~"~~	~~"~~	~~5~~	~~69,20~~	~~+TAROW-9, -TAROW-9~~
2											
BKR CONTROL SWITCH (OPEN)	RE52CS-2	1C	"		CSR	SCADA CAB.#2	"	D20C2-2	1	3,52	PRE-2, ROP-2
BKR CONTROL SWITCH (CLOSE)	RE52CS-2	2C	"		CSR	"	"	"	2	4	RCL-2
INVERTER CONTROL - DISABLE		3C	"		I/O MOD.	"	"	"	3	6,55	RD1-2, RD2-2
INVERTER CONTROL - RESET		4C	"		"	"	"	"	4	57,7	RR1-2, RR2-2
INVERTER CONTROL - RESTART		5C	"		"	"	"	"	5	9,58	RS1-2, RS2-2

SHEET 5 OF SHEETS	DRAWING NUMBER	REVISION	PVUSA KERMAN PHOTOVOLTAIC PLANT	REVISION
P G & E C O	0 6 5 7 6 1	2	MICROFILM	2

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
CB # 52-2 INVERTER # 2		ELEMENTARY									
	DEVICE NUMBER	SYMBOL NUMBER	DRAWING NUMBER	SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
BREAKER STATUS (OPEN)	52X-2	1S	4008191		AUX. RLY	PCU	SCADA CAB.#2	D20C1-2	1	84,35	KSCOM-21,KOP-2
LOCAL/REMOTE SW STATUS (LOCAL)	43LR-2	2S	"		ELECTRO.SW	"	"	"	2	36	KLR-2
PCS ON		3S	"		PCS	"	"	"	3	37	K1-2
PCS STANDBY/READY		4S	"		"	"	"	"	4	38	K2-2
PCS STANDBY/FAULT		5S	"		"	"	"	"	5	39	K3-2
PCS SHUTDOWN		6S	"		"	"	"	"	6	40	K4-2
PCS OVER-TEMPERATURE		7S	"		"	"	"	"	7	41	K5-2
DC GROUND FAULT		8S	"		"	"	"	"	8	42	K6-2
SMOKE DETECTED		9S	"		"	"	"	"	9	43	KSCOM-22,K7-2
PCS FAULT		10S	"		"	"	"	"	10	44	K8-2
SYNC FAILURE		11S	"		"	"	"	"	11	45	K9-2
PCS IN SCADA/AUTO		12S	"		"	"	"	"	12	46	K10-2
FAN FAILURE WARNING		13S	"		PCS	"	"	"	13	47	K11-2

SHEET 6 OF SHEETS	DRAWING NUMBER	REVISION		REVISION
P G & E CO	065761	2	PVUSA KERMAN PHOTOVOLTAIC PLANT	MICROFILM 2

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
89-1 12KV MOTOR OPER. FUSED DISC. SW.	DEVICE NUMBER	ELEMENTARY SYMBOL NUMBER	ELEMENTARY DRAWING NUMBER	ELEMENTARY SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
AMPS A - PHASE	....	1A	4008189		BITRONICS	SWITCH RACK	SCADA SWRACK	D20C1	1	64,15	+AMP A-1, COM-A1
AMPS B - PHASE	....	2A	"		"	"	"	"	2	16,66	+AMP B-1,
AMPS C - PHASE	....	3A	"		"	"	"	"	3	17,67	+AMP C-1,
WATTS 3 - PHASE	....	4A	"		SQUARE D	"	"	"	4	68,19	+WATT 3ϕ-1, -WATT 3ϕ-1
VARS 3 - PHASE	....	5A	"		"	"	"	"	5	69,20	+VAR 3ϕ-1, -VAR 3ϕ-1
VOLTS A - PHASE	....	6A	"		BITRONICS	"	"	"	6	21,71	+VOLT A-1, COM-V1
VOLTS B - PHASE	....	7A	"		"	"	"	"	7	22,72	+VOLT B-1,
VOLTS C - PHASE	....	8A	"		"	"	"	"	8	73,24	+VOLT C-1,
BKR CONTROL SWITCH (OPEN)	RE89CS-1	1C	"		CSR	"	"	"	1	3,52	PRE-1, ROP-1
BKR CONTROL SWITCH (CLOSE)	RE89CS-1	2C	"		CSR	"	"	"	2	4	RCL-1
JEM KWH PULSE OUT	JEM	1S	"		SCI.COL.	"	"	"	1	84,35	KSCOM, K1,
JEM KWH PULSE IN.	"	2S	"		"	"	"	"	2	36	K2
JEM KVARH PULSE OUT	"	3S	"		"	"	"	"	3	37	K3
JEM KVARH PULSE IN	"	4S	"		"	"	"	"	4	38	K4
		5S							5	39	
		6S							6	40	
		7S							7	41	
		8S							8	42	
BREAKER STATUS (OPEN)	89X-1	9S	4008189		AVR	"	"	D20C1	9	92,43	KSCOM-1, KOP-1
LOCAL/REMOTE SW STATUS (LOCAL)	43LR-1	10S	"		ELECTRO.SW	"	"	"	10	44	KLR-1
RELAY FLAG - GROUND FAULT	59N-1	11S	"		BE1	"	"	"	11	45	KGF-1
T/T TRANSMIT FAIL (KERMAN S/S)	RFL6580	12S	"		RFL	"	"	"	12	46	KTTTF-1
T/T RECEIVE FAIL (KERMAN S/S)	"	13S	"		"	"	"	"	13	47	KTTRF-1
T/T TRANSMIT FAIL (RECLOSER)	" (R2686)	14S	"		"	"	"	"	14	48	KTTTR-1
T/T RECEIVE FAIL (RECLOSER)	" "	15S	"		"	"	"	"	15	49	KTTRR-1

SHEET 7 OF SHEETS

P G & E CO

DRAWING NUMBER 0 6 5 7 6 1

REVISION 1

PVUSA KERMAN PHOTOVOLTAIC PLANT

REVISION 1

MICROFILM

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
		ELEMENTARY									
CONTROL BUILDING	DEVICE NUMBER	SYMBOL NUMBER	DRAWING NUMBER	SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
~~STATION BATTERY VOLTS~~ △2		~~1A~~	~~4008193~~		~~DC XDCR~~	~~AUX. PNL.~~	~~SCADA RTU~~	~~D20A1~~	~~1~~	~~1,51~~	~~+VDC, -VDC~~
~~CONTROL BLDG. TEMPERATURE~~		~~2A~~	~~"~~		~~TEMP.CONTR~~	~~SWRACK~~	~~"~~	~~"~~	~~2~~	~~3,53~~	~~+T1, -T1~~
SITE SECURITY- CONT. BLDG.-SMOKE		1S	"		SMOKE DET.	CONT.BLDG	"	D20S1	1	67,1	KSCOM, K1
~~" " " " INTRUSION~~		~~2S~~	~~"~~		~~DOOR SW~~	~~"~~	~~"~~	~~"~~	~~2~~	~~2~~	~~K2~~
~~CONTROL BLDG. HIGH TEMPERATURE~~		~~3S~~	~~"~~		~~TEMP.CONTR~~	~~SWRACK~~	~~"~~	~~"~~	~~3~~	~~3~~	~~K3~~
UPS INPUT FAILURE △2		4S	"		......	CONT.BLDG	"	"	4	4	K4
UPS ON BYPASS		5S	"		......	"	"	"	5	5	K5
UPS TROUBLE		6S	"		......	"	"	"	6	6	K6
~~DATABASE COMPUTER #1 TROUBLE~~		~~7S~~	~~"~~		~~......~~	~~TRAILER~~	~~"~~	~~"~~	~~7~~	~~7~~	~~K7~~
~~DATABASE COMPUTER #2 TROUBLE~~		~~8S~~	~~"~~			~~"~~	~~"~~	~~"~~	~~8~~	~~8~~	~~K8~~
TRAILER HIGH TEMPERATURE - △2		9S	"		TEMP.CONTR	"	"	"	9	75,9	KSCOM-1,K9
TRAILER SMOKE		10S	"		SMOKE DET.	"	"	"	10	10	K10
~~RELAY FLAG - AUX. POWER UNDERVOLTAGE~~	~~27AG~~	~~11S~~	~~"~~		~~......~~	~~AUX PNL~~	~~"~~	~~"~~	~~11~~	~~11~~	~~K11~~
~~RELAY FLAG STATION BATTERY UNDERVOLTAGE~~	~~27DC~~	~~12S~~	~~"~~			~~"~~	~~"~~	~~"~~	~~12~~	~~12~~	~~K12~~
~~RELAY FLAG BATTERY CHARGER TROUBLE~~		~~13S~~	~~"~~		~~......~~	~~CONT.BLDG~~	~~"~~	~~"~~	~~13~~	~~13~~	~~K13~~
ANNUNCIATOR FAILURE △2	30	14S	"		......	SWRACK	"	"	14	14	K14
SITE SECURITY · SYSTEM ARMED·	(FUTURE)										
" " · POWER SUPPLY	"										
" " · SYSTEM TROUBLE	"										
" " · SPARE	"										

SHEET 8 OF SHEETS	DRAWING NUMBER	REVISION		
P G & E C O	0 6 5 7 6 1	2	PVUSA KERMAN PHOTOVOLTAIC PLANT	MICROFILM
				REVISION 3

DESCRIPTION	SWITCHBOARD DEVICES						REMOTE TERMINAL UNIT				
WEATHER STATION	DEVICE NUMBER	ELEMENTARY SYMBOL NUMBER	ELEMENTARY DRAWING NUMBER	ELEMENTARY SECTION NUMBER	RELAY OR SWITCH TYPE	PANEL NO	PANEL DES	MODULE /BLOCK NUMBER	CHAN NO	TERMINAL NUMBER	WIRE DESIGNATIONS
I-AXIS TRACKER IRRADIANCE	--------	1A	4008193		METEOR. EQPT.	METEOR. STATION	SCADA RTU	D20A1	3	4,54	+IATI, -IATI
GLOBAL HORIZONTAL IRRADIANCE	--------	2A	"		"	"	"	"	4	6,56	+GHI, -GHI
DIRECT NORMAL INCIDENCE IRRADIANCE	--------	3A	"		"	"	"	"	5	7,57	+DNII, -DNII
WIND SPEED	--------	4A	"		"	"	"	"	6	9,59	+WS, -WS
WIND DIRECTION	--------	5A	"		"	"	"	"	7	10,60	+WD, -WD
AMBIENT TEMPERATURE	--------	6A	"		"	"	"	"	8	12,62	+AT, -AT
~~PLANE OF ARRAY IRRADIANCE~~	~~--------~~	~~7A~~	~~"~~		~~"~~	~~"~~	~~"~~	~~"~~	~~9~~	~~13,63~~	~~+POA, -POA~~
RELATIVE HUMIDITY	--------	8A	"		"	"	"	"	10	15,65	+RH, -RH
~~I-AXIS TRACKER RESET~~ △2	~~--------~~	~~1C~~	~~"~~		~~"~~	~~SWRACK~~	~~"~~	~~D20C1~~	~~3~~	~~6,55~~	~~ATR1, ATR2~~
I-AXIS TRACKER TROUBLE	--------	1S	"		"	"	"	"	16	99,50	KSCOM-1,K16
DATA ID NUMBER	--------	---	"		"	METEOR. STATION	"	-----	--	-----	-------
SITE NUMBER	--------	"	"		"	"	"	"	--	-----	-------
YEAR	--------	"	"		"	"	"	"	--	-----	-------
DAY	--------	"	"		"	"	"	"	--	-----	-------
HOUR/MINUTES	--------	"	"		"	"	"	"	--	-----	-------
SECONDS	--------	"	"		"	"	"	"	--	-----	-------
REDUND WATTS		A			CSI	SWRACK	"	D20A1	15	22,72	+WATTS, -WATTS
REDUND VARS △2		A			CSI	SWRACK	"	"	16	24,74	+VARS, -VARS

SHEET 9 OF 9 SHEETS	DRAWING NUMBER	REVISION		REVISION
P G & E C O	0 6 5 7 6 1	2	PVUSA KERMAN PHOTOVOLTAIC PLANT	MICROFILM 2

Appendix B

SCHEDULES

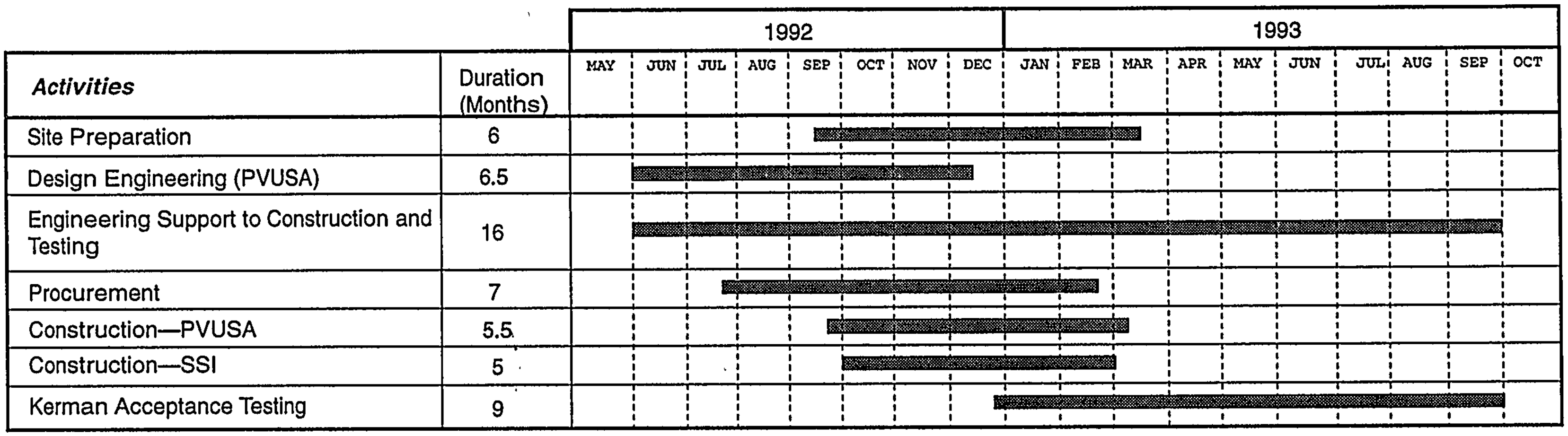
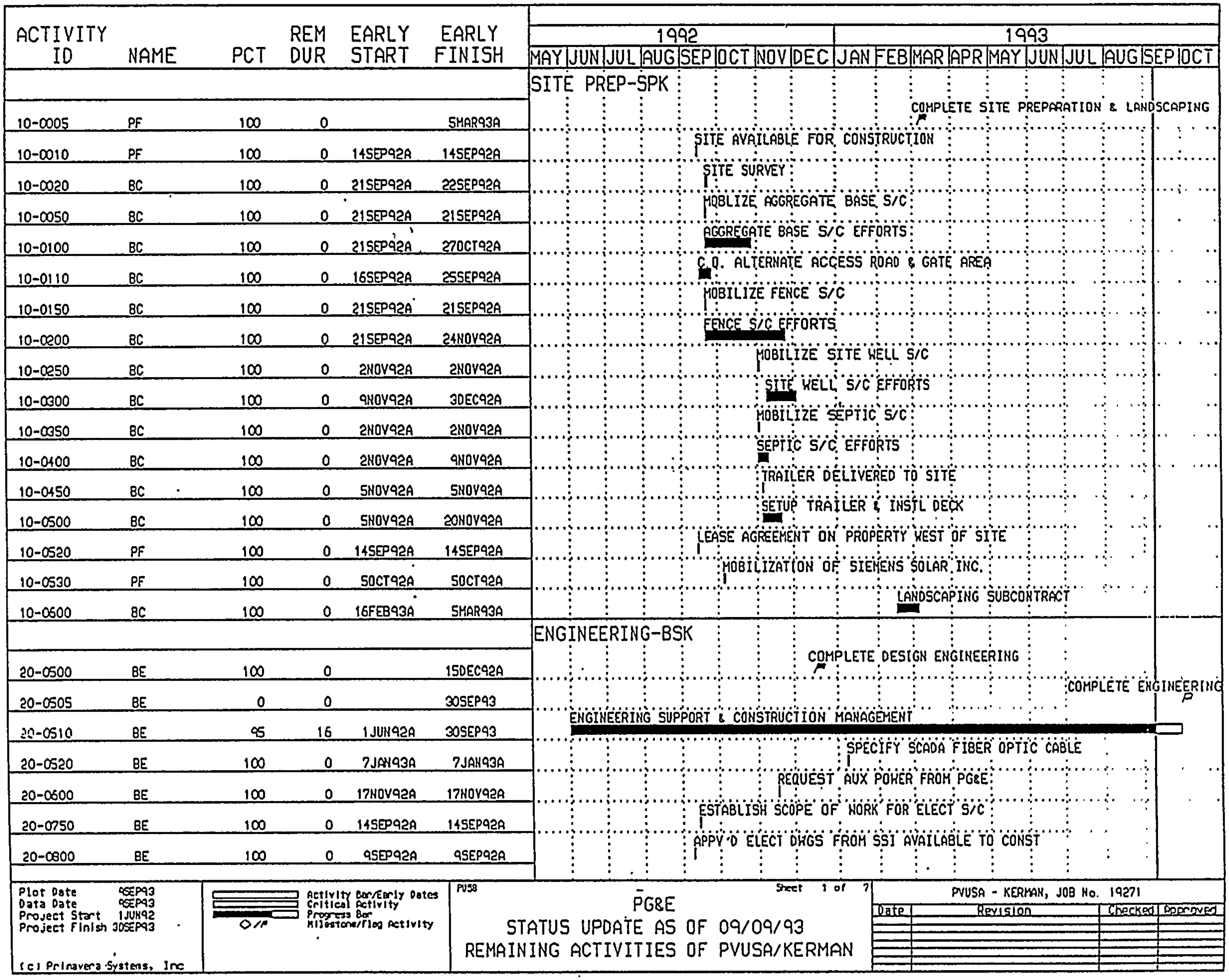


Figure B-1. PVUSA Kerman summary schedule.



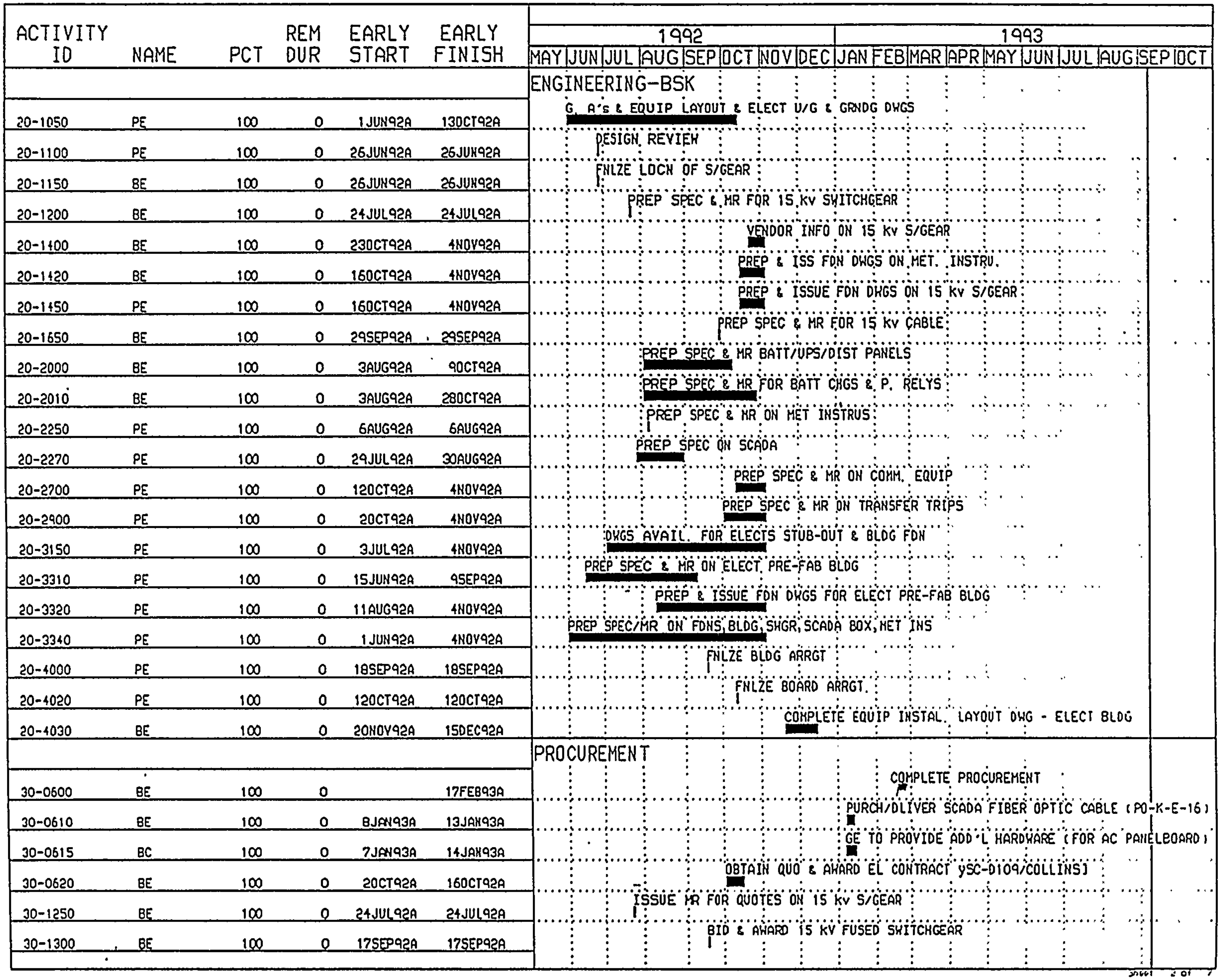
ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH
10-0005	PF	100	0		5MAR93A
10-0010	PF	100	0	14SEP92A	14SEP92A
10-0020	BC	100	0	21SEP92A	22SEP92A
10-0050	BC	100	0	21SEP92A	21SEP92A
10-0100	BC	100	0	21SEP92A	27OCT92A
10-0110	BC	100	0	16SEP92A	25SEP92A
10-0150	BC	100	0	21SEP92A	21SEP92A
10-0200	BC	100	0	21SEP92A	24NOV92A
10-0250	BC	100	0	2NOV92A	2NOV92A
10-0300	BC	100	0	9NOV92A	3DEC92A
10-0350	BC	100	0	2NOV92A	2NOV92A
10-0400	BC	100	0	2NOV92A	9NOV92A
10-0450	BC	100	0	5NOV92A	5NOV92A
10-0500	BC	100	0	5NOV92A	20NOV92A
10-0520	PF	100	0	14SEP92A	14SEP92A
10-0530	PF	100	0	5OCT92A	5OCT92A
10-0600	BC	100	0	16FEB93A	5MAR93A
20-0500	BE	100	0		15DEC92A
20-0505	BE	0	0		30SEP93
20-0510	BE	95	16	1JUN92A	30SEP93
20-0520	BE	100	0	7JAN93A	7JAN93A
20-0600	BE	100	0	17NOV92A	17NOV92A
20-0750	BE	100	0	14SEP92A	14SEP92A
20-0800	BE	100	0	9SEP92A	9SEP92A

Plot Date 9SEP93
Data Date 9SEP93
Project Start 1JUN92
Project Finish 30SEP93

(c) Primavera Systems, Inc

PG&E
STATUS UPDATE AS OF 09/09/93
REMAINING ACTIVITIES OF PVUSA/KERMAN

Figure B-2. PVUSA Kerman detailed schedule.



ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH
20-1050	PE	100	0	1JUN92A	13OCT92A
20-1100	PE	100	0	26JUN92A	26JUN92A
20-1150	BE	100	0	26JUN92A	26JUN92A
20-1200	BE	100	0	24JUL92A	24JUL92A
20-1400	BE	100	0	23OCT92A	4NOV92A
20-1420	BE	100	0	16OCT92A	4NOV92A
20-1450	PE	100	0	16OCT92A	4NOV92A
20-1650	BE	100	0	29SEP92A	29SEP92A
20-2000	BE	100	0	3AUG92A	9OCT92A
20-2010	BE	100	0	3AUG92A	28OCT92A
20-2250	PE	100	0	6AUG92A	6AUG92A
20-2270	PE	100	0	29JUL92A	30AUG92A
20-2700	PE	100	0	12OCT92A	4NOV92A
20-2900	PE	100	0	2OCT92A	4NOV92A
20-3150	PE	100	0	3JUL92A	4NOV92A
20-3310	PE	100	0	15JUN92A	9SEP92A
20-3320	PE	100	0	11AUG92A	4NOV92A
20-3340	PE	100	0	1JUN92A	4NOV92A
20-4000	PE	100	0	18SEP92A	18SEP92A
20-4020	PE	100	0	12OCT92A	12OCT92A
20-4030	BE	100	0	20NOV92A	15DEC92A
30-0600	BE	100	0		17FEB93A
30-0610	BE	100	0	8JAN93A	13JAN93A
30-0615	BC	100	0	7JAN93A	14JAN93A
30-0620	BE	100	0	2OCT92A	16OCT92A
30-1250	BE	100	0	24JUL92A	24JUL92A
30-1300	BE	100	0	17SEP92A	17SEP92A

Figure B-2. PVUSA Kerman detailed schedule (continued).

ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH	
						PROCUREMENT
30-1350	BE	100	0	4NOV92A	18NOV92A	VEND PRINT SUBMITTAL, RVW & APPVL 15 kv S/GEAR
30-1550	BE	100	0	30NOV92A	25JAN93A	FAB & DEL 15 Kv FUSED S/GEAR KERMAN yPO-K-E-01]
30-1700	BE	100	0	29SEP92A	14OCT92A	TELEPHONE QUOTES & AWARD PO FOR 15 Kv CABLE
30-1750	BE	100	0	29SEP92A	4NOV92A	DELIVER 15Kv CABLE yK-E-12]
30-2100	BE	100	0	12OCT92A	12OCT92A	ISSUE RFQ ON BATT/UPS/DIST PANELS
30-2110	BE	100	0	28OCT92A	8NOV92A	ISSUE RFQ ON BATT CHGS & P RELYS
30-2150	BE	100	0	16OCT92A	13NOV92A	BID & AWARD BATTERY/CHARGER yPO-K-E-02 & 08]
30-2155	BE	100	0	13NOV92A	6JAN93A	FAB & DEL BATTERY STACKS(4)TO KERMAN yK-E-02]
30-2157	BE	100	0	13NOV92A	16FEB93A	FAB/SHIP/DEL BATTERY CHARGER TO KERMAN yK-E-08]
30-2160	BE	100	0	8NOV92A	10DEC92A	BID & AWARD DISTRIBUTION PANELBOARDS yPO-K-E-13]
30-2161	BE	100	0	10DEC92A	23DEC92A	FAB & DEL AC DIST PANELy1] TO KERMAN yPO-K-E-13]
30-2165	BE	100	0	10DEC92A	23DEC92A	FAB & DEL DIST PANELBOARDS TO KERMAN yPO-K-E-13]
30-2210	BE	100	0	25NOV92A	10DEC92A	BID & AWARD UPS yPO-K-E-11]
30-2220	BE	100	0	10DEC92A	23DEC92A	FAB & DEL UPS TO KERMAN yPO-K-E-11]
30-2350	PE	100	0	6AUG92A	20AUG92A	AWARD PO MET INSTRMTS yPG&E PO]
30-2450	PE	100	0	21SEP92A	2NOV92A	FAB SHIP & DEL MET INSTRUS TO KERMAN
30-2800	PE	100	0	8AUG92A	17SEP92A	AWARD COMM EQUIP -PARTIAL ASSIGN(P.A.)- PG&E
30-2850	PE	100	0	17SEP92A	22JAN93A	FAB SHIP & DEL COMM EQUIP TO KERMAN
30-3000	PE	100	0	8AUG92A	17SEP92A	AWARD TRANSFER TRIP-PARTIAL ASSIGN (P.A.)-PG&E
30-3100	PE	100	0	5NOV92A	3FEB93A	FAB SHIP & DEL TRANSFER TRIP TO KERMAN
30-3110	PE	100	0	11DEC92A	22DEC92A	PG&E PO-LEASE LINE FOR TRANSFER TRIP
30-3120	PE	100	0	18JAN93A	3FEB93A	SHIP/DELIVER LEASE LINE FOR TRANSFER TRIP yPG&E]
30-3200	BE	100	0	4NOV92A	11NOV92A	AWARD S/C FDNS FOR BLDG,SWGR,SCADA & MET INSTR
30-3250	PE	100	0	21SEP92A	28SEP92A	BID & AWARD ELECT PRE-FAB BLDG
30-3300	BE	100	0	7OCT92A	30NOV92A	FAB SHIP & DEL ELECT PRE-FAB BLDG TO KERMAN
30-4050	PE	100	0	11SEP92A	11SEP92A	AWARD SCADA EQUIP PARTIAL ASSIGN (P.A.)-PG&E
30-4060	PE	100	0	2NOV92A	30NOV92A	FAB/DEL TRIPLEX AMME./VOLTM.R TO DAVIS yK-E-03]
30-4100	PE	100	0	10OCT92A	2DEC92A	FAB SCADA EQUIPMENT AND CABINETS (2)

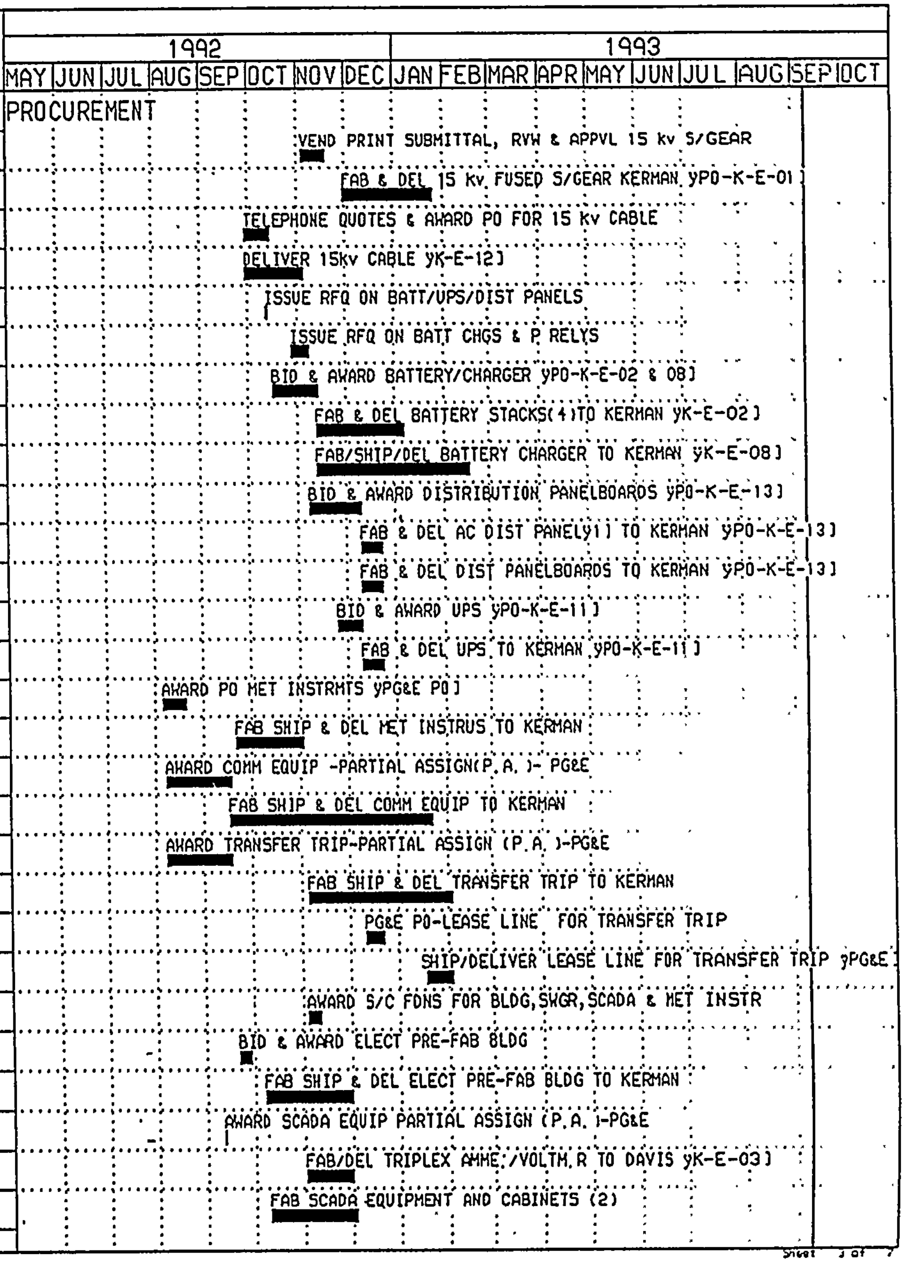


Figure B-2. PVUSA Kerman detailed schedule (continued).

ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH
30-4105	PE	100	0	7DEC92A	9DEC92A
30-4110	PE	100	0	3DEC92A	8JAN93A
30-4120	BE	100	0	10OCT92A	5NOV92A
30-4125	BE	100	0	11SEP92A	29SEP92A
30-4130	BE	100	0	11SEP92A	29SEP92A
30-4135	BE	100	0	11SEP92A	9OCT92A
30-4140	BE	100	0	10OCT92A	2NOV92A
30-4145	BE	100	0	5NOV92A	16DEC92A
40-0400	BC	100	0		5MAR93A
40-0510	BC	100	0	17OCT92A	5MAR93A
40-0511	BC	100	0	2NOV92A	8JAN93A
40-0512	BC	100	0	11NOV92A	12NOV92A
40-0514	BC	100	0	10NOV92A	12NOV92A
40-0516	BC	100	0	16NOV92A	18NOV92A
40-0518	BC	100	0	19NOV92A	24NOV92A
40-0520	BC	100	0	16NOV92A	19NOV92A
40-0522	BC	100	0	16NOV92A	19NOV92A
40-0524	BC	100	0	18NOV92A	18NOV92A
40-0526	BC	100	0	18NOV92A	19NOV92A
40-0528	BC	100	0	5NOV92A	6NOV92A
40-0530	BC	100	0	6NOV92A	6NOV92A
40-0532	BC	100	0	18NOV92A	24NOV92A
40-0534	BC	100	0	1DEC92A	14DEC92A
40-0536	BC	100	0	30NOV92A	11DEC92A
40-0538	BC	100	0	25NOV92A	1DEC92A
40-0540	PF	100	0	15DEC92A	23DEC92A
40-0542	BC	100	0	30NOV92A	4JAN93A

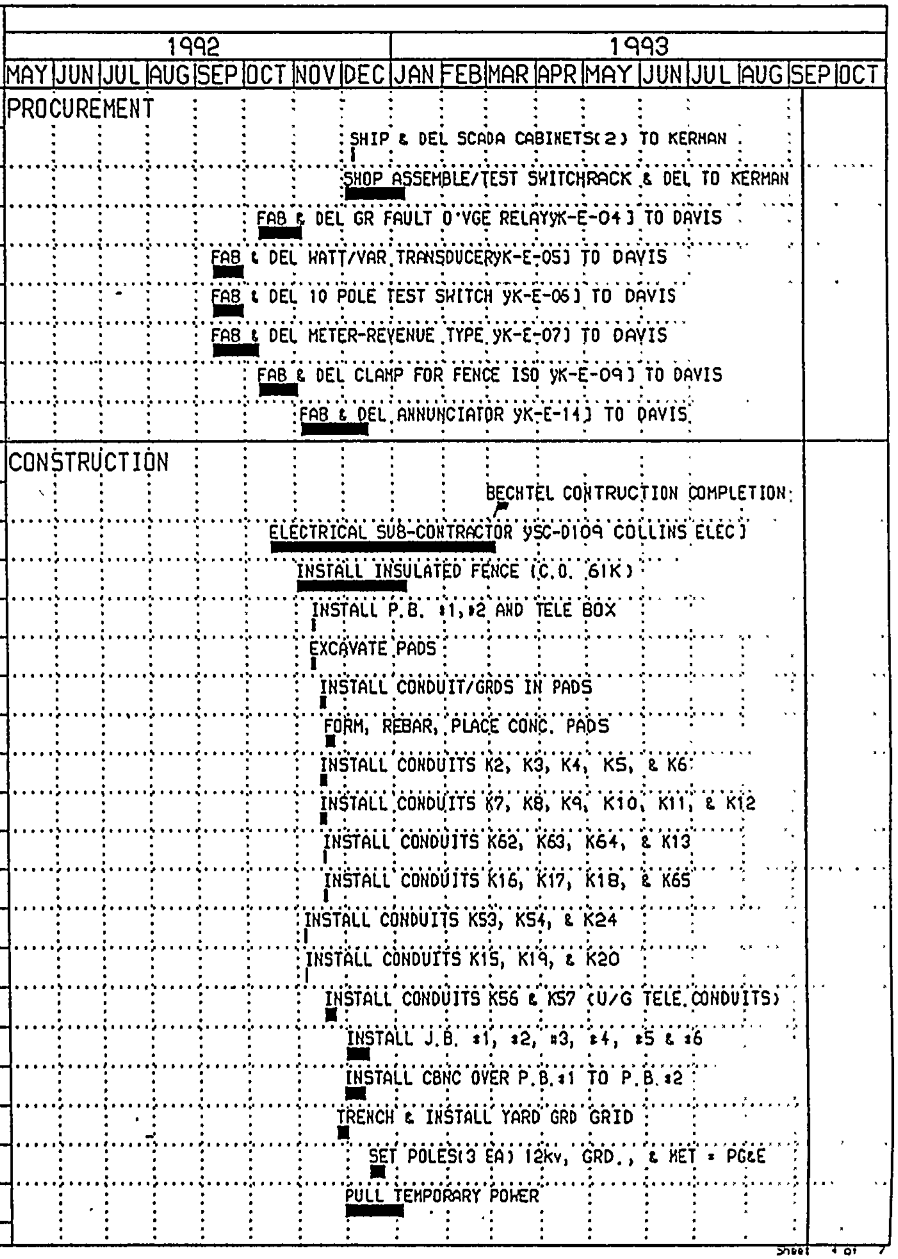


Figure B-2. PVUSA Kerman detailed schedule (continued).

ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH
40-0544	BC	100	0	15DEC92A	28DEC92A
40-0546	BC	100	0	30NOV92A	3DEC92A
40-0548	BC	100	0	7DEC92A	6JAN93A
40-0554	PF	100	0	19JAN93A	20JAN93A
40-0556	BC	100	0	22JAN93A	25JAN93A
40-0558	PF	100	0	15DEC92A	24DEC92A
40-0560	BC	100	0	2DEC92A	9DEC92A
40-0562	BC	100	0	4DEC92A	14DEC92A
40-0564	BC	100	0	8DEC92A	14DEC92A
40-0650	BC	100	0	25NOV92A	30NOV92A
40-0700	PF	100	0	12NOV92A	12NOV92A
40-0900	BC	100	0	15DEC92A	20DEC92A
40-1500	BC	100	0	23NOV92A	24NOV92A
40-1510	BC	100	0	29DEC92A	30DEC92A
40-1600	BC	100	0	25JAN93A	25JAN93A
40-1800	BC	100	0	14DEC92A	16DEC92A
40-2500	PF	100	0	8FEB93A	19FEB93A
40-3350	BC	100	0	23NOV92A	24NOV92A
40-3370	BC	100	0	23NOV92A	24NOV92A
40-3380	PF	100	0	15DEC92A	23DEC92A
40-3400	BC	100	0	1DEC92A	16DEC92A
40-3450	PF	100	0	2FEB93A	19FEB93A
40-3451	PF	100	0	2FEB93A	19FEB93A
40-3452	PF	100	0	8FEB93A	26FEB93A
40-3455	PF	100	0	22JAN93A	19FEB93A
40-3460	PF	100	0	4FEB93A	12FEB93A
40-3465	BC	100	0	7JAN93A	7JAN93A
40-3466	BC	100	0	17FEB93A	17FEB93A

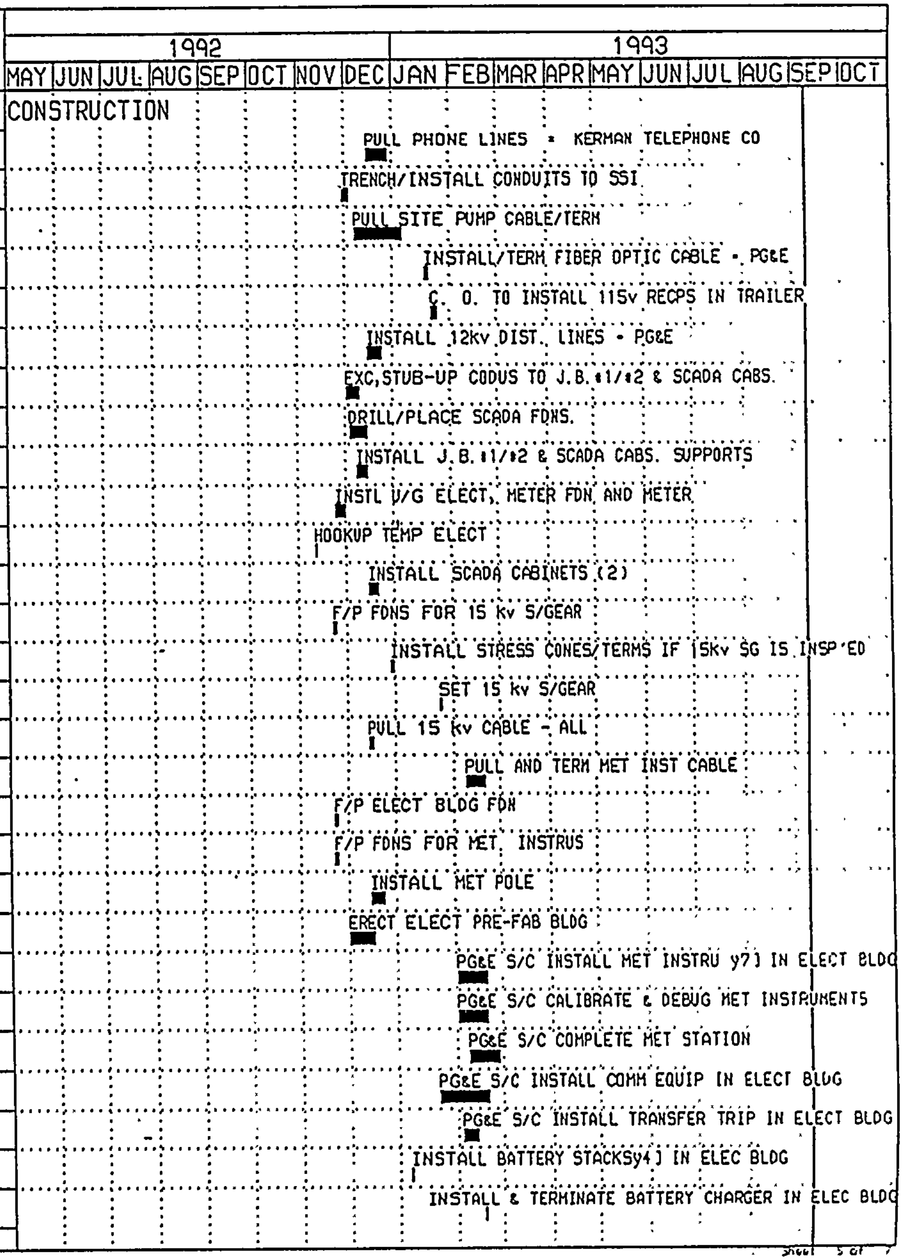
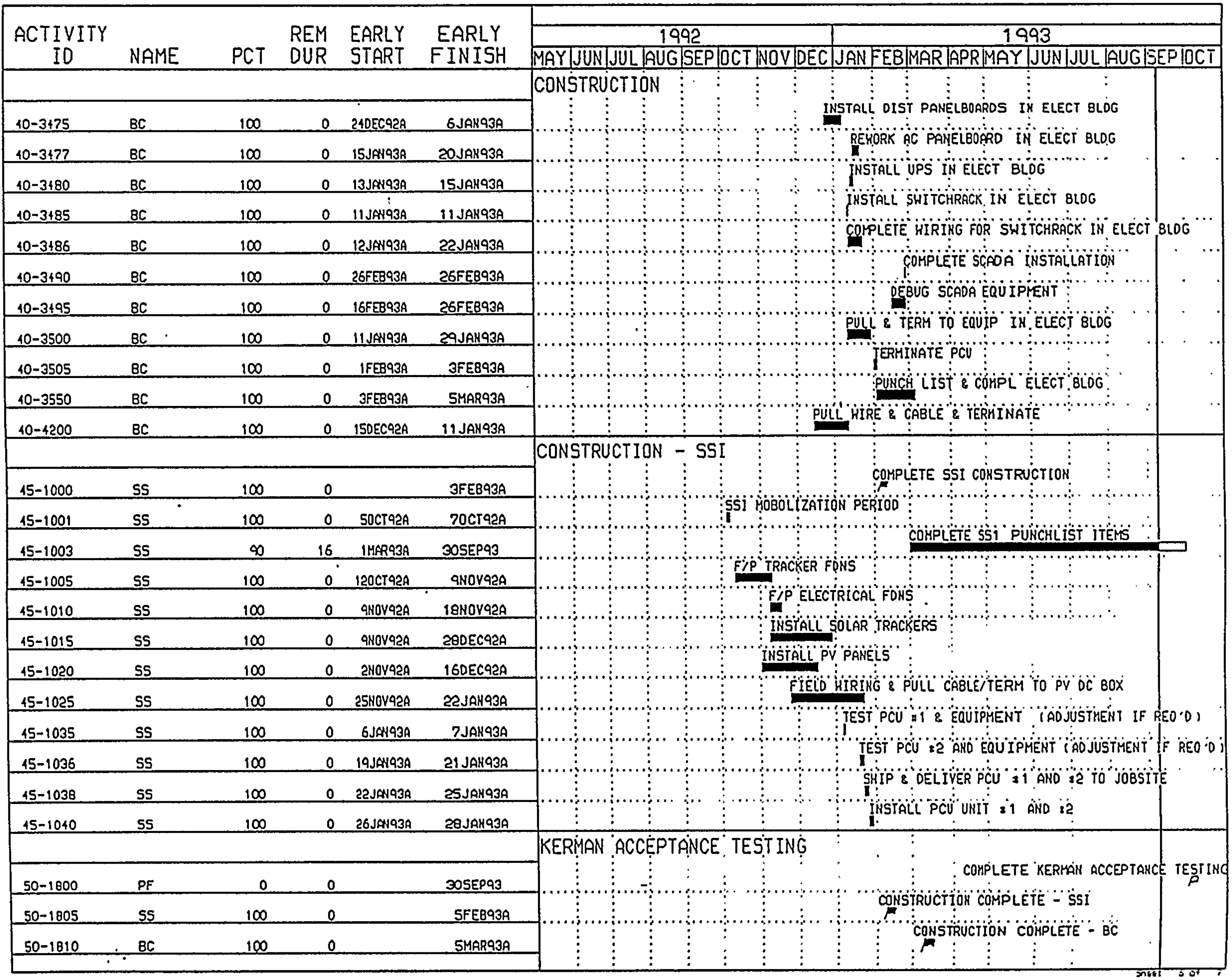


Figure B-2. PVUSA Kerman detailed schedule (continued).



ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH
40-3475	BC	100	0	24DEC92A	6JAN93A
40-3477	BC	100	0	15JAN93A	20JAN93A
40-3480	BC	100	0	13JAN93A	15JAN93A
40-3485	BC	100	0	11JAN93A	11JAN93A
40-3486	BC	100	0	12JAN93A	22JAN93A
40-3490	BC	100	0	26FEB93A	26FEB93A
40-3495	BC	100	0	16FEB93A	26FEB93A
40-3500	BC	100	0	11JAN93A	29JAN93A
40-3505	BC	100	0	1FEB93A	3FEB93A
40-3550	BC	100	0	3FEB93A	5MAR93A
40-4200	BC	100	0	15DEC92A	11JAN93A
45-1000	SS	100	0		3FEB93A
45-1001	SS	100	0	5OCT92A	7OCT92A
45-1003	SS	90	16	1MAR93A	30SEP93
45-1005	SS	100	0	12OCT92A	9NOV92A
45-1010	SS	100	0	9NOV92A	18NOV92A
45-1015	SS	100	0	9NOV92A	28DEC92A
45-1020	SS	100	0	2NOV92A	16DEC92A
45-1025	SS	100	0	25NOV92A	22JAN93A
45-1035	SS	100	0	6JAN93A	7JAN93A
45-1036	SS	100	0	19JAN93A	21JAN93A
45-1038	SS	100	0	22JAN93A	25JAN93A
45-1040	SS	100	0	26JAN93A	28JAN93A
50-1800	PF	0	0		30SEP93
50-1805	SS	100	0		5FEB93A
50-1810	BC	100	0		5MAR93A

Figure B-2. PVUSA Kerman detailed schedule (continued).

ACTIVITY ID	NAME	PCT	REM DUR	EARLY START	EARLY FINISH
50-1815	BE	100	0	22JAN93A	23FEB93A
50-1820	BC	100	0	4FEB93A	4FEB93A
50-1840	BC	100	0	28DEC92A	30DEC92A
50-1845	BC	100	0	13JAN93A	14APR93A
50-1850	EN	100	0	22MAR93A	26MAR93A
50-1855	EN	100	0	22MAR93A	26MAR93A
50-1860	PF	100	0	5FEB93A	8FEB93A
50-1865	PF	100	0	8FEB93A	10FEB93A
50-1870	PF	100	0	10FEB93A	10FEB93A
50-1875	PF	100	0	10FEB93A	11FEB93A
50-1880	PF	100	0	11FEB93A	12FEB93A
50-1885	PF	100	0	16FEB93A	23FEB93A
50-1900	PF	100	0	23FEB93A	23FEB93A
50-1950	PF, SS, BC	100	0	23FEB93A	1APR93A
50-1955	SS	100	0	22FEB93A	2MAR93A
50-1970	SS, PE, BE	100	0	22FEB93A	1APR93A
50-1972	SS	100	0	15MAR93A	14APR93A
50-1975	SS, BC	100	0	2APR93A	14JUL93A
50-1980	PE	71	16	15JUL93A	30SEP93
50-2600	BC	100	0	15JUL93A	1AUG93A
50-2650	SS, BE, BC	87	16	12APR93A	30SEP93
50-2660	SS	100	0	25MAY93A	26MAY93A
50-4220	PE, BE, BC	0	0		30SEP93

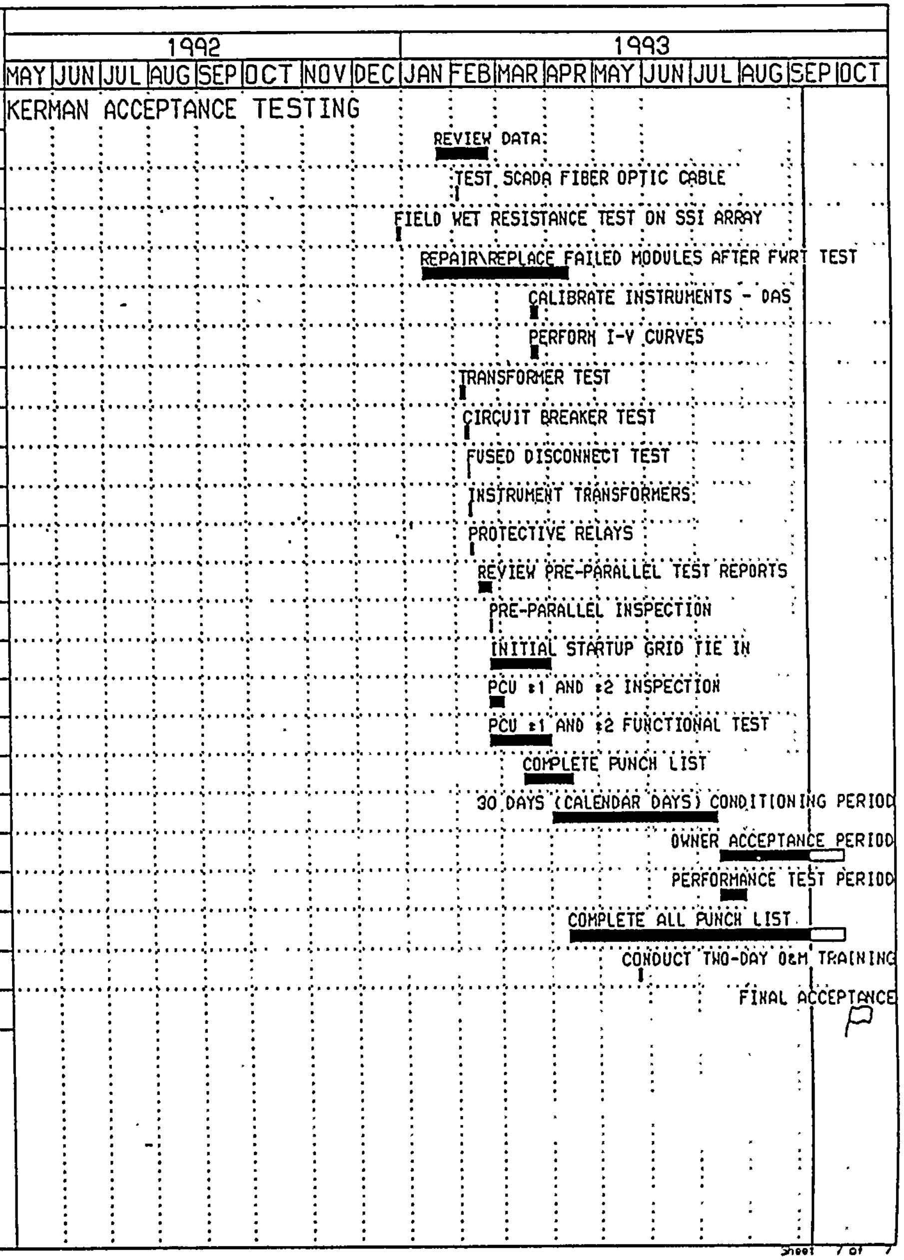
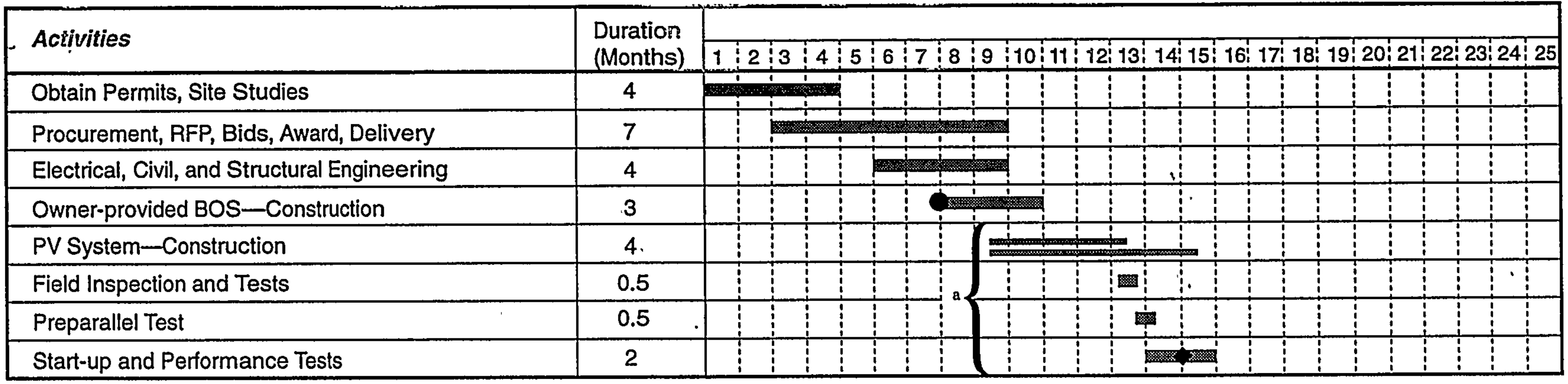
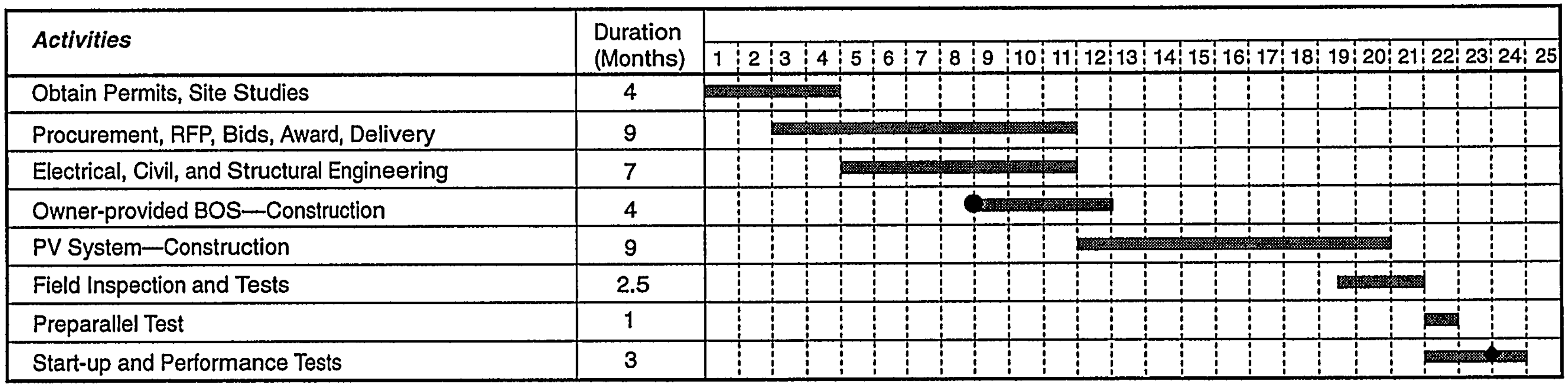


Figure B-2. PVUSA Kerman detailed schedule (continued).

500- and 1,000-kW Plant



5-MW Plant



● Site mobilization.

◆ Complete start-up, start performance test.

[a] Schedule shown for 500-kW plant. PV construction is 4 months for a 500-kW plant and 6 months for a 1,000-kW plant.

Figure B-3. Improved PV plant schedules.

Appendix C

COST EVALUATION METHODOLOGY

This appendix outlines the work breakdown structure used by PVUSA, describes an improved structure, and provides recommendations to those considering cost tracking of utility-scale PV plants.

PVUSA WORK BREAKDOWN STRUCTURE

PVUSA Davis and Kerman costs are charged to PG&E's work breakdown structure (WBS) for PVUSA. WBS charging is a method of project management cost collection that has been implemented at PG&E to control project costs. The WBS is a top-down structure of project work divided into manageable units. Tailored for each project, the WBS defines and organizes the work to be performed in accomplishing project objectives.

The WBS that PVUSA established and used includes five categories: PV system subcontract, site development, electrical infrastructure, SCADA, and project management. The last four categories capture PVUSA-provided BOS costs:

- The *site development* cost category includes siting, land acquisition or leasing, permitting, soils testing, biological evaluation, civil engineering, surveying, fencing, grading, laydown areas, access roads, erosion prevention, storm water runoff control, a construction trailer, a prefabricated control building, a storage container, a water well, a septic system, and landscaping.
- The *electrical infrastructure* cost category includes PVUSA's electrical engineering review of each US system and engineering, procurement, installation, start-up testing, and calibration of all PVUSA-provided electrical equipment. It includes the 12-kV switchgear and enclosure; 12-kV protection, metering, and control circuits; cabling from the service poles to the 12-kV switchgear; transfer trips; cabling to infrastructure loads; a grounding grid; distribution panel boards; switchracks; a UPS; a battery and its charger; a revenue meter; a relay panel; and a meter pedestal. Additionally, installation of medium-voltage cable to the PV supplier's transformer (point of power interface) is also included.
- The *SCADA* cost category accounts for engineering, procurement, shop assembly, installation, start-up testing, and calibration of the SCADA system, which includes telecommunication equipment, meteorological equipment, a database computer and associated software development.
- The *project management* cost category includes developing and maintaining the schedule, developing and issuing the PV system request for proposals (RFP), developing and issuing infrastructure bid packages, evaluating proposals and bids, establishing contracts, administering project labor agreements, and managing construction and safety practices.

IMPROVED WORK BREAKDOWN STRUCTURE

The WBS that PVUSA uses is successful in capturing costs but is insufficiently detailed to function as a basis for cost reviews. For this report a detailed PV plant WBS was developed that is more consistent with standard power plant construction accounting (see **Table C-1**). The improved WBS facilitates both the identification of potential cost reductions and the cost comparison of PV plants with competing

Table C-1

Improved Work Breakdown Structure

Acct. No.	Description
1000	OWNER HOME-OFFICE MANAGEMENT, ENGINEERING, AND PROCUREMENT
1100	Management Services
1200	Engineering Services
1300	Procurement Services
1400	Accounting, Administration, Corporate, Legal, and Safety Support Services
1500	Travel Expenses
1600	Employee-related Expenses
1700	Miscellaneous Office Expenses
1800	Geotechnical Studies and Other Site-specific Tests
1900	Permits
2000	CONSTRUCTION
2100	Owner On-site Labor
2110	Owner On-site Manual Labor
2120	Owner On-site Nonmanual Labor
2130	Owner Start-up Services
2200	Site Selection, Land Acquisition
2300	Site Preparation and Improvements
2310	Clear and Grub
2320	Grading
2330	Drainage
2340	Utilities
2350	Paving and Roads
2360	Landscaping and Vegetation Control
2370	Fencing
2380	Buildings
2381	Control
2382	Construction Trailer
2383	Storage
2400	Foundations
2410	Buildings
2420	Owner-provided Equipment
2500	PV System
2510	Foundations for PV Array and Equipment
2520	PV Array Structure
2530	PV Modules/Panels
2540	Power Conditioning Unit
2550	dc Wires, Raceways, Switches, Boxes, Grounding
2560	Balance of PV System
2600	Electrical Equipment
2610	Transformers
2620	Switchgear
2630	Field Interconnect Wiring
2640	Protective Relays
2650	Interconnection to Grid
2700	Instrumentation and Control
2710	SCADA
2720	DAS
2730	Meteorological Instruments
2740	Security Systems
2800	Specialized Maintenance Tools and Equipment
2900	Spare Parts for PV System and Owner-provided BOS

generation alternatives, while attempting to avoid a level of detail that allows accounting errors to significantly impact cost breakdown accuracy. The system also allows real-time cost tracking for prudent project and construction management. The two main WBS categories are

- *Owner Management, Engineering, and Procurement Services (1000)* includes labor, labor overhead, materials, expenses, and subcontracts incurred by PG&E and its subcontractors for work that is performed in the PV plant owner's home-office(s).
- *Construction (2000)* includes labor, labor overhead, materials, and expenses incurred by PG&E and its subcontractors for work that is performed in the field, including all construction subcontracts for site preparation, infrastructure, and the turnkey PV system.

PV system price breakdowns and PVUSA-provided Kerman BOS costs from the WBS used by PVUSA have been retrofitted into **Table C-1** (Table 5-2). Labor (fully burdened) and expenses are associated with PVUSA project team members at PG&E and Bechtel. Materials are those acquired by PG&E and Bechtel. Subcontracts involve labor, expenses, materials, and profit. Taxes are embedded in the appropriate cost categories.

RECOMMENDATIONS FOR PV PLANT COST TRACKING

The following recommendations should help yield accurate quantification of all costs associated with the installation of a PV system, and facilitate investigating areas of potential cost reduction. Project management costs may increase in accordance with the level of detail desired. Less rigor will undoubtedly be employed as part of a commercial procurement.

1. Define the PV plant WBS at the beginning of the project. Use a PV plant WBS that is both detailed enough to facilitate the cost tracking of BOS cost drivers and similar enough to traditional power plant WBSs to facilitate comparison of PV plants with other alternatives. The WBS should not be so complex that accounting errors significantly impact cost accuracy. If the PV plant has research-related components, consider using a cost breakdown structure that segregates research costs to facilitate estimation of commercial PV plant costs.
2. Require in the PV system RFP that proposals be broken down to correspond to the PV system WBS categories. Ideally, augment the PV system contract to include provision of the supplier's actual costs, lessons learned, assessment of potential for system cost reduction through improved design, and cost sensitivity to system size, efficiency, and site characteristics. Verify that all project team members are familiar with the cost breakdown structure. Throughout the project period, document regularly the lessons learned by the project team and the PV system supplier.
3. Recognize all factors and assumptions that affect costs (e.g., utility-grade requirement, research-related BOS, system performance assumptions, and project schedule) when reviewing PV plant cost results.

Appendix D
COST TABLES

Table D-1

PVUSA Home-office Costs and Expenses for Kerman

Acct. No.	Description	H.O. Labor (Hr)	H.O. Labor ($)	H.O. O.D.C. ($)	Total H.O. Cost ($)
1000	Owner Home-office Mgmt., Eng'r., & Proc.				
1100	Management Services				
1110	Bechtel	237	17,909		17,909
1120	Bechtel Agency	N/A			
1130	PG&E	117	6,652		6,652
1140	PG&E Agency	N/A			
	Total Management Services	354	24,561		24,561
1200	Engineering Services				
1210	Bechtel	3,974	294,964		294,964
1220	Bechtel Agency	N/A	735	4,969	5,704
1230	PG&E	3,417	192,385		192,385
1240	PG&E Agency	N/A		130,587	130,587
1250	Design Services	N/A		56,137	56,137
	Total Eng'r. Services	7,391	488,084	191,693	679,777
1300	Procurement Services				
1310	Bechtel	1,158	77,253		77,253
1320	Bechtel Agency	N/A			
1330	PG&E				
1340	PG&E Agency	N/A			
	Total Procurement Services	1,158	77,253		77,253
1400	Acct., Admin., Corp., Legal, & Safety Support Services				
1410	Bechtel	2,132	97,822		97,822
1420	Bechtel Agency	N/A	4,546	26,263	30,809
1430	PG&E	40	1,508		1,508
1440	PG&E Agency	N/A		8,376	8,376
	Total Acct., Admin., Corp., Legal, & Safety Support Services	2,172	103,876	34,639	138,515
1500	Travel Expenses				
1510	Bechtel		4,092	26,251	30,343
1520	PG&E			3,730	3,730
	Total Travel Expenses		4,092	29,981	34,073
1600	Employee-related Expenses				
1610	Bechtel		2,301	12,725	15,026
1620	PG&E			9,052	9,052
	Total Employee-related Expenses		2,301	21,776	24,077
1700	Misc. Office Expenses				
1710	Bechel		5,098	24,700	29,798
1720	PG&E			2,250	2,250
	Total Misc. Office Expenses		5,098	26,950	32,048
1800	Geotechnical Studies & Other Site-specific Tests (PG&E)	1,108	57,133	1,940	59,072
1900	Permits (PG&E)	79	4,402		4,402
	Total Owner Home-office Mgmt., Eng'r., & Proc.	12,262	766,800	306,980	1,073,779

Table D-2

PVUSA-provided Kerman Electrical Infrastructure Cost

Acct. No.	Description	Labor (Hr)	Labor Unit Rate ($/Hr)	Mat'l. Qty. Unit	Mat'l. Unit Rate ($/Qty)	H.O. Labor ($)	Const. Labor ($)	Material ($)	S/C ($)	Total Costs ($)
1000	Owner Home-office Mgmt., Eng'r., & Proc.									
1100	Management Services	61				4,404				4,404
1200	Engineering Services	3,631				290,284				290,284
1300	Procurement Services	471				28,685				28,685
1400	Acct., Admin., Corp., Legal, & Safety Support Services	673				42,840				42,840
1500	Travel Expenses					21,264				21,264
1600	Employee-related Expenses					1,630				1,630
1700	Misc. Office Expenses					5,213				5,213
1800	Geotechnical Studies and Other Site-specific Tests									
1900	Permits									
	Total Home-office	4,836				394,320				394,320
2000	Construction									
2100	Owner On-site Labor									
2110	Owner On-site Manual Labor	98					6,426		149,779	156,205
2120	Owner On-site Nonmanual Labor	285					13,700			13,700
2130	Owner Start-up Services	454					36,914			36,914
	Total Owner On-site	837					57,039		149,779	206,818
2200	Site Selection, Land Acquisition									
2300	Site Preparation and Improvements									
2310	Clear and Grub									
2320	Grading									
2330	Drainage									
2340	Utilities									
2350	Paving and Roads									
2360	Landscaping and Vegetation Control									
2370	Fencing									
	Total Site Preparation & Improvements	W/2120								
2380	Buildings									
2381	Control								22,075	22,075
2382	Construction Trailer									
2383	Storage									
	Total Buildings	W/2120							22,075	22,075
2400	Foundations									
2410	Buildings								W/2110	W/2110
2420	Owner-provided Equipment								W/2110	W/2110
	Total Foundations	W/2120								
2500	PV System									
2510	Foundations for PV Array and Equipment									
2520	PV Array Structure									
2530	PV Modules/Panels									
2540	Power Conditioning Unit									
2550	dc Wires, Raceways, Switches, Boxes, Grounding									
2560	Balance of PV System									
	Total PV System	W/2120								
2600	Electrical Equipment									
2610	Transformers									
2620	Switchgear							27,886		27,886
2630	Field Interconnect Wiring							8,241		8,241
2640	Protective Relays							8,625		8,625
2650	Interconnection to Grid							8,247		8,247
	Total Electrical Equipment	W/2120						53,000		53,000
2700	Instrumentation and Control									
2710	SCADA							24,994		24,994
2720	DAS							399		399
2730	Meteorological Instruments									
2740	Security Systems									
	Total Instrumentation and Control	W/2120						25,393		25,393
2800	Specialized Maintenance Tools and Equipment	W/2120						1,902		1,902
2900	Spare Parts for PV System and Owner-provided BOS	W/2120						14,214		14,214
	Total Cost					394,320	57,039	94,510	171,854	717,723

Table D-3

PVUSA-provided Kerman Site Development Cost

Acct. No.	Description	Labor (Hr)	Labor Unit Rate ($/Hr)	Mat'l. Qty. Unit	Mat'l. Unit Rate ($/Qty)	H.O. Labor ($)	Const. Labor ($)	Material ($)	S/C ($)	Total Costs ($)
1000	**Owner Home-office Mgmt., Eng'r., & Proc.**									
1100	**Management Services**	29				2,327				2,327
1200	**Engineering Services**	1,152				81,693				81,693
1300	**Procurement Services**	250				17,056				17,056
1400	**Acct., Admin., Corp., Legal, & Safety Support Services**	228				23,502				23,502
1500	**Travel Expenses**					4,880				4,880
1600	**Employee-related Expenses**					143				143
1700	**Misc. Office Expenses**					18,032				18,032
1800	**Geotechnical Studies and Other Site-specific Tests**	684				38,614				38,614
1900	**Permits**	79				4,402				4,402
	Total Home-office	2,422				190,649				190,649
2000	**Construction**									
2100	**Owner On-site Labor**									
2110	Owner On-site Manual Labor									
2120	Owner On-site Nonmanual Labor	1,641					71,352			71,352
2130	Owner Start-up Services									
	Total Owner On-site	1,641					71,352			71,352
2200	**Site Selection, Land Acquisition**						8,554	89,500	3,716	101,770
2300	**Site Preparation and Improvements**									
2310	Clear and Grub								1,305	1,305
2320	Grading								W/2350[1]	W/2350
2330	Drainage								W/2350	W/2350
2340	Utilities								20,788	20,788
2350	Paving and Roads								132,720	132,720
2360	Landscaping and Vegetation Control								4,098	4,098
2370	Fencing								38,729	38,729
	Total Site Preparation & Improvements	W/2120							197,640	197,640
2380	**Buildings**									
2381	Control									
2382	Construction Trailer							4,743	27,853	32,596
2383	Storage							1,995		1,995
	Total Buildings	W/2120						6,738	27,853	34,591
2400	**Foundations**									
2410	Buildings									
2420	Owner-provided Equipment									
	Total Foundations	W/2120								
2500	PV System									
2510	Foundations for PV Array and Equipment									
2520	PV Array Structure									
2530	PV Modules/Panels									
2540	Power Conditioning Unit									
2550	dc Wires, Raceways, Switches, Boxes, Grounding									
2560	Balance of PV System									
	Total PV System	W/2120								
2600	**Electrical Equipment**									
2610	Transformers									
2620	Switchgear									
2630	Field Interconnect Wiring									
2640	Protective Relays									
2650	Interconnection to Grid							80		80
	Total Electrical Equipment	W/2120						80		80
2700	**Instrumentation and Control**									
2710	SCADA									
2720	DAS									
2730	Meteorological Instruments									
2740	Security Systems									
	Total Instrumentation and Control	W/2120								
2800	**Specialized Maintenance Tools and Equipment**	W/2120								
2900	**Spare Parts for PV System and Owner-provided BOS**	W/2120						945		945
	Total Cost					190,649	79,906	97,263	229,209	597,027

Table D-4
PVUSA-provided Kerman Project Management Cost

Acct. No.	Description	Labor (Hr)	Labor Unit Rate ($/Hr)	Mat'l. Qty. Unit	Mat'l. Unit Rate ($/Qty)	H.O. Labor ($)	Const. Labor ($)	Material ($)	S/C ($)	Total Costs ($)
1000	Owner Home-office Mgmt., Eng'r., & Proc.									
1100	Management Services	263				17,757				17,757
1200	Engineering Services	1,963				134,687				134,687
1300	Procurement Services	432				31,083				31,083
1400	Acct., Admin., Corp., Legal, & Safety Support Services	1,219				66,038				66,038
1500	Travel Expenses					7,267				7,267
1600	Employee-related Expenses					19,539				19,539
1700	Misc. Office Expenses					8,103				8,103
1800	Geotechnical Studies and Other Site-specific Tests	424				20,458				20,458
1900	Permits									
	Total Home-office	4,301				304,932				304,932
2000	Construction									
2100	Owner On-site Labor									
2110	Owner On-site Manual Labor									
2120	Owner On-site Nonmanual Labor	694					31,925			31,925
2130	Owner Start-up Services									
	Total Owner On-site	694					31,925			31,925
2200	Site Selection, Land Acquisition									
2300	Site Preparation and Improvements									
2310	Clear and Grub									
2320	Grading									
2330	Drainage									
2340	Utilities									
2350	Paving and Roads									
2360	Landscaping and Vegetation Control									
2370	Fencing									
	Total Site Preparation & Improvements	W/2120								
2380	Buildings									
2381	Control									
2382	Construction Trailer									
2383	Storage									
	Total Buildings	W/2120								
2400	Foundations									
2410	Buildings									
2420	Owner-provided Equipment									
	Total Foundations	W/2120								
2500	PV System									
2510	Foundations for PV Array and Equipment									
2520	PV Array Structure									
2530	PV Modules/Panels									
2540	Power Conditioning Unit									
2550	dc Wires, Raceways, Switches, Boxes, Grounding									
2560	Balance of PV System									
	Total PV System	W/2120								
2600	Electrical Equipment									
2610	Transformers									
2620	Switchgear									
2630	Field Interconnect Wiring									
2640	Protective Relays									
2650	Interconnection to Grid									
	Total Electrical Equipment	W/2120								
2700	Instrumentation and Control									
2710	SCADA							1,319		1,319
2720	DAS									
2730	Meteorological Instruments									
2740	Security Systems									
	Total Instrumentation and Control	W/2120						1,319		1,319
2800	Specialized Maintenance Tools and Equipment	W/2120								
2900	Spare Parts for PV System and Owner-provided BOS	W/2120								
	Total Cost					304,932	31,925	1,319		338,176

Table D-5
PVUSA-provided Kerman SCADA Cost

Acct. No.	Description	Labor (Hr)	Labor Unit Rate ($/Hr)	Mat'l. Qty. Unit	Mat'l. Unit Rate ($/Qty)	H.O. Labor ($)	Const. Labor ($)	Material ($)	S/C ($)	Total Costs ($)
1000	Owner Home-office Mgmt., Eng'r., & Proc.									
1100	Management Services	1				73				73
1200	Engineering Services	645				173,113				173,113
1300	Procurement Services	5				429				429
1400	Acct., Admin., Corp., Legal, & Safety Support Services	52				6,136				6,136
1500	Travel Expenses					663				663
1600	Employee-related Expenses					2,765				2,765
1700	Misc. Office Expenses					699				699
1800	Geotechnical Studies and Other Site-specific Tests									
1900	Permits									
	Total Home-office	703				183,878				183,878
2000	Construction									
2100	Owner On-site Labor									
2110	Owner On-site Manual Labor	285					15,977			15,977
2120	Owner On-site Nonmanual Labor	111					5,758			5,758
2130	Owner Start-up Services	340					28,853			28,853
	Total Owner On-site	736					50,589			50,589
2200	Site Selection, Land Acquisition									
2300	Site Preparation and Improvements									
2310	Clear and Grub									
2320	Grading									
2330	Drainage									
2340	Utilities									
2350	Paving and Roads									
2360	Landscaping and Vegetation Control									
2370	Fencing									
	Total Site Preparation & Improvements	W/2120								
2380	Buildings									
2381	Control									
2382	Construction Trailer									
2383	Storage									
	Total Buildings	W/2120								
2400	Foundations									
2410	Buildings									
2420	Owner-provided Equipment									
	Total Foundations	W/2120								
2500	PV System									
2510	Foundations for PV Array and Equipment									
2520	PV Array Structure									
2530	PV Modules/Panels									
2540	Power Conditioning Unit									
2550	dc Wires, Raceways, Switches, Boxes, Grounding									
2560	Balance of PV System									
	Total PV System	W/2120								
2600	Electrical Equipment									
2610	Transformers									
2620	Switchgear									
2630	Field Interconnect Wiring									
2640	Protective Relays									
2650	Interconnection to Grid							3,011		3,011
	Total Electrical Equipment	W/2120						3,011		3,011
2700	Instrumentation and Control									
2710	SCADA							34,252		34,252
2720	DAS							49,768		49,768
2730	Meteorological Instruments							23,544	12,203	35,747
2740	Security Systems							2,555		2,555
	Total Instrumentation and Control	W/2120						110,119	12,203	122,322
2800	Specialized Maintenance Tools and Equipment	W/2120								
2900	Spare Parts for PV System and Owner-provided BOS	W/2120								
	Total Cost					183,878	50,589	113,129	12,203	359,799