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A 20-kW Solar Photovoltaic Flat-Panel Power System for an Uninterruptible Power-System Load in El Paso, Texas

Phase II - System Fabrication (October 1, 1979 to May 31, 1981)

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PHASE II--SYSTEM FABRICATION

Final Report

31 March 1981

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LIST OF ABBREVIATIONS

NMSEI	New Mexico Solar Energy Institute
EPE	El Paso Electric Company
BCS	Boeing Computer Service
SNL	Sandia National Laboratories
SP	Solar Power Corporation
GE	General Electric Company
NOCT	Nominal operating cell temperature °C
V_{OC}	Open circuit voltage
ODAS	On-site data acquisition system
I_{SC}	Short circuit current
PCJB	Panel connection junction box
RSJB	Row summing junction box
MIJB	Main instrumentation junction box
MADB	Main array disconnect box
UPS	Uninterruptible power supply

A 20-KILOWATT SOLAR PHOTOVOLTAIC FLAT-PANEL POWER SYSTEM FOR AN UNINTERRUPTIBLE POWER SYSTEM LOAD IN EL PASO, TEXAS

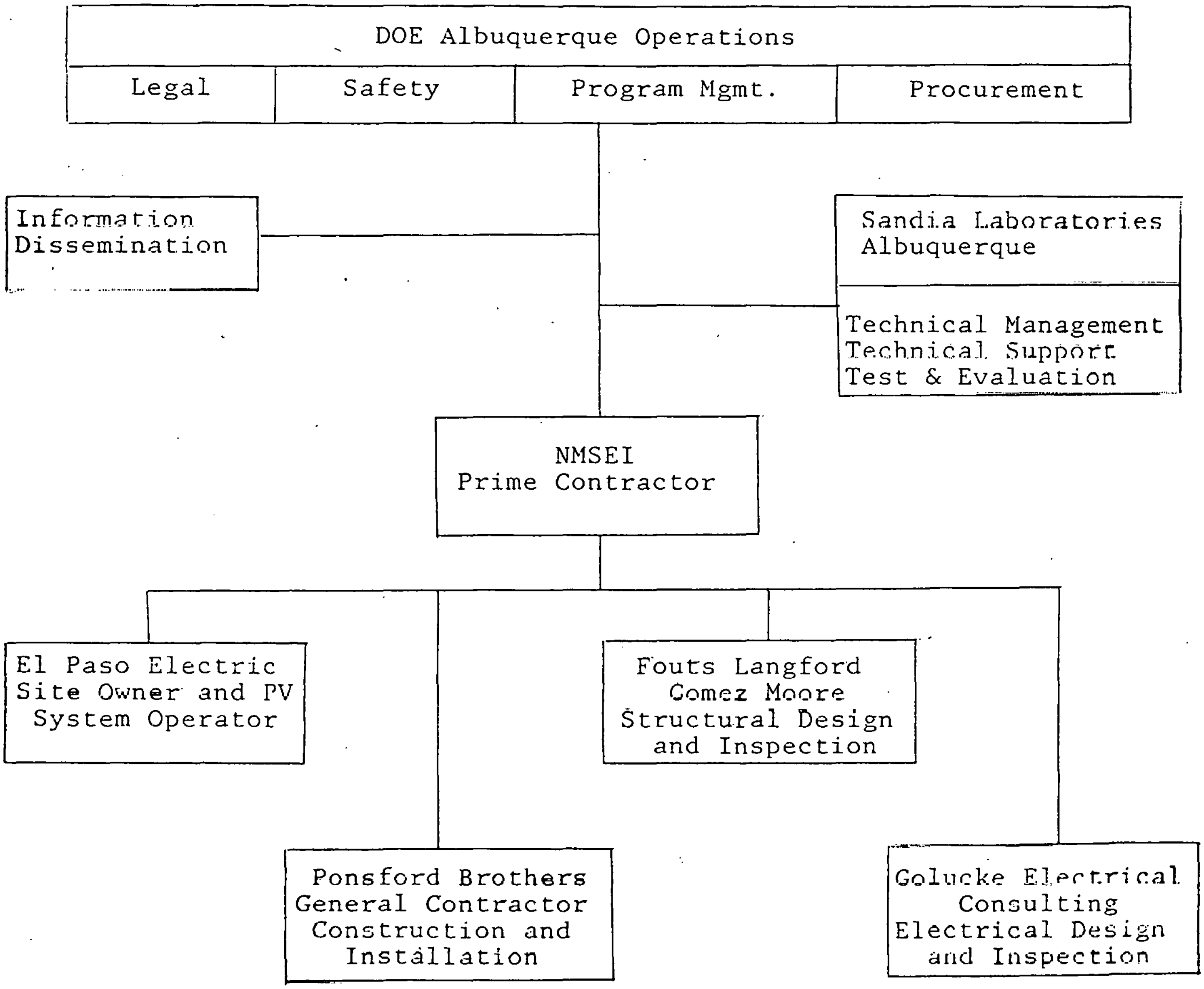
1.0 INTRODUCTION

The New Mexico Solar Energy Institute (NMSEI), as prime contractor, and El Paso Electric (EPE), Ponsford Brothers Construction Company, Fouts Langford Gomez and Moore Architects, and Lanneau Golucke Consulting, as subcontractors, have designed and fabricated the 20-kilowatt photovoltaic (PV) system at the Newman Power Station, El Paso, Texas (figure 1). The Phase II contract from the Department of Energy (DOE) was let 1 October 1979. Construction was started 1 June 1980, and on 4 December 1980 the PV system was first connected to the Newman Power Station load. After extensive initial testing, the system was approved for automatic unattended operation on 27 January 1981.

The system consists of 64 parallel-connected panels, each panel containing nine series-connected modules. The panels face due south and are tilted at 26 degrees from horizontal. The tilt cannot be changed. The system is connected, through power monitoring equipment, to an existing dc bus that supplies uninterruptible power to a computer that controls the power generation equipment at Newman Station. The bus operates at 134 volts, which, after adjustment for resistance losses, relates to a panel voltage of approximately 139 volts. The nine series-connected modules should operate at 15.2 volts, which is expected to be quite near the maximum power point. An analysis showed the cost of a peak power tracker could not be justified for this application.

The 64 panels are placed in three rows of 20, 22, and 22 panels (figure 2 and Appendix A, drawing 1). Each row is electrically divided

20-KW EL PASO PV PROJECT



NMSEI

Figure 1. Project Management Structure

Figure 2. Photovoltaic Array, Newman Power Station

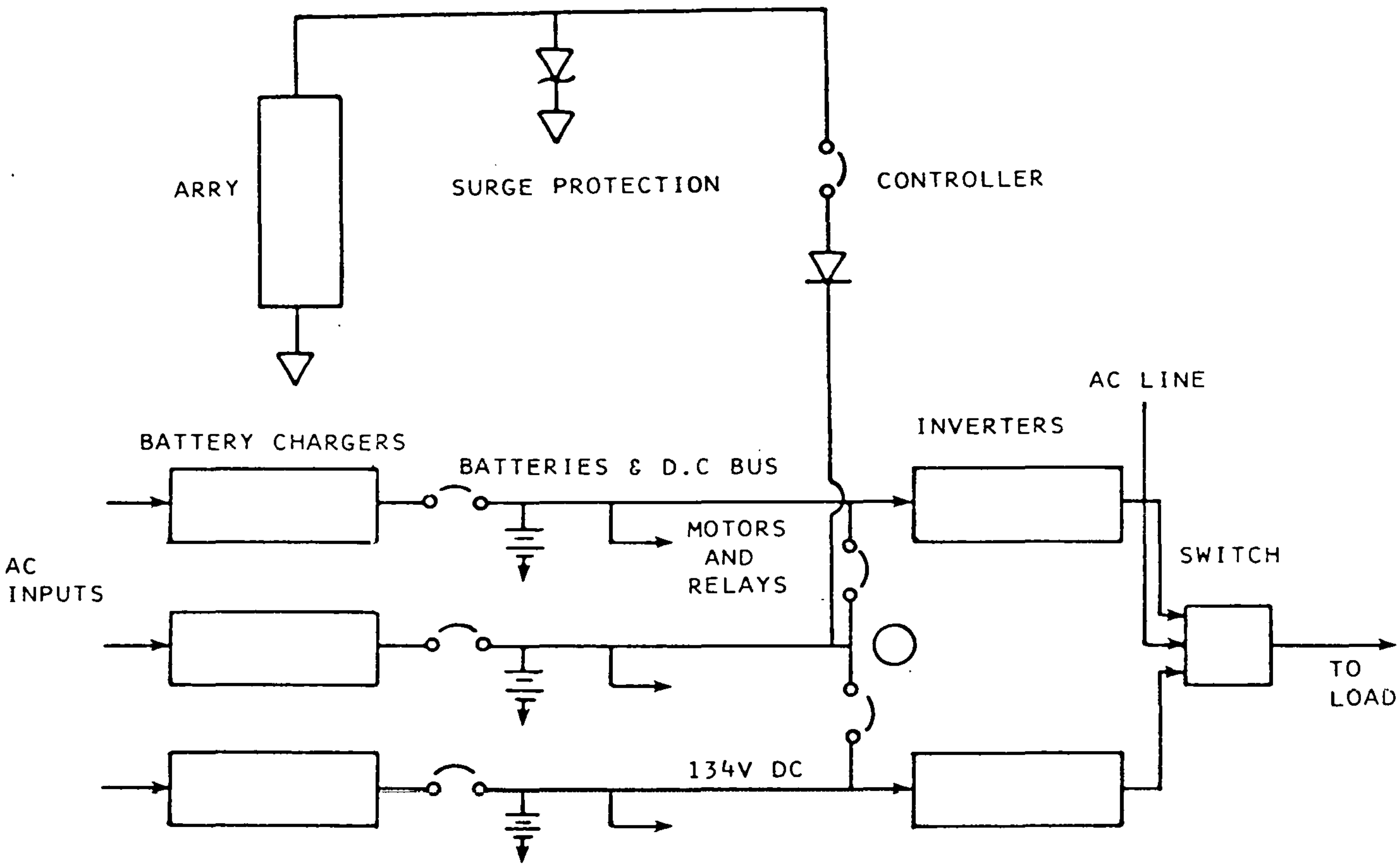
into two subarrays. Each of the six subarrays can be electrically isolated and shorted if required. The PV current from each subarray is summed and delivered through a manual disconnect to the visitor center, which contains the automatic power control equipment.

This equipment senses array output and connects (disconnects) the array to the existing dc bus as appropriate. The dc load at Newman Station is large enough to utilize all PV power produced. The system configuration is given in figure 3.

The construction schedule proposed in the Phase II proposal [1] shows a 12-month construction schedule. Although actual construction time was less than 12 months, delays in starting the contract work, delivery problems on selected power control units, and a higher than expected failure rate of PV modules caused a three-month schedule slip. However, the contractors were able to contain expenses and the original cost estimates were met. The system costs are given in table 1.

TABLE 1. COST CATEGORIES

Category	\$/Watt (17.5 kw nominal)
Engineering and Project Management	5.30
Electrical Design	0.06
Mechanical Design	0.42
Civil Work Site	0.86
Fabrication	1.40
Collector Cost	9.15
Collector Freight Cost	0.30
Electrical System	3.50
Data System	0.80
Visitor System	0.85
Safety and Security System	0.25
Instrumentation and Testing	2.40
Control System	1.75
Total	\$27.53



°64 Panels in Parallel
°9 Modules/Panel in Series
°3 Rows of 20, 22, 22 Panels
°6 Subarrays - 2 per Row

Each subarray may be isolated and shorted.

NMSEI

Figure 3. 20-Kilowatt El Paso PV System Configuration

The system performance has matched design predictions. Since operation began, the peak power was registered at 22.9 kilowatts, for an insolation of 1,222 kilowatts per square meter in the plane of array and a measured cell temperature of 22°C. For the first 80 days of operation the system produced an average of 95.1 kilowatt hours per day. The system efficiency for this period was 5.95 percent.

2.0 SYSTEM PLANS

Planning for the El Paso Photovoltaic Project started with the initial Phase I proposal activity and has continued throughout the project [2]. This planning incorporated the nontechnical issues as well as the system technical aspects. Many of these issues are discussed in this report.

2.1 Site Selection

There were three major reasons for locating the system at the El Paso Electric Company (EPE) Newman Station. First, since studies show that electricity consumption will increase compared to other forms of energy consumption, this demonstration project with a utility will help assess the problems associated with a photovoltaic/utility tie-in and will give a utility practical operating experience with a photovoltaic system.

Second, the application of direct current photovoltaic power finds applications throughout the business world. Many businesses provide a dc interface between their computers and the commerical power source to isolate the systems from any variations or "spikes" that may appear in the utility power system. This also allows a convenient backup power supply (batteries) to interface with the computer so that no interruption in computer functioning will occur should commercial power fail. Since the majority of utilities and numerous other business enterprises now have uninterruptible power supplies (UPS), the potential for the application is widespread. Also, as the application is dc to dc, interfacing problems are minimized. This leads directly to the third reason, which is that generation stations normally have numerous dc applications. The concept of generating ac electricity to be converted to dc electricity for final use is inefficient, and the electrical losses are wasteful. Direct solar conversion raises efficiency of the generating stations, permitting a higher output of energy per unit of fuel, thus benefitting the consumer. Also, in the case of gas- or oil-fired generation, a savings is realized and the quantity of fuel required per unit of output is increased.

Advantages of the Newman Station site are (1) it is located in an area that receives very high annual solar insolation, (2) the existing controlled access to the site minimizes security requirements for the photovoltaic equipment, (3) the required levels of skilled labor are available locally, and (4) the site is near the New Mexico Solar Energy Institute laboratory facilities at NMSU.

Also considered during site selection planning was the environmental impact of locating the PV system at Newman Station. Newman Station is located in an isolated area north of El Paso, Texas. Surrounding land, owned by El Paso Water Utilities, is a pumping area, with surface use of land strictly controlled.

The general topography around the photovoltaic array site is gently sloping west to east. Four existing power generating units are located

100 feet to the north of the site. Farther north, about 1,000 feet from the array, there is a recreation and park area, open only to EPE employees. To the south, 200 feet from site, is the power station water retention pond. The cooling tower area is located 200 feet to the east; the area to the west of the site is not populated. There are no residential buildings within a two-mile radius of Newman Station. The environmental impact planning included the following conditions:

Hydrological Conditions--Surface water runoff from the project site is directed through an existing ditch to the water retention pond. The pond's main supply of water is from cooling towers and power station water discharges. There is no known hydrological hazard, such as flood or storm runoff, to the project site. The existing water supply for Newman Station is well water purchased from the El Paso Water Utilities (EPWU).

Geological and Archaeological Conditions--Since the site is essentially flat, noticeable erosion from wind and water runoff is not expected. There are no known mineral resources or unique geological/landform features nearby. There have been no known archaeological findings in close proximity to the site. Seismic hazard is negligible.

Plant and Animal Species--The site area supports minimal vegetation, principally grasses, on about 25 percent of the land area. There is no vegetation of high brush or forest fire potential in close proximity to the array. There are no known nesting or breeding sites for wildlife species near the site. There are no known unique vegetation and wildlife communities or rare or endangered species in the area.

Sonic Conditions--The project site is beside the generating units and cooling towers of the station. These facilities are high level noise sources: the noise level varies from 70 to 115 decibels. At the project site, a noise level of about 65 decibels is expected.

Visual Conditions--The area within view of the project includes generating units, cooling towers, retention pond, and open land with some grasses. Areas outside of the station boundary include only open lands.

Socioeconomic Conditions--The project site is away from major population centers of the city of El Paso; there is no human habitation in close proximity. Manpower needed during construction would have to come from the city of El Paso and nearby areas.

The direct impact of the project on these conditions are as follows:

Hydrologic--Water needs for the project are undetermined but will probably be less than 4,000 gallons per year for washing and rinsing of the photovoltaic array. Water needs are met, without difficulty, by the power plant's existing water system.

Except for these wash waters and rain water runoff from the project area, there are no other surface water discharges. Any detergent used will be government approved and biodegradable; however, the predicted total amount of detergent used would be too small to cause any significant effect. The water runoff route from the array field follows the existing ditch to the water retention pond, as does the runoff from the site.

Atmospheric--Air quality effect of the photovoltaic project is negligible. Moreover, even this negligible effect will be beneficial, since the project energy output will displace burning of fossil fuel (natural gas) of about 540 Mcf/year. There are no odors or other unpleasant smell from the panels. In addition, because of its low height, the array field does not disturb the existing air circulation pattern. A small amount of heat is discharged to the air due to array cooling; again the effect of this is negligible.

Biotic--In order to keep the array field out of any shadows and to keep the array undersurfaces open for natural air circulation, it was necessary to gravel the project area. It also will be necessary to treat the ground at the array field occasionally with some antiweed chemical. The net effect of these actions, as far as biotic conditions are concerned, is that there will be a continued absence of vegetation in the area. As far as wildlife is concerned, no significant habitat loss is anticipated.

Sonic--The project does not generate any appreciable sound. Furthermore, any sound generated will be below levels of that generated by the adjacent power plant.

Visual--Photovoltaic arrays and related structures are not visually repulsive. The array is low in profile with respect to the surrounding structures. The array field as a whole looks like a parallel series of slanted glass panes. It is aesthetically pleasing. Reflected light from the panels does not create any hazard. The lightning protection poles with the hanging wire between them will be no different, visually, from a regular utility pole with power wires. They do not have significant visual impact.

The safety and hazard impacts of the project are as follows:

Natural Hazards--The project should not be affected significantly by any of the natural hazards such as flood, landslides, earthquakes, etc. The photovoltaic panels are anchored securely to the ground so there is very little likelihood they could be washed away by expected water runoffs. Poles of the lightning protection system are embedded 10 feet underground and are secure.

The site is located in an area where potential earthquakes of magnitudes of 4-5 on the Richter scale could occur. Damage from such quakes could involve breaking of windows, so, potentially, the tempered glass panels could break. This unlikely prospect should be further reduced by the cushioning effect of the bonding material; other components are expected to be unaffected.

Since the project site is surfaced with gravel, whatever possibilities of landslide or land erosion that presently exist are reduced.

Fire and Explosion Hazards--There are no known project-inherent fire and explosion sources. Outside sources for such hazards could be nearby generating units, direct lightning hit, or a plane crash. Adequate safety measures are practiced in the generating station, so there is little possibility of fire or explosion originating from there. Project design incorporates an adequate lightning protection system. Newman station is not on the flight path to the airport. Since, the project site will be surfaced with gravel and since antiweed treatment will be used, the possibilities of brush fire or fire resulting from careless smoking in the area are remote. If there is an accidental fire in the array field, however, there is the possibility of release of some amounts of toxic gasses. In addition, in the event of a fire, sharp pieces of flying glass from collapsing panels could be hazardous to personnel within and near the area.

Electrical Hazards--The array field must be considered as a potential source of electrical hazard because of its very nature as an electricity-generating device. However, since interpanel wiring is underground, panel modules have a protecting glass surface, and intrapanel wiring is under the panels, actual potential for electrical hazard to a visitor with a competent guide is negligible. In addition, since the segment that needs maintenance may be isolated from the rest of the array field, potential electrical hazard to technical people is negligible.

The project's socioeconomic impacts are discussed below.

Land Use--Because of the small size of the project, it is not expected to have any impact on future land-use patterns.

Employment--There will be no impact whatsoever on the employment situation since existing station personnel will be responsible for operation and maintenance.

Taxes--EPE will pay additional property tax based on property value of the project.

Utility Rates--The project will have no effect on the existing EPE rate structure.

Based upon the above assessment of the major environmental considerations, it was decided that there would be no major environmental impacts resulting from the proposed project at Newman Station at El Paso, Texas.

2.2 Photovoltaic Module Procurement

El Paso Electric Company was chosen to procure the photovoltaic modules for two reasons: (1) at the end of the two-year operation period, the ownership of the array would be turned over to EPE, and (2) with the expected long life of the modules, a rapport needed to be developed between the manufacturer and the final owners of the array.

In the baseline proposal for Phase II, the module chosen for this project was manufactured by Photon Power, Inc. This system was optimal in the sense that the cadmium sulfide modules produced by Photon Power represent an emerging technology that has great potential for low cost and high volume production. In addition, Photon Power, the manufacturer, is located in El Paso, Texas, so that all aspects of the installation at El Paso Electric's Newman Station would be carried out by a local team.

The disadvantage with the baseline system was that the cadmium sulfide modules were of low efficiency and the pilot plant was still in its experimental stages.

An optional proposal was later submitted. It differed from the baseline proposal in only one major respect. Namely, the chemically sprayed, thin film cadmium sulfide/copper sulfide photovoltaic modules were replaced with silicon photovoltaic modules produced by Solar Power Corporation (SPC).

This proposal had the advantage that the silicon modules had a much higher efficiency and were readily available from an established production plant.

The differences in the design were minimal. Fortunately, the optimum operating voltage of the silicon module was almost the same as the cadmium sulfide modules, so that panels composed of nine series-connected modules could be used. The panel dimensions changed, of course, and the field area was considerably reduced. Design changes were made for the optional proposal without problem.

SPC was chosen as the silicon module supplier. They were already involved with two other PRDA projects--the Lovington Project, where they supplied the modules, and the Beverly High School Project, where they were prime contractor. Their module had met all performance specifications and tests and was approved by DOE for these applications. There was also a time constraint that made the SPC module an attractive choice. Had this time constraint not existed, EPE would have solicited competitive bids on the module.

It was difficult for EPE to obtain an authorization to order the modules without a firm price quote, and SPC was reluctant to give a firm price quote without an order. Finally, through the insistence of NMSEI, a price quote was obtained. This price was only good for an order placed within 180 days of the quote date. This time period lapsed before EPE was given authorization to order the modules. When EPE did receive authorization, the price paid was $9.15 per peak watt @ 28°C, 15 cents more per peak watt than the original quote.

When purchasing expensive equipment, the standard procedure for EPE is to write specifications and conduct a competitive bid process. SPC felt there was no reason for specifications to be written when purchasing an off-the-shelf item. EPE, however, continued with the specifications, complying with standard utility procedure. The specifications included items such as contractual relationships, warranties, indemnifications, cancellation, etc. SPC rejected many sections of the specification, insisted that they be changed, and refused to compromise on any of the points in question. Finally, at government direction, EPE changed the specifications according to SPC's requests. At this point, had this not been a DOE experimental project, EPE would probably have looked for another supplier.

One major objection that EPE had was SPC's warranty [7]. It seemed to EPE that a manufacturer should be willing to warrant a module, with an expected life of 20 years, for more than one year. However, even though EPE was willing to purchase additional years of warranty, SPC would not extend the warranty. Under standard conditions a warranty such as this would not be sufficient from a utility viewpoint.

2.3 Fabrication and Installation

The system installation was accomplished for the most part according to the Assembly Installation and Checkout Plan [4]. The only major change was in module handling. When the modules arrived from the manufacturer, the handling instructions supplied by Solar Power Corporation (Appendix C) were carefully followed. Suction cup lifters were procured to lift the glass-faced modules and align them in the frames. However, using these devices proved to be cumbersome, unreliable, and unnecessary. Taking advantage of the rubber-like gasket that had been placed around the module edge to protect against transverse impact during shipping, workers could position the modules by hand with no damage in panel population.

2.4 Integration and Test Plan

The integration and test plan emphasized two points--personnel safety and prevention of damage to existing equipment. Following the test plan presented below resulted in a successful integration of the PV power system into the UPS.

20-Kilowatt El Paso Electric PV Array
Test Plan

Before connection to the UPS bus, a thorough check of the PV system, including the array and associated control circuitry, will be conducted. This paper enumerates the tests that will be performed by NMSEI with assistance of the electrical contractor, Callaghan Electric of El Paso, Texas. All test data will be logged and maintained on-site at the Visitor Center (VC). The following tests will be conducted (refer to Site Plans, sheets 5 and 6):

Test #1. Open Circuit Voltage (V_{OC})

At each of the 12 panel connection junction boxes (PCJB), measure and record V_{OC} for each panel. The six manual shorting switches in the array field must be open. Before each PCJB check, the insolation(S) and ambient temperature (T_A) are to be recorded.

Test #2. Panel Short Circuit Current (I_{SC})

Sequentially close the six shorting switches and measure the I_{SC} for each panel at the PCJB. Both S and T_A are to be measured and logged before each set of PCJB measurements. The manual shorting switches are to be opened after the test is complete.

Test #3. Protection Diode Check

At each PCJB, disconnect the negative side of the diode and check forward and reverse biased resistance. Record. The six shorting switches must be open.

Test #4. 0.1 Ohm Resistor Check

At each PCJB, measure but do not record each 0.1 ohm resistor. No action to be taken unless value exceeds 0.15 ohm. Then, replace resistor and record action. Shorting switches must be open.

Test #5. Loaded Voltage Test

At the main array junction box (MAJB), connect 1.2 ohm 25-kilowatt resistive load. The double breaker at the MAJB is positioned to short the array and open the VC side. The six manual shorting switches must be open and the switches at the in-line fuses must be closed to allow PV current to flow to the MAJB. At the MAJB, unshort the array and allow array current to flow to the load. At each of the three row summing junction boxes (RSJB), measure and record the operating voltage. Measure and record S and T_A.

Test #6. Operating Current

With the same setup as Test 5, measure the operating current at each RSJB. Measure and record S and T_A.

NOTE: It will be necessary to perform both Test #5 and Test #6 in a series of steps due to heating of the resisitive load.

Test #7. Transients

At the MAJB, use an oscilloscope and camera to record transients in the operating voltage when the resistive load is switches on/off the array. At the RSJB, monitor and photograph current transients with the oscilloscope when the resistive load is switched on/off the array. Monitor and photograph transients present on the UPS bus at Point A.

Test #8. Logitrol Sequence Check

The Logitrol performs three major switching functions: (1) short/ unshort, (2) ground/unground, and (3) close/open contactors to the UPS bus. After installation of the dc switchboard and Logitrol equipment in the VC, proper operation can be tested by attaching the resistive load at the outdoor control room circuit breaker box. Simultaneous tests can be performed at the array grounding point, at the VC for short circuit current, and at the resistive load for contractor closure to determine the proper sequencing of the Logitrol. The timing for a complete switching sequence in both ordinary and emergency switching conditions will be recorded.

Test #9. Instrumentation Wiring Checkout

Verify correct and valid connections between the PCJB and the array instrumentation junction box (AIJB). Further verify correct connections between the AIJB and the main instrumentation junction box (MIJB) in the VC.

Test #10. Remote Temperature Sensor Check

Verify circuitry between the six array temperature sensors and the MIJB. Check and record the reading at the MIJB.

Test #11. Weather Station Wiring Checks

Verify corrections of wiring between all weather station instruments and MIJB. Check and record voltage readings of pyranometers and reference cell.

Test #12. ODAS Check

Verify proper connections of all instrumentation to the ODAS rack. With resistive load connected to Control Room circuit breaker box, initiate ODAS software scan of all sensors. Command hard copy printout and check for appropriateness.

Test #13. Panel I-V Curves

Measure and record the I-V curve for each panel in the array, using X-Y plotter and reostat connected at the PCJB. Measure and record S and T_A before each plot.

2.5 Operation and Verification Plan

A preliminary plan was prepared and submitted early in Phase II [5]. This plan was updated and used as a basis for the 30-day test that was conducted after system integration. Emphasis was placed on the operation of the PV control system. This microprocessor-controlled unit has much versatility, and different sensing levels may be programmed into the unit. Selecting the proper setting for automatic turn on/off, arranging for immediate disconnect under emergency conditions, and providing overvoltage protection for both the array and the UPS were issues to be resolved. The basic plan also called for testing the instrumentation system, protection system, and PV array. Each subsystem operation was to be verified before total system operation commenced. This method proved to be an efficient and logical approach and the 30-day test was completed without delay.

3.0 SYSTEM CONSTRUCTION

The El Paso PV system was fabricated and electrically connected by small business firms with no prior PV experience. The construction was completed without significant problems. Many areas were completed before schedule. The total time required was just over five months. A schedule showing major milestones is given in figure 4.

3.1 Site Preparation

The selected site required little preparation. No fill work or grading was needed. The site had approximately a 1 foot per 100 foot drop from west to east and was very near level north to south. The array was located south of an existing 12-foot drainage waterway. Since the Visitor Center building was located on the north side of this ditch, the power and instrumentation cabling conduits were incorporated into the design of a pedestrian crosswalk across the ditch. Initial plans called for this walkway to be procured and placed on site. However,

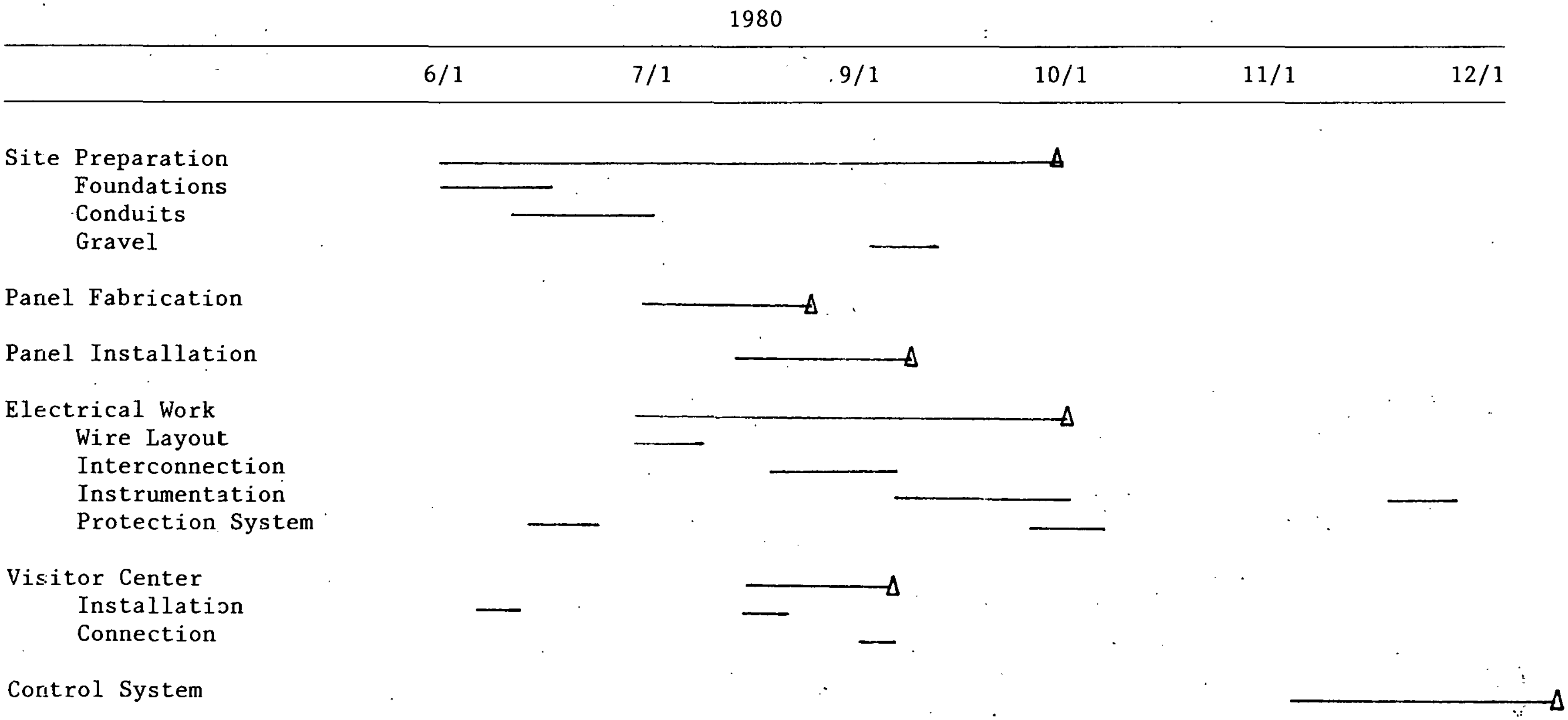


Figure 4. Construction Schedule

because of escalating costs for this item, the project contractor, Ponsford Brothers, constructed a form and poured a concrete walkway, including underneath conduit access ways, in place.

Based on information obtained by taking soil samples, the concrete foundation curbs for the three rows of PV panels were designed and installed without major trenching required. The details of this work are given in Appendix A, drawing 3. The curbs were leveled north-south, but allowed to follow the gradual west-to-east slope. Tie-down bolts were placed in the concrete curbs during installation. The curbs are designed to provide secure foundations for the panels to withstand 45 meters per second winds.

All peripheral concrete work was accomplished at the same time as the panel foundation curbs. This included the pads for the weather station, the main array disconnect box, and support bases for the Visitor Center.

The trenching for all cabling conduit installation was completed concurrently with the concrete work. After installation, gravel base was spread to reduce dust problems in the construction area (figure 5).

3.2 Panel Fabrication and Installation

The panels are composed of nine series-connected modules in a 3 x 3 matrix. Panel dimensions are 10 feet $4\frac{7}{8}$ inches x 4 feet $4\frac{7}{8}$ inches, Appendix A, drawing 2. The panel structural material selected for this application is pressure-treated pine (figure 6). This material was selected for the following reasons: (1) it is readily available, (2) it is easily worked, (3) it is ideal for small business fabrication, (4) it has long life, (5) the wood itself is a renewable solar energy resource,

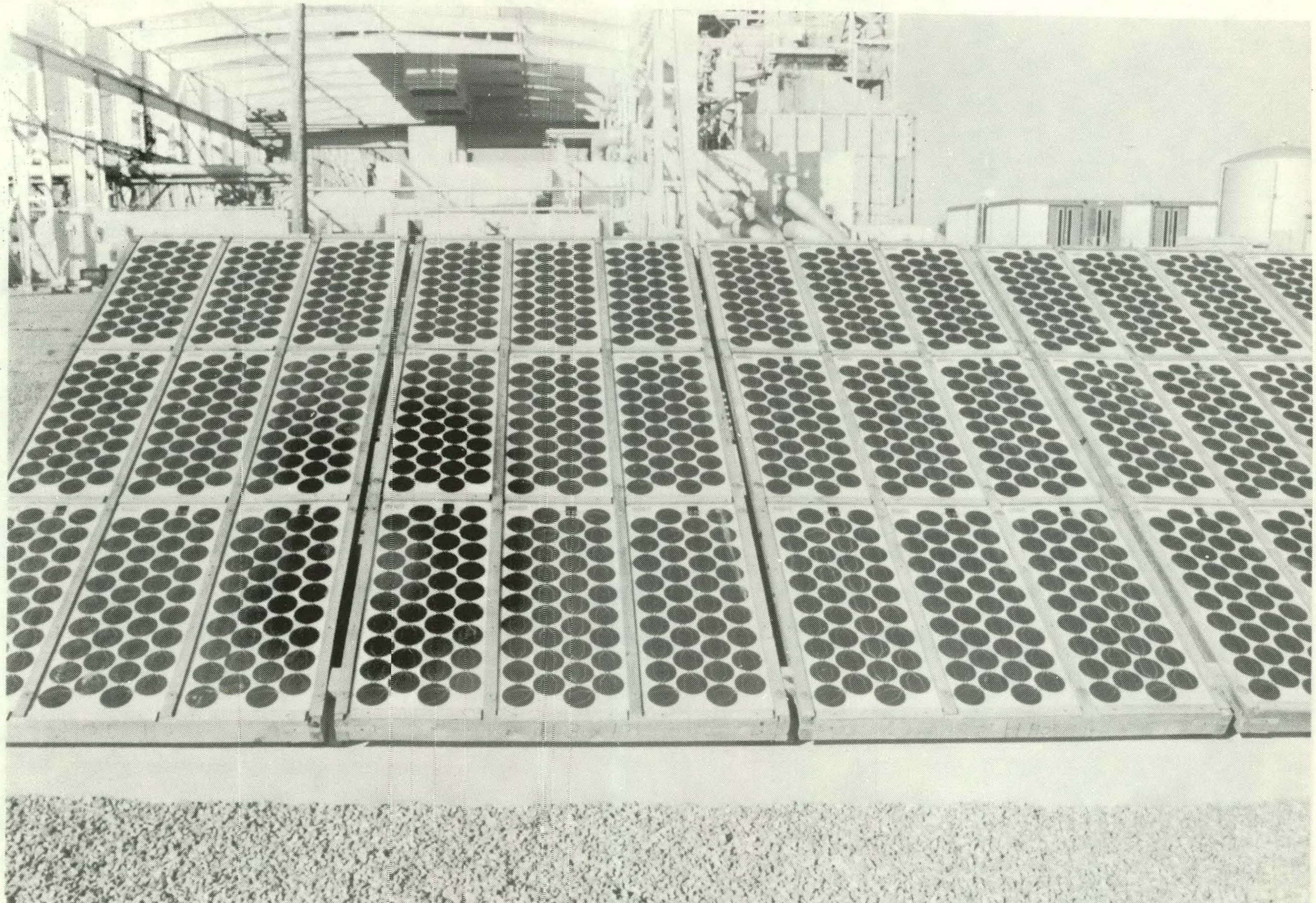


Figure 5. PV Array, Showing Gravel and Concrete Curbs

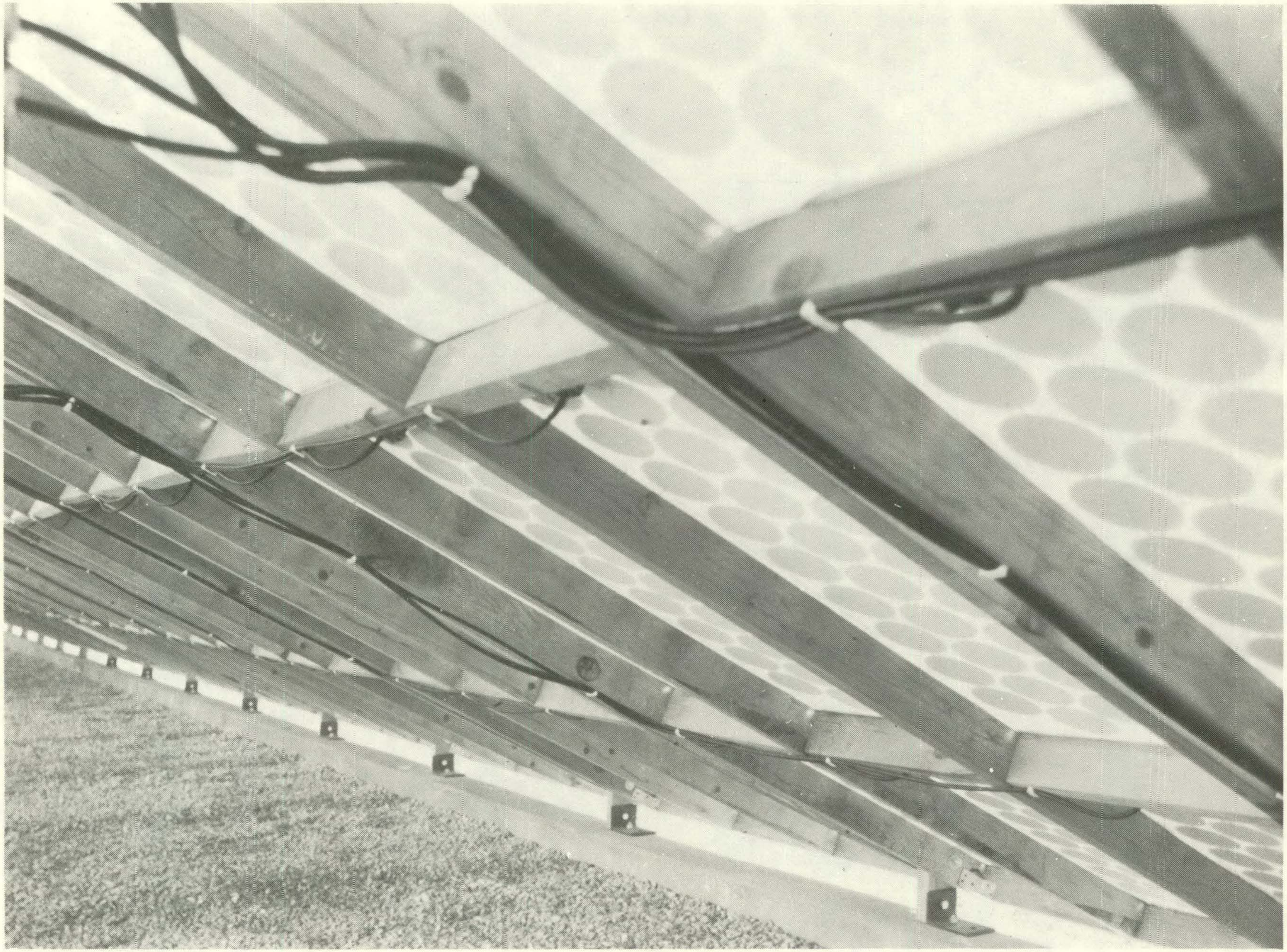


Figure 6. Pressure-Treated Pine Panel Frames. Note panel tie-down clamps on concrete curbs.

and (6) the cost for this project was lower than could be realized using metal frames. It was also noted that in the dry desert climate of the Southwest similarly treated wood structures have lasted for years.

The pressure-treated pine used for panel fabrication was delivered to the Ponsford Brothers warehouse immediately after treatment and had to be dried before fabrication could begin. The 2 x 4s were first sawed, then routed, then fabricated.

Original plans called for complete fabrication of the panels, including the module installation, in the shop, with subsequent delivery to the Newman Station. However, the flexibility of the panels raised concern over the risk involved in transporting them; so the frames were made in the shop, transported to the site, and partially installed without the modules. Modules were installed in the frames in situ and the panels were then raised to the proper tilt angle and fixed in place. The modules are aligned into the recessed frame so that they are flush with the top of the panel frame. They are held in place by a 1½-inch-wide ¼-inch wooden batten held down by 12 wood screws. The total installation process was efficient and reliable--none of the 576 modules was damaged.

3.3 Electrical Power Cabling Installation

The system power cabling was installed according to plan, Appendix A, drawings 4, 5, and 6. The design criterion was to minimize the power loss due to resistance heating. This required routing the heavy current-carrying conductors the shortest possible distance and sizing the conductors as large as economically practical. The system, as installed, has a voltage drop wire loss of 2.5 volts at 150 amperes.

The power loss is 357 watts, or less than 1.8 percent, for these conditions.

All cabling is enclosed in conduit from the array to the Visitor Center. Starting at row three, the southernmost row, the power is collected from the two subarrays and united at the row summing junction box (RSJB). For this operation, #6 TW-3/4"C cable is used. This power is routed to the RSJB at row two, where it is combined with the power from the row two subarrays. This run uses #350 MCM TW-2"C cable. This power is subsequently carried to the row three RSJB, where it is again combined with row three power. The total array power is then conducted, using #350 MCM cable, through the main arrary disconnected box to the Visitor Center.

All junction boxes and switch boxes are galvanized (figure 7). This may not be necessary for the dry Southwest climate, and some savings could be realized by eliminating this contract requirement. All the boxes are also oversized. This allows convenient testing on the subsystem level, but would not be necessary on future systems.

The main array disconnect box was originally designed to house two circuit breakers with a kirk key interlock. The breakers were to open/close the array to the Visitor Center power circuit and to short and ground the array at the disconnect box. The interlock was to prevent the array from being shorted, grounded, and connected simultaneously. This function was redundant since the same control exists in the dc switchboard in the Visitor Center, and each subarray may be isolated and shorted (but not grounded) at the subarray level. Because of the redundancy, the shorting and grounding capability were removed, leaving only a manually operated circuit breaker in the main array disconnect box.

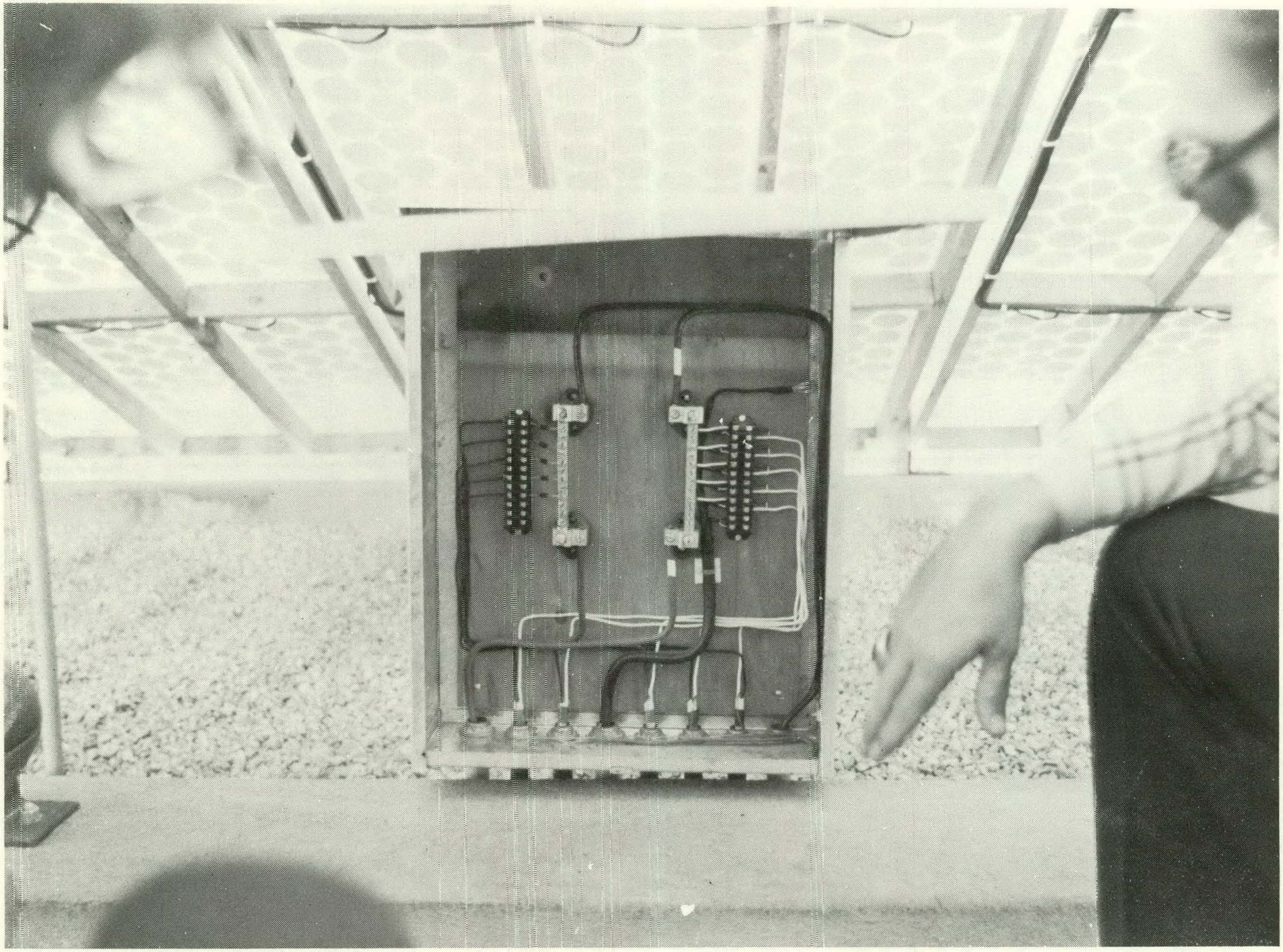


Figure 7. Galvanized Panel Connection Junction Box

The physical connection to the existing UPS is made and controlled at the dc switchboard in the Visitor Center. From the Visitor Center the power is routed through another PV system disconnect switch at the #4 control room of Newman Station.

3.4 Instrumentation Subsystem

To monitor the performance of the PV system and weather conditions, an extensive instrumentation network was designed and installed [6]. All wiring was installed in conduit. The instrumentation cabling used was individually shielded #22 twisted pairs. The cable shield was collected and grounded at one point only--the power ground available at the dc switchbox in the Visitor Center.

To provide string current information, a 0.1-ohm, 2-watt resistor was placed in each panel output circuit. These resistors are located in the panel collection junction box (PCJB). This requires 64 pairs of cable to be distributed throughout the array. To accomplish this, each row has an instrumentation summing box with direct access to the main instrumentation box in the Visitor Center. In addition to this circuitry, provision for six cell temperature monitors were located in the array--two per row. An integrated circuit temperature sensor--the LM 334--was selected over other techniques because of low cost and compatibility with ODAS hardware signals available. The specifications of the LM 334 are given in figure 8. The devices were all calibrated to a 45°C set point at NMSEI before installation.

The weather station cabling was a straightforward installation except that the amount of control cabling required for the Sun Tracker was not specified when the initial conduit was laid. When the

National Semiconductor

AUGUST 1977

LM134/LM234/LM334 3-Terminal Adjustable Current Sources

General Description

The LM134/LM234/LM334 are 3-terminal adjustable current sources featuring 10,000:1 range in operating current, excellent current regulation and a wide dynamic voltage range of 1V to 40V. Current is established with one external resistor and no other parts are required. Initial current accuracy is ±3%. The LM134/LM234/LM334 are true floating current sources with no separate power supply connections. In addition, reverse applied voltages of up to 20V will draw only a few microamperes of current, allowing the devices to act as both a rectifier and current source in AC applications.

The sense voltage used to establish operating current in the LM134 is 64 mV at 25°C and is directly proportional to absolute temperature (°K). The simplest one external resistor connection, then, generates a current with ≈+0.33%/°C temperature dependence. Zero drift operation can be obtained by adding one extra resistor and a diode.

Applications for the new current sources include bias networks, surge protection, low power reference, ramp generation LED driver, and temperature sensing The LM134-3/LM234-3 and LM134-6/LM234-6 are specified as true temperature sensors with guaranteed initial accuracy of ±3°C and ±6°C, respectively. These devices are ideal in remote sense applications because series resistance in long wire runs does not affect accuracy. In addition, only 2 wires are required.

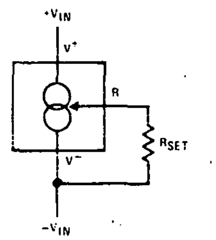
The LM134 is guaranteed over a temperature range of −55°C to +125°C, the LM234 from −25°C to +100°C and the LM334 from 0°C to +70°C. These devices are available in TO-46 hermetic and TO-92 plastic packages.

Features

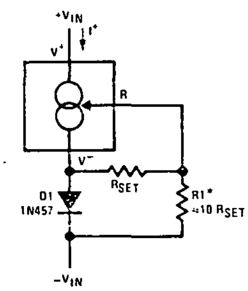
- Operates from 1V to 40V
- 0.02%/V current regulation
- Programmable from 1 μA to 10 mA
- True 2-terminal operation
- Available as fully specified temperature sensor
- ±3% initial accuracy

Typical Applications

Basic 2-Terminal Current Source

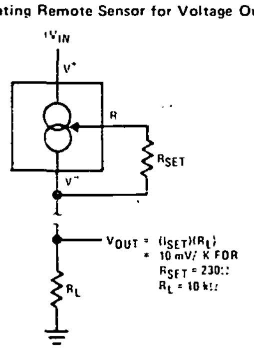


Zero Temperature Coefficient Current Source

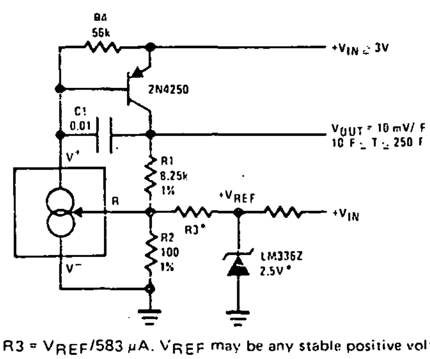


*Select ratio of R1 to R_{SET} to obtain zero drift. $I^+ \approx 2\ I_{SET}$

Terminating Remote Sensor for Voltage Output



Ground Referred Fahrenheit Thermometer



*Select R3 = V_{REF}/583 μA. V_{REF} may be any stable positive voltage ≥ 2V Trim R3 to calibrate

IM-B20M87/Printed in U.S.A.

Figure 8. Specifications for the LM 334

additional cabling requirement was known, the extra wires were routed to the weather station via an oversized conduit from the Visitor Center to the main array disconnect box. A short length of conduit was installed from the main array disconnect box to the weather station.

3.5 Weather Station

The weather station instruments were supplied by DOE through a "loan" from Sandia National Laboratories (SNL). A list of equipment is given in table 2.

TABLE 2. WEATHER STATION EQUIPMENT LIST

Quantity	Property Number	Description
1	B948232	Aspirated shield, P/N 100325-2, S/N 338
1	20629-003	Dew point sensor, P/N 100743
1	20629-004	Bobbin, P/N 100743-1
1	20629-005	Temperature sensor, P/N 100093
1	B948203	Wind speed and direction, P/N 100108, S/N 1057
1	B948235	Heated precipitation gauge, P/N 100508-2
1	2069-006	WM-III Cup assembly, P/N 100160, S/N 149
1	20629-007	Vane assembly, P/N 100107
1	B948214	Barometric pressure gauge, S/N 15013
1	B948023	Pyranometer, P/N 100PSP, S/N 18533F3
1	B948022	Pyranometer, P/N 100PSP, S/N 18530F3
1	B948037	Pyrheliometer, P/N 100N1P, S/N 18644E6

The weather station equipment, instrumentation, cabling, and power were installed by the contractors. All units are operational except the sun tracker. This instrument, under development by SNL, has not been used because of hardware problems and a lack of control software.

3.6 Visitor Center

Plans for the Visitor Center called for a small prefabricated building to house the dc switchboard and controller, the ODAS, and to provide a display area for system information. Because the original Visitor Center supplier raised his price 50 percent before the order was placed, an alternative supplier, Sun Country Homes, Las Cruces, was located and the Visitor Center was purchased, installed, and electrified for about $15,000. The 240-square-foot building is equipped with two window-mounted heat pumps to provide a stable temperature environment.

No problems were encountered with the Visitor Center and, to date, the simple inexpensive building has proven adequate for all purposes. Located north of the PV array, the Visitor Center can be seen in figure 2.

3.7 Protection System

The PV system, as installed, has incorporated redundant system protection schemes. At the panel level, a blocking diode is installed in each panel lead. These diodes, located in the RSJB, prevent current flow into the series string of modules. Each two subarrays (each row) is equipped with a 750-volt dc G.E. 18L4NH surge capacitor. These were installed to provide a ground path for any high frequency transients. At the dc switchboard in the Visitor Center, two G.E. 300A blocking diodes are incorporated into the UPS connection scheme to prevent any current flow from the UPS toward the array. These diodes cause a voltage drop of 2 volts at 150 amperes, but were mandatory to protect the array from the near unlimited current capacity of the UPS.

The lightning protection provided has several facets. First, all cabling is buried in conduit and this decreases the potential effects of a lightning strike dramatically. In addition, a grounded overhead cable has been installed approximately 5 feet north of the northernmost row of the array. This cable is suspended from two 30-foot wooden poles and is designed to provide lightning protection for the three rows of the array. In case of a nearby lightning strike inducing voltage and current on the array cabling, a transient suppressor has been installed, figure 9. This device is specified to become active at 250 volts and to provide a ground path for up to 1.2 Joules of induced energy. The response time is purported to be $<$ 10 microseconds.

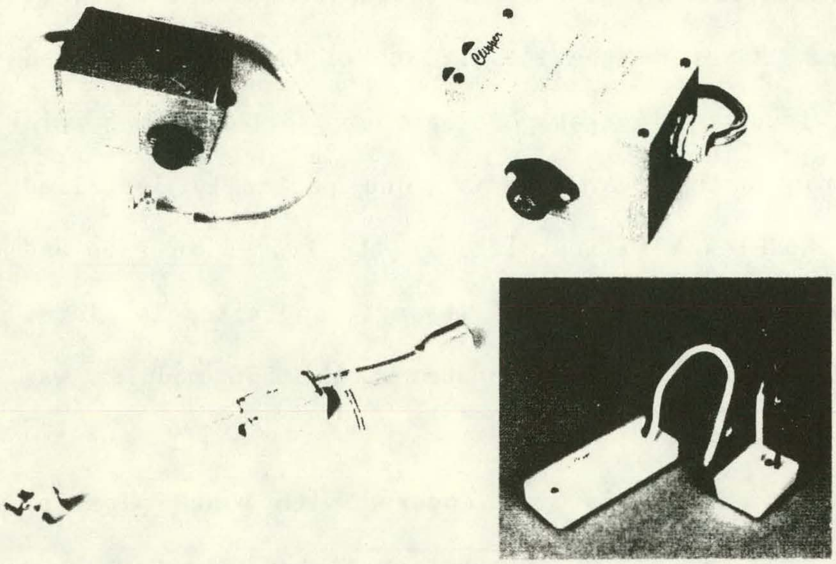
Finally, an operational procedure has been defined so that during severe electrical storms in close proximity to the PV array, the system will be disconnected from the UPS and shorted and grounded. The redundancy of the protective devices should provide adequate protection to the PV system.

4.0 SYSTEM INTEGRATION AND TEST

System integration and checkout were conducted according to the Assembly, Installation, and Checkout Plan [4], the Operation and Verification Plan [5], and the Instrumentation Plan [6] developed during Phase II.

The *Clipper*™

LINE VOLTAGE TRANSIENT SUPPRESSORS



- Bi-Directional
- Parallel Operation
- Less Then 5 nanosecond Response Time
- Duty Cycle of .05%
- Polar and Bi-Polar
- Fused with Pilot Light Indicator
- Operates from 50Hz to 415Hz
- Operating Temperature from —35°C to 75°C

Typical Applications Requiring CLIPPER Protection:

- Computer Systems
- Process Control
- Instrumentation
- Communications Systems
- Video and Audio Equipment
- Medical Monitoring Equipment
- Mobile Broadcast Equipment
- Computerized POS Systems
- Electrical Motors

TRANSIENT VOLTAGE SURGE SUPPRESSOR
UL FILE No. E70373(M)

678F
UL
LISTED

MEETS UL 1449 FOR SURGE SUPPRESSORS

MEETS IEEE GUIDELINE FOR SURGE VOLTAGES

****FULL ONE-YEAR WARRANTY****

DYMARC Industries, Inc warrants these products, including, but not limited to those products manufactured to specifications supplied to them, for a period of one (1) year from the date of delivery to the purchaser to be free from defects in both workmanship and materials. Any defect appearing more than one year from the date of delivery to purchaser shall be deemed to be due to ordinary utilization of the product. DYMARC assumes no risk or liability for results of the use of these products purchased from them, including, but without limiting the generality of the foregoing (1) The use in combination with any electrical or electronic components, circuits, systems, assemblies or any other material or substances; (2) unsuitability of any product for use in any circuit or assembly. Purchaser's rights under this warranty shall consist solely of requiring DYMARC Industries to repair, or in DYMARC Industries sole discretion replace, free of charge, F.O.B., factory, Baltimore, Maryland, any defective items received at said factory within said year and determined by DYMARC to be defective. The giving of or failure to give any advice or recommendations by DYMARC shall not constitute any warranty by or impose any liability upon DYMARC. The foregoing constitutes the sole and exclusive remedy of the purchaser and the exclusive liability of DYMARC Industries, and is in lieu of any and all other warranties, expressed, implied or statutory as to merchantability, fitness for purpose sold, description, productiveness, quality, or any other matter. In no event shall DYMARC Industries be liable for special or consequential damages or for delay in performance of this warranty.

PATENT NOS. 247.030-247.031 OTHERS PENDING

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Figure 9. DYMARC Line Voltage Transient Suppressor

Original plans called for complete fabrication of the panels, including the module installation, in the shop, with subsequent delivery to the Newman Station. However, the flexibility of the panels raised concern over the risk involved in transporting them; so the frames were made in the shop, transported to the site, and partially installed without the modules. Modules were installed in the frames in situ and the panels were then raised to the proper tilt angle and fixed in place. This process was efficient and reliable--none of the 576 modules was damaged.

During this process the panels were covered with black plastic. This was done to allow electrical interconnection of the panels with no voltage or current being generated. However, it soon became apparent that the labor required to keep the black plastic on the panels was more than could be justified. The plastic was removed and the electrician wired the system from the Visitor Center outward--making all connections up to and including the module junction box while the modules themselves were still disconnected. The last step was connecting the nine modules in series at the module junction box. This could be done with exposure to only the module voltage (V_{OC}) of approximately 20 volts. The electrical contractor, Callaghan Electric of El Paso, expressed confidence in this method and found no safety concerns in implementing the wiring.

4.1 Initial System Checkout

The checkout sequence focused on three items: array wiring verification, instrumentation wiring verification, and array interconnect with the uninterruptible power supply (UPS).

Array wiring verification demonstrated that module interconnect wiring within panels was correct, and that panels were correctly tied in correct routing of wiring from distributed field sensors to the main instrumentation junction box (MIJB) in the Visitor Center. The interconnect to the UPS is necessarily the last step and was not attempted until successful completion of the previous two tests. These tests were carried out according to the informal test plan given in Section 2.4.

Following this test plan resulted in a successful, safe system checkout. Data recorded during each step are now part of the project log.

Conducting Test #1 (V_{OC}), it became apparent that a large number of panels exhibited below normal open circuit voltage. Further testing at the module level found a number of modules with either zero output or a V_{OC} one-half the nominal value. These problems seemed to be more numerous at cold temperatures.

A number of failed modules were returned to Solar Power Corporation for repair or replacement. Although information concerning the problem and the proposed solution was not forthcoming in a timely manner, there was no alternative but to continue replacing the modules that displayed the problem and returning them for repair. Fortunately, a larger than recommended number of spares (28) had been purchased for this project, so the full complement of the array was maintained at all times.

The module failure history is given in table 3.

TABLE 3. MODULE REPLACEMENT

October 80	9
November 80	6
December 80	4
January 81	11
System Start-up	
February 81	3
March 81	4
April 81	1

4.2 Module Performance Baseline

During June 1980, the 602 modules were delivered and each was visually inspected for obvious defects or breakage due to shipping. Thirty of the modules were randomly selected for further electrical testing, which included automated I-V plotting in natural sunlight. Solar insolation was measured and a thermal instrumented module, adjacent to the test modules, was monitored for nominal operating cell temperature (NOCT). The I-V curves were normalized to 1,000 watts per square meter and 46°C NOCT, and the data were compared with that supplied by the module manufacturer. The module performance obtained by NMSEI was consistently lower than data exhibited by Solar Power Corporation, but the difference was small (~6 percent) and may not be statistically significant. None of the 30 modules was found to be inoperative. A summary of results is given in Table 4.

4.3 Control Subsystem

The PV system controller selected for this project is the General Electric Company's Logitrol 550. This microprocessor-based controller

TABLE 4. 30 JULY DATA/SOLAR POWER DATA (NORMALIZED)

Serial # 13xxx	SP* V_{OC}	SEI** V_{OC}	%	SP I_{SC}	SEI I_{SC}	%	SP Pop	SEI Pop	%
004	19.4	19.0	2	2.26	2.39	5	30.9	29.1	6
015	18.9	18.8	<1	2.22	2.34	5	28.7	29.2	1.7
070	19.5	18.8	3.7	2.21	2.33	5.4	29.5	27.4	7.6
084	19.4	18.6	3	2.22	2.36	6	30.2	26.0	16
086	19.4	19.12	1.5	2.32	2.44	5	31.0	29.2	6
109	19.6	18.9	4	2.23	2.43	9	30.3	27.9	8.6
138	20.1	19.8	1.5	2.23	2.34	4	31.6	30.4	4
147	19.5	19.1	2	2.35	2.46	4	30.5	28.3	7.7
157	19.6	19.3	1.5	2.26	2.41	6.6	30.2	29.1	3.8
212	19.5	19.4	-	2.15	2.29	6.5	29.6	28.0	5.7
226	19.6	19.3	1.6	2.33	2.4	2.8	31.0	29.1	6.5
304	19.8	19.1	3.6	2.25	2.36	4.6	31.8	30.4	4.6
331	19.7	19.4	1.5	2.29	2.35	2.5	30.5	29.3	4
398	19.7	19.3	2	2.26	2.40	5.8	30.3	29.8	1.7
375	19.7	19.2	2.6	2.27	2.37	4.4	31.7	30.6	3.6
607	19.2	19.0	-	2.21	2.47	11.7	29.0	28.0	3.6
674	19.4	18.9	2.6	2.19	2.26	3.1	28.4	26.9	5.6
683	19.7	19.7	-	2.12	2.19	3	30.4	30.1	1
687	19.1	18.4	3.8	2.12	2.18	2.7	27.0	23.4	15
697	19.2	18.2	5.5	2.17	2.28	5	27.4	23.5	16.6
707	18.9	18.3	3.3	2.18	2.27	4	27.0	24.0	12.5

* SP - Solar Power Corporation
** SEI - New Mexico Solar Energy Institute

TABLE 4. -Continued

Serial #	SP* V_{OC}	SEI** V_{OC}	%	SP I_{SC}	SEI I_{SC}	%	SP Pop	SEI Pop	%
753	19.1	18.7	2	2.14	2.23	4	28.0	25.7	8.9
773	19.6	19.4	1	2.24	2.32	3.4	31.6	30.4	3.9
794	19.4	18.9	2.6	2.24	2.31	3	30.2	28.5	5.9
840	19.0	18.7	1.6	2.24	2.38	6	27.9	26.4	5.7
848	19.1	18.4	5.9	2.16	2.30	6.5	29.1	26.4	10
855	19.8	19.5	1.5	2.29	2.31	1	31.7	30.6	3.6
866	19.4	19.2	1	2.22	2.35	5.8	30.1	28.4	5.9
926	19.9	19.3	3.6	2.23	2.40	7.6	32.0	30.2	5.9
960	19.7	19.0	3.7	2.21	2.35	6.3	31.2	29.1	7.2
μ			2.32			4.99			6.63
σ			1.47			2.16			3.98

* SP - Solar Power Corporation
** SEI - New Mexico Solar Energy Institute

has a wide range of capability and can be programmed to control up to 69 relays and/or latching relays. Logic networks may be programmed to perform complex switching functions based on the state of monitored sensors.

Seventeen separate circuits have been programmed to perform the various control functions desired. Four separate contactors in the dc switchboard are controlled. These perform shorting, grounding, and connection of + and - array lines to the existing UPS. The contactors are controlled according to the sensed array current--in both operational and short circuit conditions--and the UPS bus voltage when the array is connected. In normal operation the following procedure is used.

Before Dawn	Array is shorted, grounded, and disconnected. Short circuit current I_{SC} is monitored.
After Sunup	When I_{SC} reaches 8 amperes, a 60-second timer is initiated. The timer is reset each time I_{SC} falls below 8 amperes.
After Sunup	When I_{SC} >8A for 60 consecutive seconds, the + and - wires are connected to the UPS bus and an 0.8-second timer is initiated.
After Sunup	After 0.8 seconds, the array is ungrounded and unshorted. (During this brief period current flow from the bus to the array is prevented by the blocking diodes. The reason for this sequence is to

prevent the V_{OC} of the array from being momentarily impressed on the UPS bus.)

Clouds — The array, once connected, will remain connected during all but extreme cloudiness. The monitored array current must fall below 8 amperes (~1 kilowatt output power) for 60 consecutive seconds before the array would be disconnected.

Near Sundown — When the array current falls below 8 amperes for 60 seconds, the morning procedure is reversed. The array will be shorted, grounded, and, 0.8 seconds later, disconnected.

In addition to normal sequencing, provision for emergency shutdown has been made. A push button and a warning light have been installed in the main El Paso Electric control room at Newman Station, and a manual push button reset switch is available on the dc switchboard in the Visitor Center. Under emergency conditions (severe electrical storms, ground fault on the UPS bus, etc.) the EPE operators can disconnect the PV array. The response is as follows:

Emergency — Push button in main control room immediately activates + and - contactors and disconnects array from bus. Array remains open-circuited and ungrounded.

Post Emergency — To reactivate array, the reset button in the Visitor Center must be switched. When reset, a

60-second timer is activated; when the 60 seconds are up, the array is shorted and grounded. The I_{SC} is then sensed and if it is greater than 8 amperes for 60 consecutive seconds, the connect sequence is initiated.

When the array is connected to the UPS, the bus voltage is monitored continually. Should this voltage exceed 140 volts for 10 seconds, the PV array will be disconnected via the emergency shutdown routine. This provides a warning alarm to EPE and investigation of possible UPS problems is initiated.

The versatile control system used for the EPE system has allowed experimentation with the connection sequences. However, once these sequences are proven, a much simpler and less expensive system would be sufficient. This is an area where experience gained can result in large savings on future systems, since the logitrol cost is $1.75 per week.

4.4 Training and Safety

An important part of initial system operation and testing was the training program for El Paso Electric operators and maintenance personnel [7]. This training was conducted both by formal sessions and by demonstration of techniques on the job.

The training program covered the following items:

1. Basic PV operation
2. Site specific operation
3. El Paso PV system layout
4. Safety operating voltages and power

5. Switches
6. Emergency conditions and reactions
7. Troubleshooting techniques
8. Module handling techniques
9. Weather station operation
10. Visitor Center and PV controller
11. Daily walk-through checks

As a result of feedback from the training sessions, the walk-through sheet (figure 10) was enhanced and refined. Also, the emergency procedures were simplified and a manual reset was provided external to the dc switchboard. This reset provides a convenient method of sequencing the PV array back on-line after an emergency shutdown.

A copy of the visual aids used for the training program is given in Appendix B.

5.0 SYSTEM PERFORMANCE

The system output power was first applied to the UPS on 4 December 1980. After extensive testing, automatic operation of the system was initiated 27 January 1981. Except for periodic testing and one nine-day period when the UPS was down for maintenance, the system has operated unattended since. Initial data analysis indicates system performance is equal or greater than design predictions. The average daily energy produced is 95.1 kilowatt hours based on the first 80 days of operation. Based on five consecutive days in March, the system efficiency was calculated to be 5.95 percent. The peak output power of 22.9 kilowatts was recorded on 9 February 1981, with a plane of array pyranometer reading 1,222 watts per square meter and a cell temperature of 22°C. More system performance data is discussed in Section 5.2.

528A

EL PASO 20KW PHOTOVOLTAIC PROJECT

DAILY OPERATOR'S LOG

DATE ____________ TIME ________ NAME ____________________

DC SWITCHBOARD & CONTROLLER

Current	Voltage
Energy	**Power**

1. Record Readings
2. Do **not** reset kwh meter

DATA ACQUISITION SYSTEM

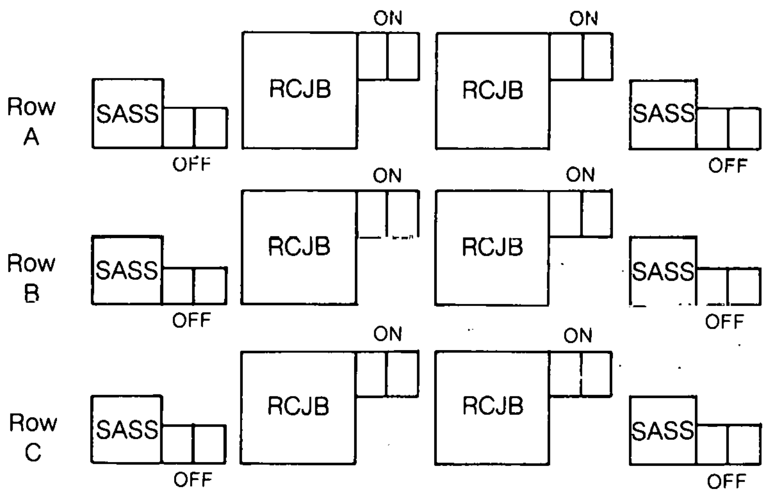
Interface _______ o B ON AC Power o _______ A
Voltmeter AC Power _______ C
Scanner AC Power _______ D
Scanner AC Power _______ E

1. Record visitor center temp. ____________
2. Place check mark next to appropriate letter if lights are on.
3. Check alarm conditions on harddcopy, if any, report to supervisor.
4. Staple all odas hard copies to this sheet.

Comments: ____________________

OUTSIDE

Switch box handles should be as shown below unless tagged.



1. Check weather station for debris ________
2. Clean pyranometer ________
3. All terminal boxes closed ________
4. Check temp sensors, 6ea. to verify attachment ________
5. Record visitor's center kwh meter reading ________
6. List below any abnormal array conditions:

Figure 10. Daily Walk-Through Sheet

REPORT ANY ABNORMAL CONDITIONS TO YOUR SUPERVISOR

5.1 Data Collection

To provide a broad data base for future system performance evaluation and analysis, a project was initiated as outlined in the Operation and Verification Plan [5]. The first portion of this plan was to verify the manufacturer's reported module performance. The results of this testing were given in Section 4.2. In this section the data collection techniques are discussed.

The instrumentation system for the photovoltaic project is extensive and independent of the PV system. The instrumentation system consists of sensors, wiring and connectors, monitoring equipment, and the computer, which controls the data acquisition rate. Much of this equipment was provided by DOE via a loan from Sandia National Laboratories. The major components of the on-site data acquisition system (ODAS) are listed in table 5.

TABLE 5. EL PASO PV SYSTEM EQUIPMENT LIST

Quantity	Property Number	Description
1	B947331	Computer, HP9845S
1	B947329	Multimeter, HP3455A
2	B947330 B949253	Data Scanners HP3495A
1	20629-12	System documentation
1	B951538	Modem
1	20629-12	Clock cable assembly
1	B949542	Power supply control, HP59590lA, S/N 1940A02977
1	20629-002	Weather station interface panel
1	206929-012	70" equipment rack

The ODAS computer (figure 11) controls the sensor scan rate and records the value of 84 sensors on magnetic tape. The parameters and scan rate are given in table 6. These recorded values are maintained on the magnetic tape and are accessible via telephone data transfer. Currently the data are being collected and archived by Boeing Computer Services and by NMSEI. After data transfer, the files may be reused, thus precluding the necessity for tape changes. At the El Paso

TABLE 6. ODAS PARAMETERS AND SCAN RATE

Parameters	Sample Interval
64 Panel String Currents	30 minutes
6 Cell Temperatures	1 minute
1 System Mode Detection	1 minute
1 Array Power	1 minute
1 Array Voltage	1 minute
1 Array Current	1 minute
1 Wind Speed Peak	1 minute
1 Wind Direction	1 minute
1 Barometric Pressure	1 minute
1 Ambient Temperature	1 minute
1 Dew Point	1 minute
1 Rain Fall	1 minute
1 Plane of Array Insolation	1 minute
1 Horizontal Insolation	1 minute
1 Direct Normal Insolation	1 minute
1 Reference Cell Insolation	1 minute

Figure 11. ODAS and DC Switchboard in Visitor Center

system, approximately six days of system performance data can be stored in a single tape.

Some problems have been experienced with data transfer routines. BCS personnel have been rectifying the problems as they appear. The biggest concern has been the implementation of software at BCS that will automatically change the data file prefix after that file data has been transferred. Changing the prefix allows the file to be "written over" with new data. If the file prefix is not changed, the data tape will fill up, and after six days of data has been recorded, the ODAS will stall because all data files are full. When this occurs, the only recourse is to go to the site, copy or replace the data tape, and restart the ODAS. Data is lost until this can be done. Several days of data were lost during early system operation because of this fault.

5.1.1 Initial System Test Data

As part of the Phase II contract, the system was operated in the "normal" mode for 30 days. The El Paso system was actually evaluated for more than four months before the Phase III contract was in place. System data were collected and evaluated. This data consisted of performance information collected by the ODAS, stored on magnetic tape, and transferred via telephone modem to NMSEI for analysis. It also consisted of fault location testing and maintenance data that was kept in the project log.

Because of the high rate of module failures experienced before the system entered this operational phase, the testing activity was maintained at a high level. After system start-up, further problems with modules were detected, with nine additional modules requiring replacement. These modules were all operating at one-half the operating voltage (~7.6 volts). With nine modules in series in each panel and with an array operating voltage of about 139 volts, each module should carry a voltage of 15.2 volts. With the array operating, this module voltage was read and recorded on numerous occasions. For any given panel the variation in module voltage was often greater than ± 1 volt, i.e., 14-16 volts. However, some modules measured as low as 12 volts. This caused the other modules in the panel to be operating at greater than 16 volts, well beyond the maximum power point.

These modules, operating at ~12 volts, were not replaced at the time but were noted and monitored closely. Some of them did drop to 7.5 volts under varying solar (temperature) conditions, but at this time it is too early to draw definitive conclusions about this problem. When the operating voltage of the module dropped to one-half value, the module was replaced. However, when the module was tested by itself, it tested good. The short circuit current grade of these modules was checked, and in seven of the nine failures the failed module was the same grade as other modules in the panel. In two of the cases, the "failed" module was of lower short circuit current grade than the remaining panel modules.

There are several open questions that must be answered.

1. Have these modules really failed or would they perform satisfactorily in lower performance panel strings?

2. Will it be necessary to categorize spares by short circuit current grade?

3. Does a measurement of 12 volts indicate an incipient failure?

These issues will be studied throughout the Phase III effort.

5.2 Data Analysis

Analysis of system performance data, as received from the ODAS, has been initiated at NMSEI. This activity consists of calculating array "figures of merit" (such as energy produced, efficiency, wiring losses, etc.), of developing and utilizing a fault insolation program, and of comparing actual results to those predicted by simulation routines. The result of the comparisons will be given in the next section.

The energy produced by the El Paso system is measured with an odometer-type instrument at the Visitor Center. It is not recorded by the ODAS but is read and recorded each day on the daily walk-through sheet. This figure may be checked by integrating the system output power, which is measured by the ODAS every minute, averaged, and recorded every 10 minutes, over time. Several days of data have been cross checked in this manner and no significant difference has been found. The meter in the Visitor Center will be utilized as the sole energy indicator in the future. Monthly performance criteria for the first two months of system operation are summarized in table 7.

5.2.1 Fault Isolation Techniques

Since the PV system is located 40 miles from NMSEI, it is desired to be able to perform some fault location without physically visiting the site. For this purpose NMSEI is perfecting a fault isolation routine that is based on statistical testing of the string currents measured on each of the 64 panels. Initial results look encouraging. Panels that are not performing as expected have been isolated and marked for further testing. A problem has been found and corrected each time. The open question is the precision to which this procedure can be refined. Analysis will continue throughout Phase III.

TABLE 7. MONTHLY PERFORMANCE*

	February	March
Peak Power (kw)	22.9	19.5
Date	9 Feb	7 Mar
Plane of Array Insolation W/m^2	1222	1097
Measured Cell Temperature °C	22	19.5
Energy Produced (kwh) Best Day/Date	111/5 Feb	128/18 Mar
Average Turn-on Time	0720	0706
Average Turn-off Time	1715	1730
Weather		
Peak Wind Speed Date m/s	12/7 Feb	24/3 Mar
Highest Ambient Temp/Date °C	28/26 Feb	22/17 Mar
Lowest Daytime Ambient Temp/Date °C	-2/11 Feb	2/8 Mar

*Based on preliminary data

5.3 Simulation Comparisons

NMSEI has developed a simulation program based on a sample of manufacturer-supplied module data sheets and on the module data obtained by the testing described in Section 4.2. This program provides a finely tuned match to the actual data obtained during the first 90 days of system operation. Figure 12 is an example of one such day. From this base line, long-term degradation of system performance will be detectable. In addition to the system-specific program, SOLCEL simulations will also be used to evaluate system performance. SOLCEL was used during the design phase and has provided the basis for system performance estimation. The actual performance data is now being used as input to the SOLCEL to compare simulated performance with actual.

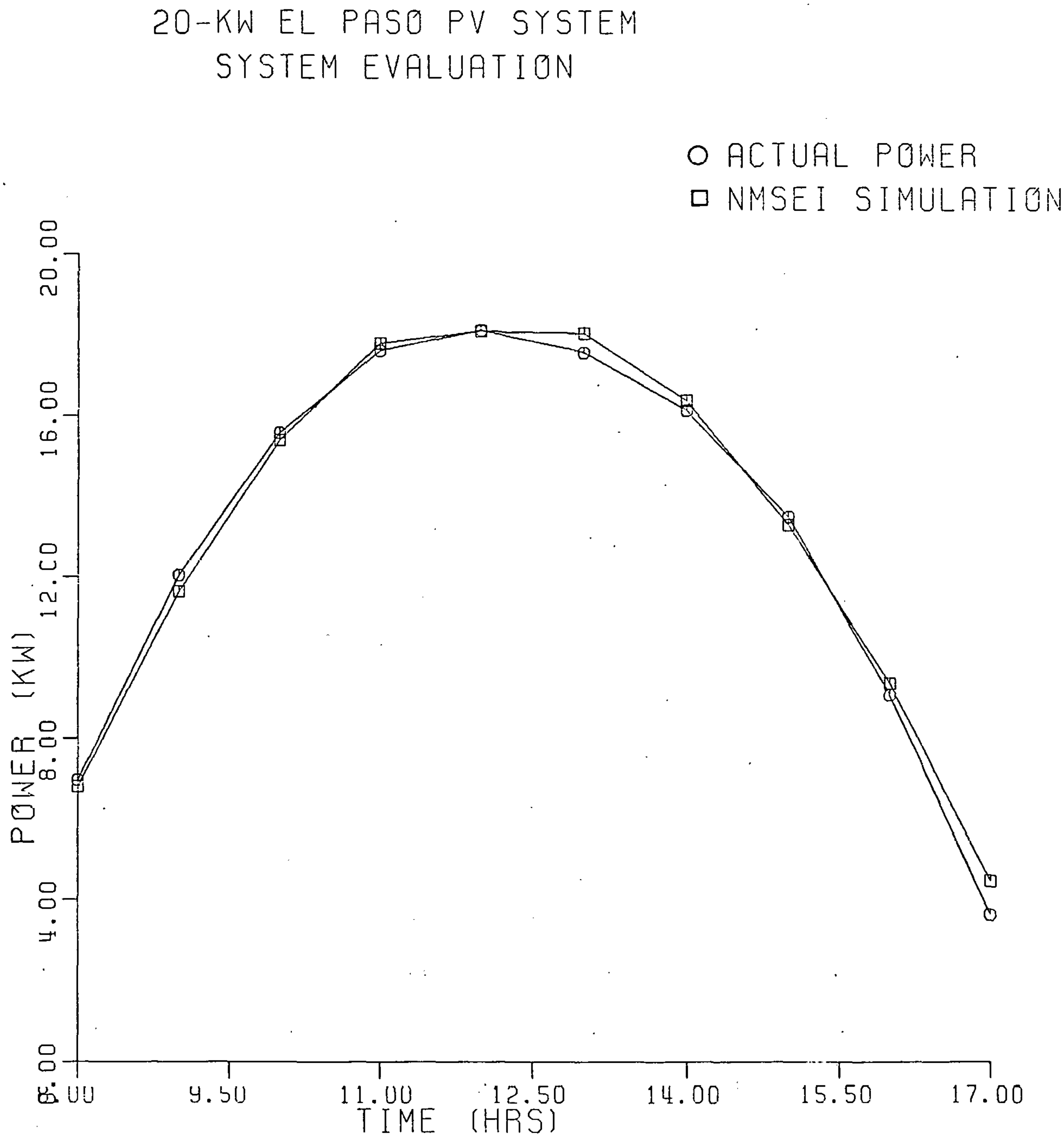


Figure 12. NMSEI System Simulation Versus Actual

The simulation programs will be used periodically throughout Phase III to try to determine the magnitude of long-term degradation. The source of any such degradation will be determined and, if possible, rectified.

6.0 SUMMARY

The successful completion of the Phase II portion of the El Paso PV project demonstrates the practicality of flat-plate PV system technology for current power generation.

The system, designed by NMSEI with assistance from an architectural firm and an electrical consultant, was fabricated, integrated, and tested by small business firms with no prior PV experience. The actual construction time was less than forecasted.

The only significant problem encountered during the integration and testing of the system was an intermittent electrical connection in the module terminal box. The module manufacturer, Solar Power Corporation, traced this to a manufacturing procedure fault and has indicated that a repair of all modules will be undertaken at their expense.

The data collection and analysis is ongoing and will continue throughout Phase III. The only instrument not functioning at this time is the sun-tracking pyrheliometer. Data is being transferred to Boeing Computer Services and NMSEI via telephone on a regular basis. Analysis indicates the system is operating at or above expectations. Fault isolation routines are being generated at NMSEI and will be refined during Phase III.

An important part of a prototype project is the learning experience. While most Phase II activities proceded according to plan, some changes were made to expedite certain tasks. The ease with which changes were incorporated into the construction plans is a salute to the project contractors. They, in fact, proposed several changes which resulted in significant savings of dollars and time.

A list of suggestions is given below. No classification of importance of the items in the list has been made. Some of the suggestions apply only to similar construction in similiar climates but many have general implications.

- °It must be recognized by photovoltaic manufacturers that utilities must be dealt with differently from a conventional free enterprise business. Because utilities are under such stringent federal and state regulations, the cost justification of a project becomes extremely important.

- °The input of the utility through specifications is a major concern. Photovoltaic modules should be ordered just as any other power plant equipment is ordered since it might effect the integrity of the entire plant.

- °Because of the long expected life of the modules, the manufacturer should be willing to provide a warranty that is appropriate for this expected life.

- °Utility personnel must undergo an attitude change. For photovoltaics to be feasible, utility personnel must be willing to become more deeply involved with the project.

- °The wooden frames that were used in the project are excellent from the viewpoint of cost and availability, and although wood proved to be a good material for this project, it may not be suitable for larger projects because of the extensive labor requirements.

- °For the ease of connection and to facilitate maintenance, a weathertight plug-in, quick-connect type of module connection should be used.

- °Experience has shown many contractors in the Southwest, and in particular the El Paso area, that it is not necessary that junction boxes be galvanized.

- °The size and complexity of the electrical switchgear can be significantly reduced.

- °The versatility of the control system is excellent for a prototype system, but significant savings can be realized by applying simple yet adequate controls.

NMSEI, EPE, Ponsford Brothers, Foutz Langford Gomez and Moore Architects, and Golucke Consulting all contributed to the successful completion of Phase II of this project. Utilization of alternate energy sources are important to the goal of an energy independent United States.

7.0 REFERENCES

1. A 20-Kilowatt El Paso Photovoltaic Project, Management and Technical Proposal, Phases I and II, New Mexico Solar Energy Insitute, March 1979.

2. 20-Kw El Paso Photovoltaic Project, Project Management Plan. Department of Energy Contract No. DE-AC04-79ET20629, November 1979.

3. 20-Kw El Paso Photovoltaic Project Quality Assurance and Control Plan, Appendix C. Department of Energy Contract No. DE-AC04-79ET2062, December 1979.

4. 20-Kw El Paso Photovoltaic Project Assembly, Installation, and Checkout Plan. Department of Energy Contract No. DE-AC04-79ET2069.

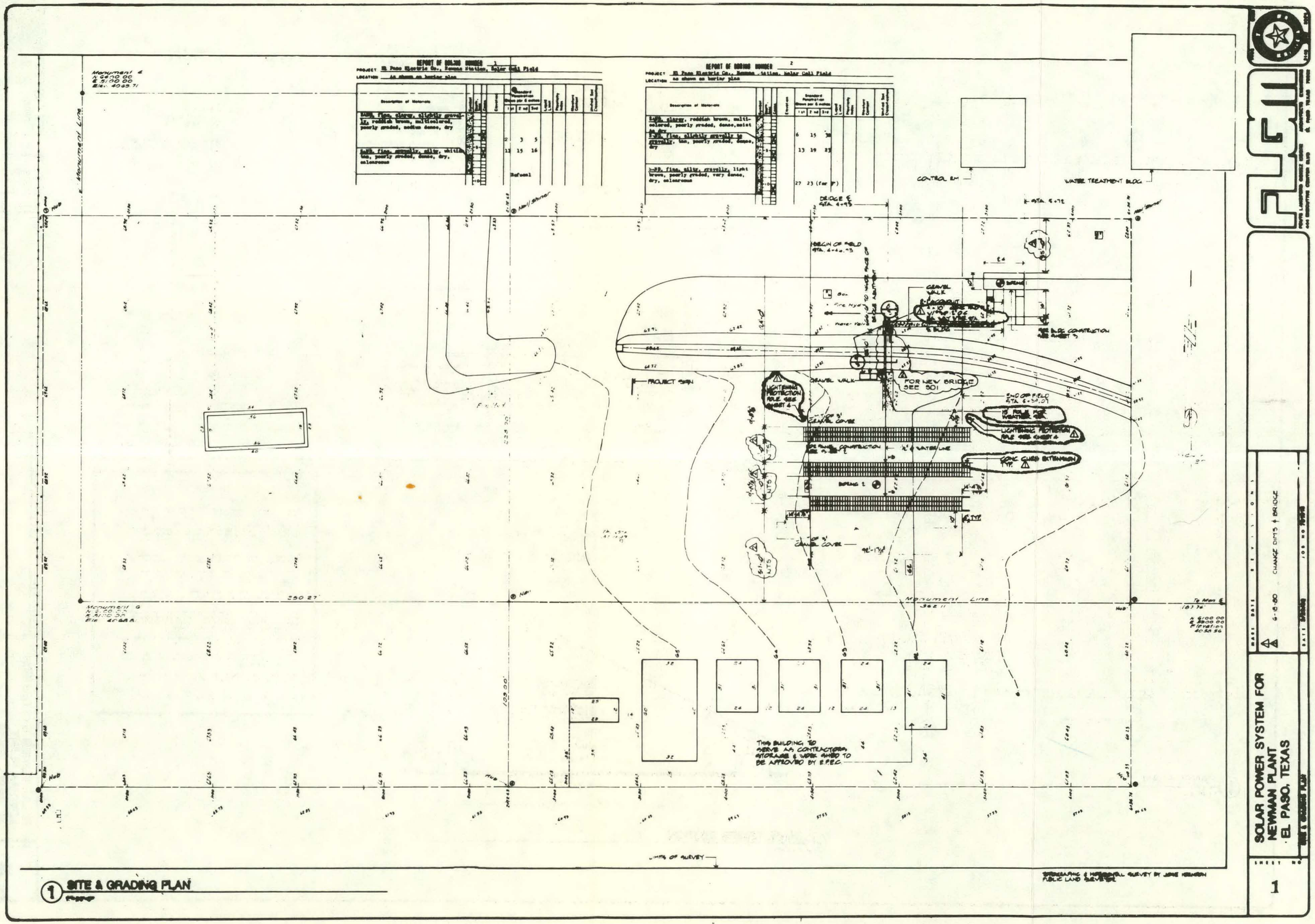
5. Operation and Verification Plan. System Engineering Plan No. 6, Department of Energy Contract No. DE-AC04-79ET20628.

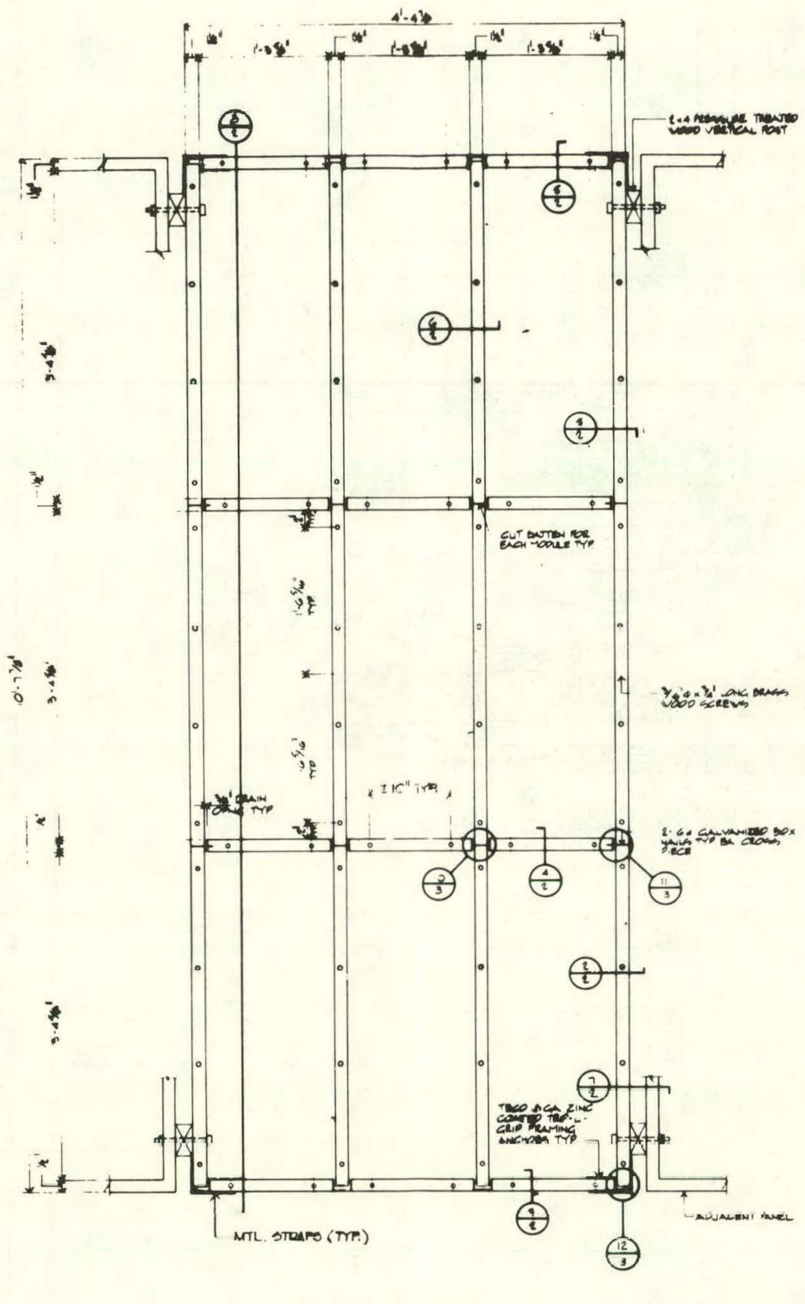
6. Instrumentation Plan. System Engineering Plan No. 5, Department of Energy Contract No. DE-AC04-20628.

7. A 20-Kw El Paso Photovoltaic Project Training and Safety Plan. Department of Energy Contract No. DE-AC04-79ET20629.

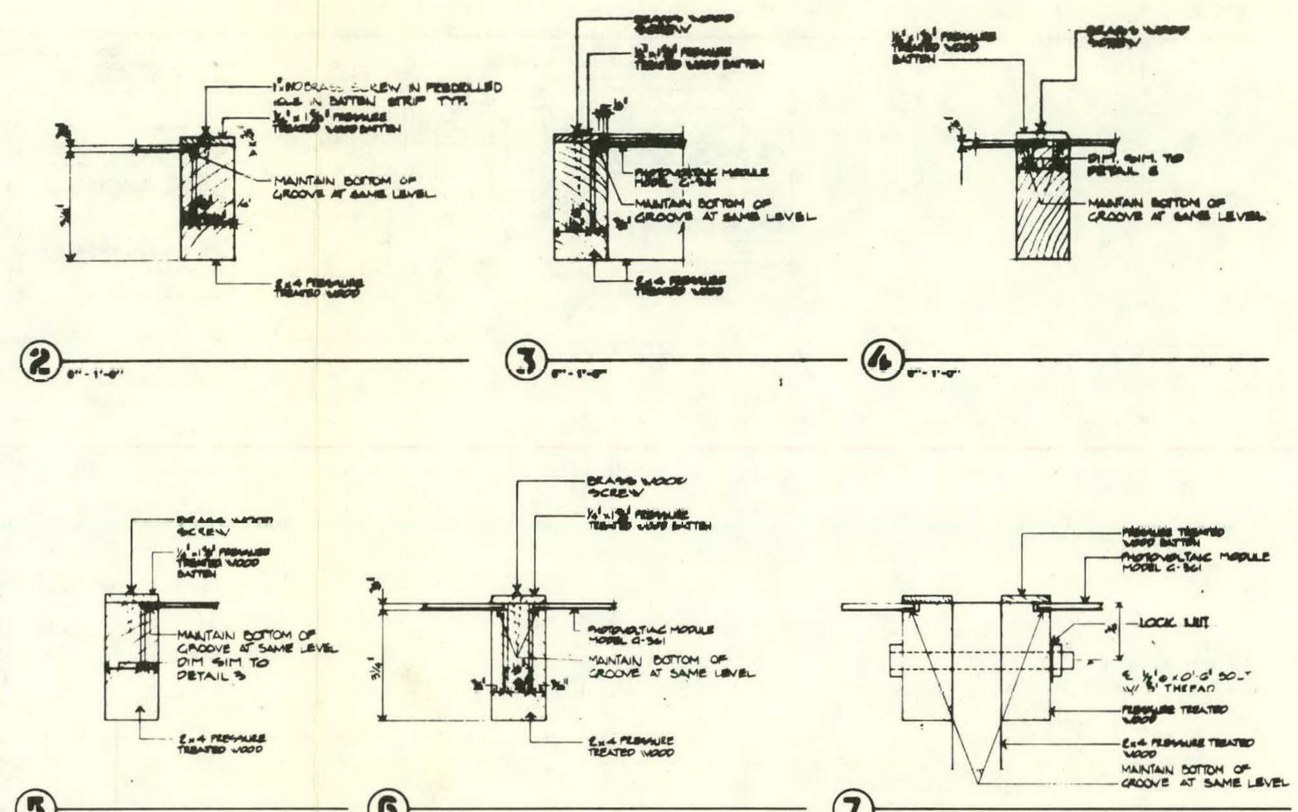
APPENDIX A

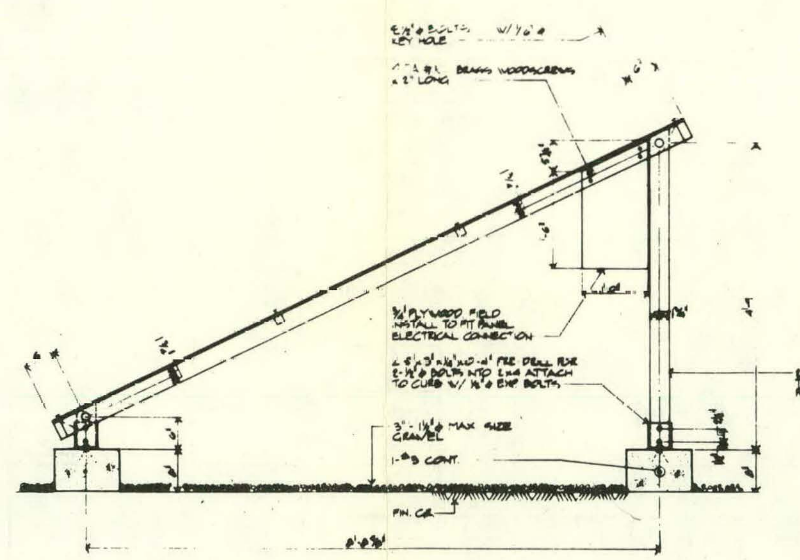
SYSTEM DRAWINGS


SITE & GRADING PLAN
SOLAR POWER SYSTEM FOR
NEWMAN PLANT
EL PASO, TEXAS
1
FOR NEW BRIDGE SEE 501
PROJECT SIGN
Monument Line
WATER TREATMENT BLDG
CONTROL RM
LIMITS OF SURVEY



① PANEL PLAN
1 1/2" - 1'-0"



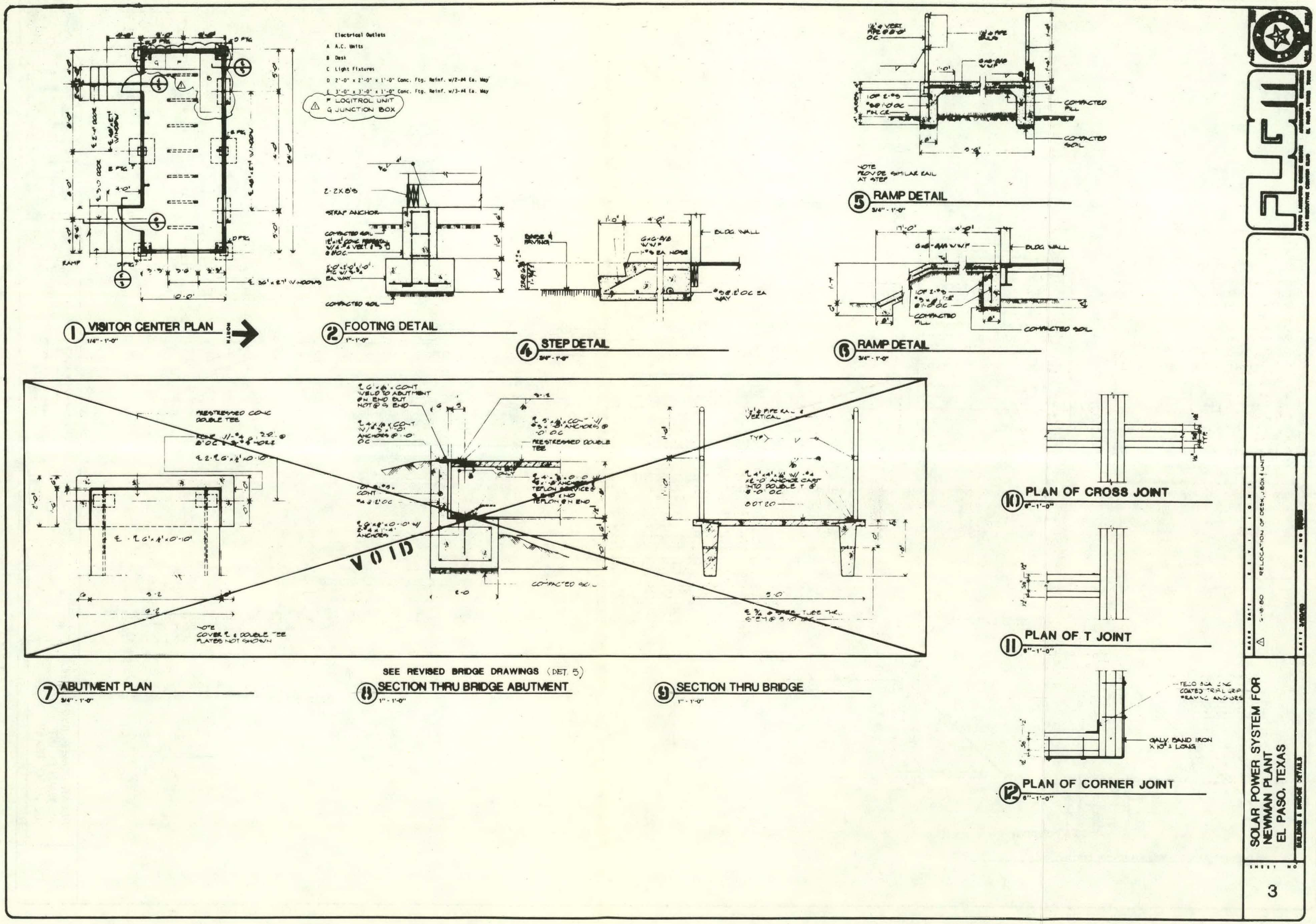


⑧ PANEL CROSS SECTION

General Notes

1. Framing anchors for connection of solar panels shall be TECO Trip-L-Grip or approved equal.
2. Pipe and fitting for water line shall be PVC-DWV schedule 40 and shall be buried 18" below grade and shall be insulated where exposed to air with Owens Corning 25 H-P pipe insulation system 1" thick and secured with Benjamin Fosters Sparkfas #85-20 adhesive.
3. Gate valves in water line shall be Jenkins Bronze Union Bonnet Inside Screw Traveling stem solid wedge for 1-1/2" diameter line.
4. Hose bibs for array field shall be Jenkins Bronze 1" diameter hose outlet Solid Wedge Inside Screw, non rising stem with outlet located 16" above grade.
5. Contractor shall provide all unions; reducers and correction materials for complete working water delivery system, to array field.
6. Live loads for bridge shall be 50 pounds per square foot. Supplier of precast bridge shall supply calculations sealed and signed by a registered engineer confirming the ability of the structure to carry the loads applied to it and its own weight.
7. Supplier of precast bridge shall provide materials certification and concrete tests verifying material strengths.
8. Provide 3/4" expansion joints in concrete curbs at 75 foot on center with 1/2" diameter smooth bars 3'-0" long centered on the expansion joint and 1 end greased.
9. Gravel for erosion protection shall have 100 percent passing a 1-1/2" sieve and 80 percent retained on a #4 sieve.
10. ... REQUIRED TO PREVENT RACKING OF PANEL DURING HANDLING AND CONSTRUCTION.

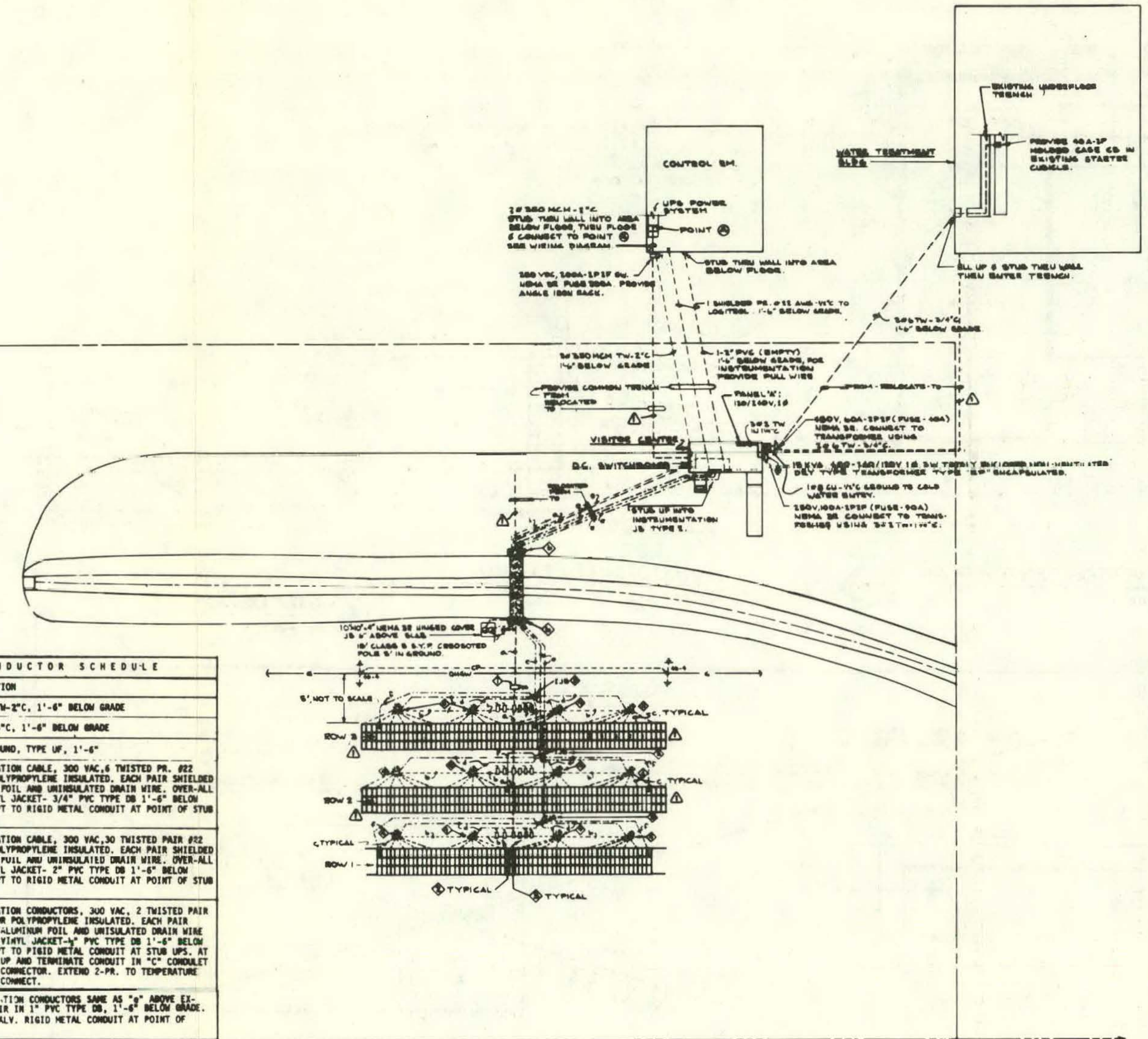
SOLAR POWER SYSTEM FOR
NEWMAN PLANT
EL PASO, TEXAS

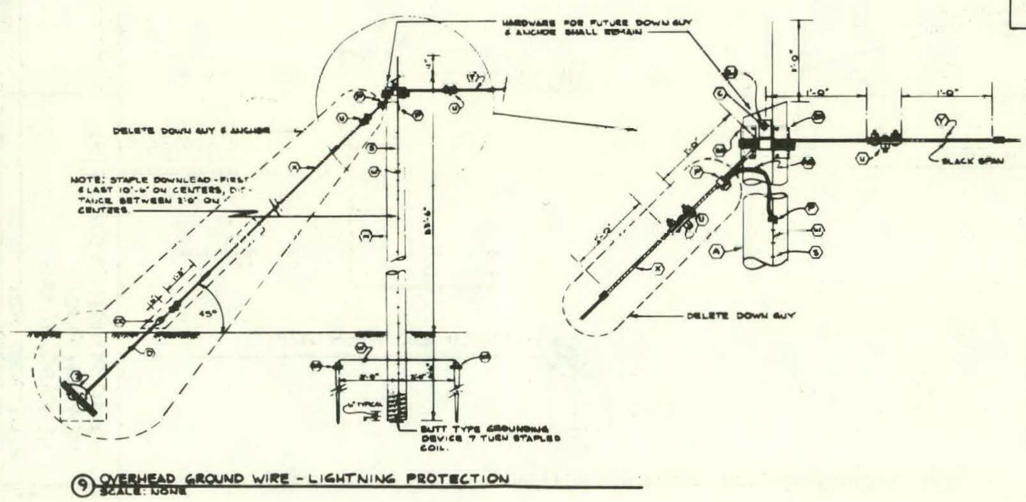

Electrical Outlets
A A.C. Units
B Desk
C Light Fixtures
D 2'-0" x 2'-0" x 1'-0" Conc. Ftg. Reinf. w/2-#4 Ea. Way
E 3'-0" x 3'-0" x 1'-0" Conc. Ftg. Reinf. w/3-#4 Ea. Way
F LOGITROL UNIT
G JUNCTION BOX
1 VISITOR CENTER PLAN
1/4" - 1'-0"
NORTH
2 FOOTING DETAIL
1" - 1'-0"
COMPACTED SOIL
4 STEP DETAIL
3/4" - 1'-0"
BLDG. WALL
5 RAMP DETAIL
3/4" - 1'-0"
COMPACTED FILL
COMPACTED SOIL
6 RAMP DETAIL
3/4" - 1'-0"
VOID
SEE REVISED BRIDGE DRAWINGS (DET. 5)
7 ABUTMENT PLAN
3/4" - 1'-0"
8 SECTION THRU BRIDGE ABUTMENT
1" - 1'-0"
9 SECTION THRU BRIDGE
1" - 1'-0"
10 PLAN OF CROSS JOINT
6" - 1'-0"
11 PLAN OF T JOINT
6" - 1'-0"
12 PLAN OF CORNER JOINT
6" - 1'-0"
GALV. BAND IRON
SOLAR POWER SYSTEM FOR
NEWMAN PLANT
EL PASO, TEXAS
BUILDING & BRIDGE DETAILS
RELOCATION OF DESK, J.BOX & UNIT
SHEET NO
3

OVERHEAD GROUND WIRE - LIGHTING PROTECTION MATERIAL LIST	
ITEM	DESCRIPTION
A	40' CLASS 4 SOUTHERN YELLOW PINE, PRESSURE TREATED CREOSOTED POLE.
C	MACHINE BOLT, 5/8"xREQUIRED LENGHT
E	1¼"x8'-0" ANCHOR ROD
P	CONNECTORS AS REQUIRED
S	2" COPPERWELD STAPLES
U	GUY CLAMP, 3 BOLT, 6" LONG
W	#4 SD BARE COPPER DOWNLEAD
X	½" 7 STRAND ZINC COATED STEEL (26,900#) EXTRA HIGH STRENGHT, GUY WIRE.
Y	3/8" 7 STRAND ZINC COATED STEEL (15,400#) EXTRA HIGH STRENGHT GUY WIRE.
Z	8-WAY EXPANDING ANCHOR (26,500# CLASS 5 SOIL)
AQ	JUMPER, #4 SD BARE COPPER
AT	GUY GUARD 8' MIN. LENGHT
BJ	GUY HOOK
BK	GUY PLATE, 4"x8", 14 GUAGE
BP	8 PENNY NAIL
CK	CLAMP, ANCHOR ROD BONDING
GR	3/4"x8'-0" COPPERWELD, GROUND ROD. TOP 2'-0" BELOW GRADE. PROVIDE REQUIRED NUMBER OF RODS TO OBTAIN 25 OHMS GROUND RESISTANCE.

LEGEND	
SYMBOL	DESCRIPTION
	PHOTOVOLTAIC PANEL, SEE DETAIL 3
	PANEL CONNECTION JUNCTION BOX
	DISCONNECT SWITCH
	DRY TYPE TRANSFORMER
- - - - -	UNDERGROUND CIRCUIT, POWER
—·—·—	UNDERGROUND CIRCUIT, INSTRUMENTATION
—··—··—	UNDERGROUND CIRCUIT, INSTRUMENTATION (TEMPERATURE)
	OVERHEAD GROUND WIRE
- - CP - -	1/0 BSD STRANDED CU COUNTERPOISE 2'-0" BELOW GRADE.
	DOWN GUY
•40-4	POLE, 40ft. CLASS 4
	GROUND
	SEE DETAIL INDICATED BY NUMBER
	JUNCTION BOX
	PANELBOARD

CONDUCTOR SCHEDULE	
LETTER	DESCRIPTION
a	2 #500MCM TW-2"C, 1'-6" BELOW GRADE
b	2 #6 TW-3/4"C, 1'-6" BELOW GRADE
c	#14/2 + GROUND, TYPE UF, 1'-6"
d	INSTRUMENTATION CABLE, 300 VAC,6 TWISTED PR. #22 VINYL OR POLYPROPYLENE INSULATED. EACH PAIR SHIELDED W/ALUMINUM FOIL AND UNINSULATED DRAIN WIRE. OVER-ALL CHROME VINYL JACKET- 3/4" PVC TYPE DB 1'-6" BELOW GRADE. ADAPT TO RIGID METAL CONDUIT AT POINT OF STUB UPS.
e	INSTRUMENTATION CABLE, 300 VAC,30 TWISTED PAIR #22 VINYL OR POLYPROPYLENE INSULATED. EACH PAIR SHIELDED W/ALUMINUM FOIL AND UNINSULATED DRAIN WIRE. OVER-ALL CHROME VINYL JACKET- 2" PVC TYPE DB 1'-6" BELOW GRADE. ADAPT TO RIGID METAL CONDUIT AT POINT OF STUB UPS.
f	INSTRUMENTATION CONDUCTORS, 300 VAC, 2 TWISTED PAIR #22 VINYL OR POLYPROPYLENE INSULATED. EACH PAIR SHIELDED W/ALUMINUM FOIL AND UNISULATED DRAIN WIRE W/OVER-ALL VINYL JACKET-½" PVC TYPE DB 1'-6" BELOW GRADE. ADAPT TO RIGID METAL CONDUIT AT STUB UPS. AT PANEL STUB UP AND TERMINATE CONDUIT IN "C" CONDULET W/CGB CORD CONNECTOR. EXTEND 2-PR. TO TEMPERATURE SENSOR AND CONNECT.
g	INSTRUMENTATION CONDUCTORS SAME AS "e" ABOVE EXCEPT 15 PAIR IN 1" PVC TYPE DB, 1'-6" BELOW GRADE. ADAPT TO GALV. RIGID METAL CONDUIT AT POINT OF STUB UPS.
h	2#12 TW - ½" GALV. RIGID METAL CONDUIT, 1'-6" BELOW GRADE. CONNECT TO SPARE BREAKER IN PANEL "A".
i	1" EMPTY GALV. RIGID CONDUIT, 1'-6" BELOW GRADE. STUB UP AT POLE 1'-0" ABOVE GRADE & CAP.





9 OVERHEAD GROUND WIRE - LIGHTNING PROTECTION
SCALE: NONE

NOTES:

1. 1-250 VDC, 400A-2P NON-AUTOMATIC CIRCUIT BREAKER. 1-250 VDC, 225A 2P NON-AUTOMATIC CIRCUIT BREAKER. KIRK KEY INTERLOCK BREAKERS. MOUNT UNITS IN FREE STANDING NEMA 3R ENCLOSURE, 24"Wx18"Dx5'-0" H. MOUNT ON CONCRETE PAD 6" ABOVE GRADE. (KIRK KEY INTERLOCK & GROUNDING CIRCUIT BREAKER REMOVED).
2. 1-250 VDC, 60A-4P4F (FUSE 2 POLES W/35A U.L. CLASS R, PROVIDE 2 POLES W/SOLID COPPER BUSS) 1-250 VDC, 60A 2PNF (SHORTING SWITCH). 1-24"x24"X8" NEMA 3R SCREW COVER JUNCTION BOX, SEE DETAIL 5.
3. SAME AS 2 ABOVE EXCEPT NEMA 3R SCREW COVER JUNCTION BOX SHALL BE 10"x10"x4", SEE DETAIL 4.
4. PANEL CONNECTION JUNCTION BOX, SEE DETAIL 7.
5. INSTRUMENTATION JUCTION BOX TYPE 1, SEE DETAIL 6.
6. SLEEVE THRU ABUTMENT. SUPPORT CONDUIT W/GALVANIZED UNISTRUT MEMBER 6' ON CENTERS SUPPORTED FROM BRIDGE.

SOLAR POWER SYSTEM FOR NEWMAN PLANT
EL PASO, TEXAS

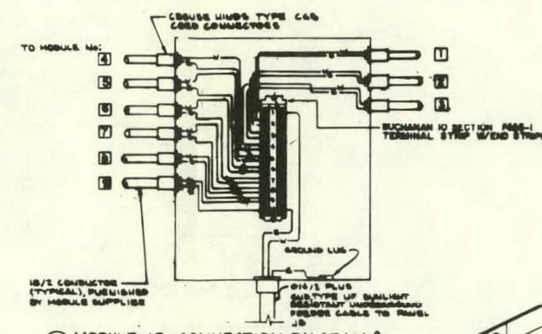
LANNEAU GOLUCKE
ELECTRICAL
CONSULTING ENGINEER
EL PASO, TEXAS

11-18-80 AS BUILT

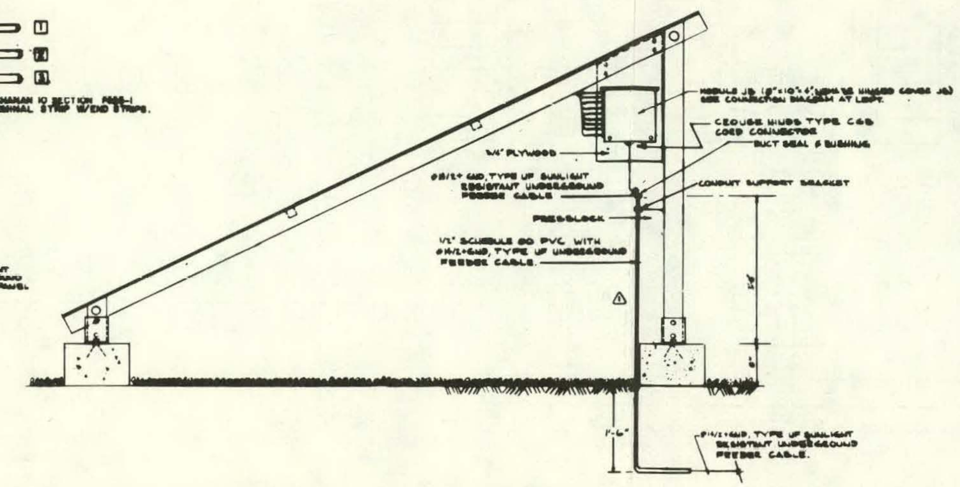
791010

4

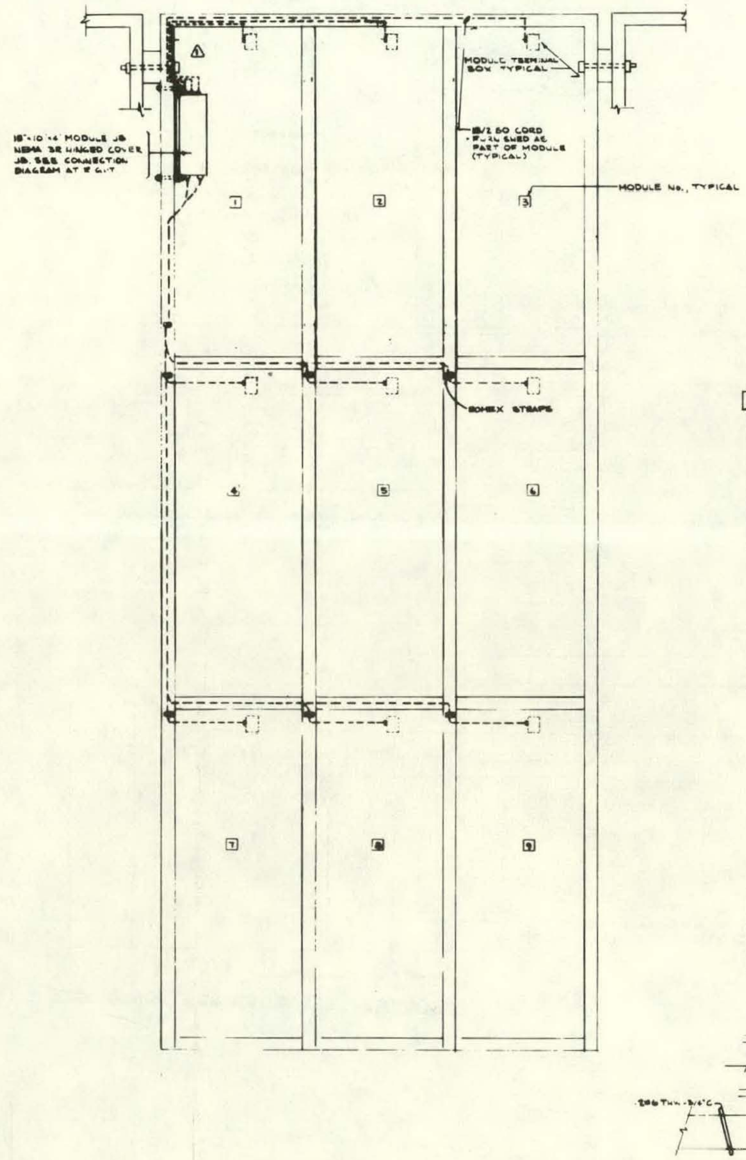
COLOR CODING OF INSTRUMENTATION CONDUCTORS IN PANEL CONNECTION JUNCTION BOX				
PR. NO.	COLOR OF CONDUCTORS COMPRISING PAIR	TERMINAL DESIGNATION	CONDUCTOR COLOR CODE	REMARKS
a	BLACK/RED	1 R	BLACK RED	VOLTAGE ACROSS SENSING RESISTOR
b	BLACK/WHITE	2 W	BLACK WHITE	
c	BLACK/GREEN	3 G	BLACK GREEN	
d	BLACK/BLUE	4 BL	BLACK BLUE	
e	BLACK/BROWN	5 BR	BLACK BROWN	
f	BLACK/YELLOW	6 Y	BLACK YELLOW	SPARE



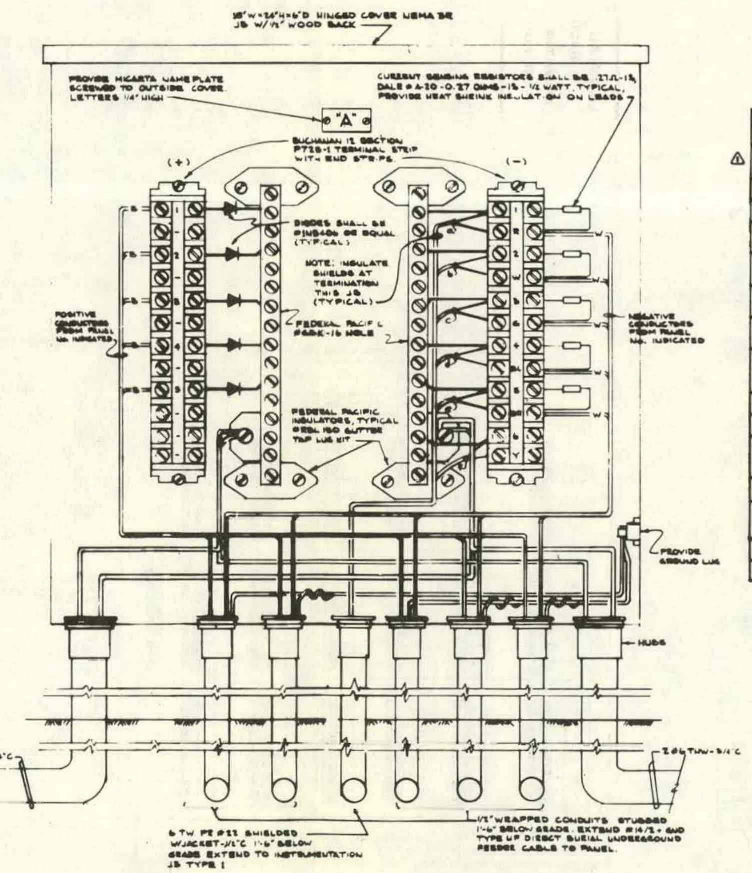
(7) MODULE JB-CONNECTION DIAGRAM
SCALE: 3/8"=1"



(1) ELECTRICAL CONNECTION AT PANEL
SCALE: 3/4"=1'-0"

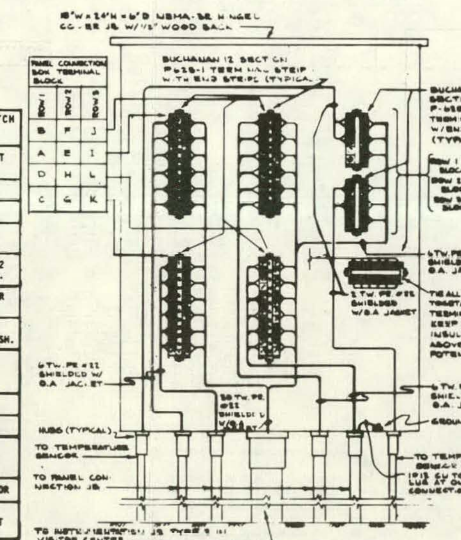


(3) PANEL WIRING
SCALE: 1 1/2"=1'-0"

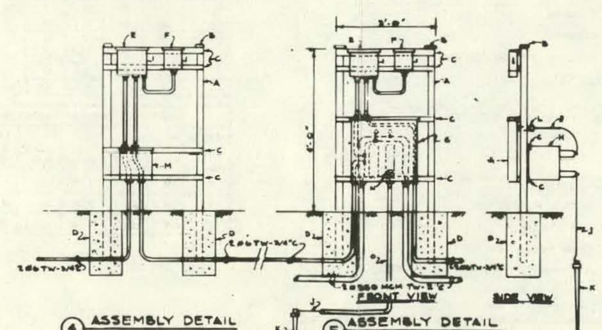


(2) PANEL CONNECTION JUNCTION BOXES
SCALE: 3/4"=1"

MATERIAL LIST FOR MOUNTING RACK, SWITCH ASSEMBLY & PULLBOX	
A	4" CHANNEL IRON. ONE COAT RED LEAD & ONE COAT OUTDOOR GREY PAINT.
B	2" PIPE CAP
C	CHANNEL MC 3x4.1 WELD TO PIPE.
D	1'ø x 2'-0",2,500 PSI CONCRETE 28 DAY FOUNDATION.
E	250 VDC,60A-4P4F (FUSE 36A UL CLASS "R", 2 POLES SOLID COPPER BUS) NEMA 3R ENCLOSURE.
F	250 VDC,60A-2PNF (SHORTING SWITCH) NEMA 3R ENCLOSURE.
G	24"x24"x6" NEMA 3R SCREW COVER JB. CODE GUAGE GALVANIZED, OUTDOOR GREY PAINT FINISH.
H	0-750 VDC SURGE CAPACITOR ARRESTOR WITH BUILT IN DISCHARGE RESISTORS. SURGE ARRESTORS SHALL BE G.E. CO. #10L40H.
I	#4THHN
J	#4S.D. BARE COPPER
K	3/4"x8'-0" COPPERWELD GROUND ROD. NOTE: PROVIDE REQUIRED NUMBER OF RODS TO OBTAIN 25 OHMS GROUND RESISTANCE.
L	1/2"x4" NIPPLE, COUPLING & C&B CORD CONNECTOR
M	10"x10"x4" NEMA 3R SCREW COVER JB. CODE GUAGE GALVANIZED STEEL, OUTDOOR GREY PAINT FINISH.
N	GROUND LUG
O	1# 4 S.D. BARE CU -1/2"C



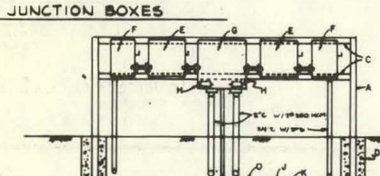
(6) INSTRUMENTATION JB TYPE 1
SCALE: 1/4"=1"



(4) ASSEMBLY DETAIL

(5) ASSEMBLY DETAIL

(4)(5) MOUNTING RACKS, SWITCH ASSEMBLY & PULLBOX
SCALE: 1/2"=1'-0"



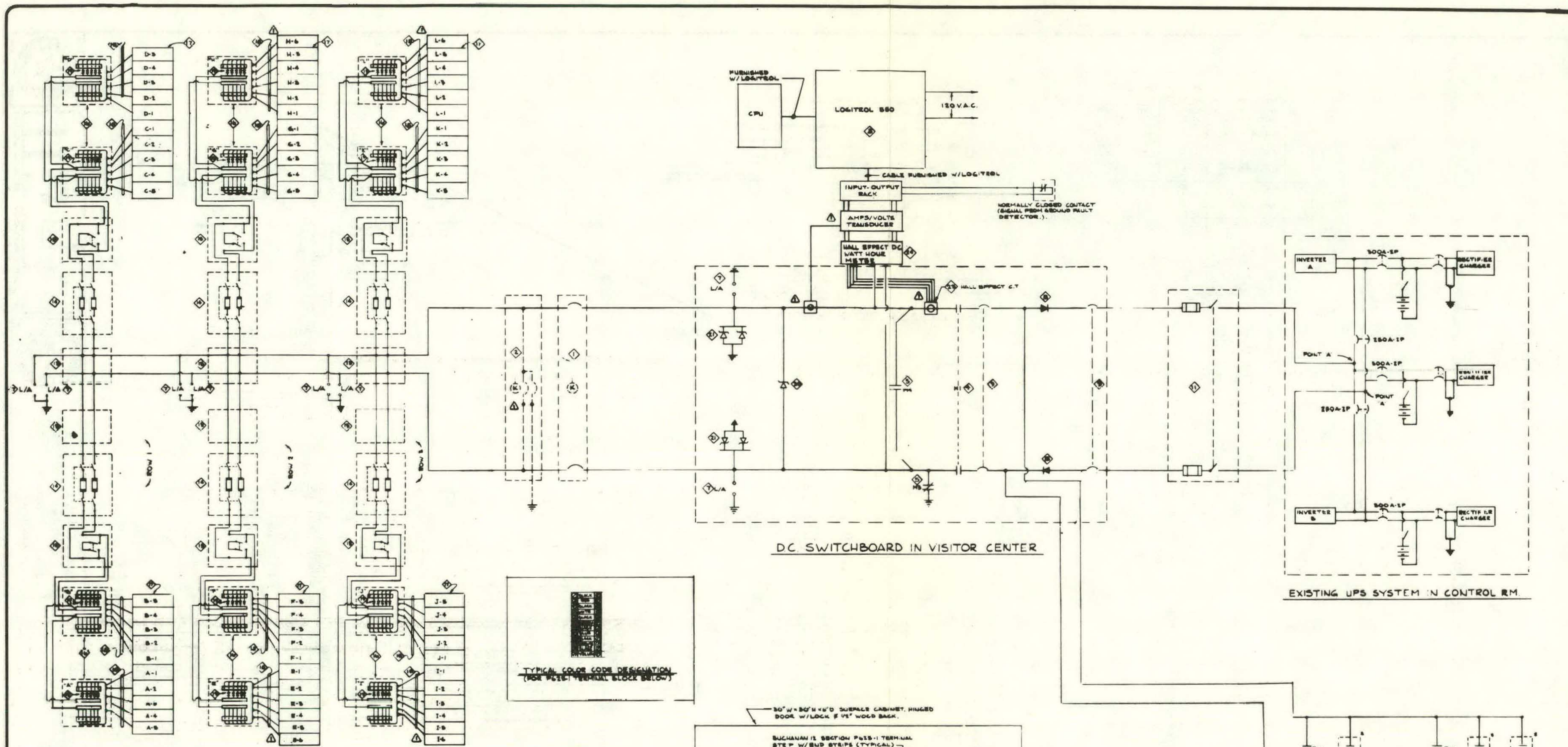
AS BUILT MOUNTING RACK, SWITCH ASSEMBLY & PULLBOX (1 ASSEMBLY PER ROW)
NOT TO SCALE

LANNEAU GOLUCKE
ELECTRICAL
CONSULTING ENGINEER
EL PASO TEXAS

REVISIONS: 1-18-80 AS BUILT

SOLAR POWER SYSTEM FOR NEWMAN PLANT
EL PASO, TEXAS

SHEET NO
5



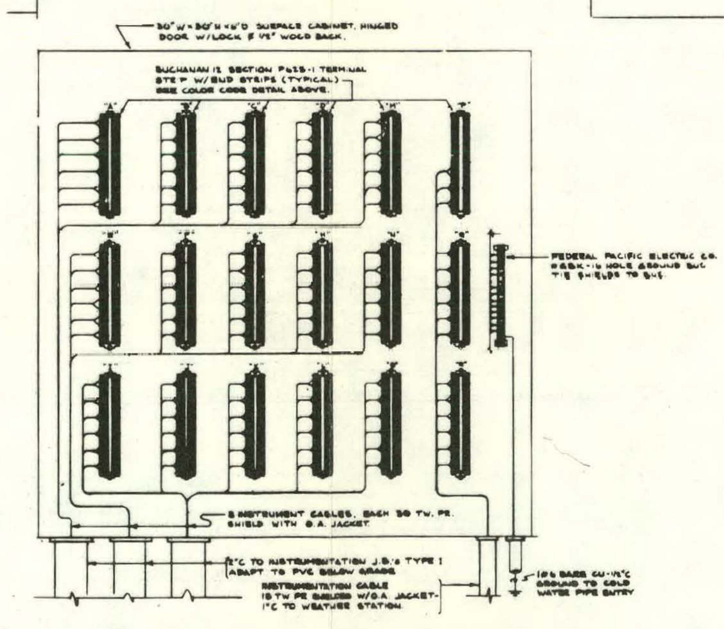
NOTES:

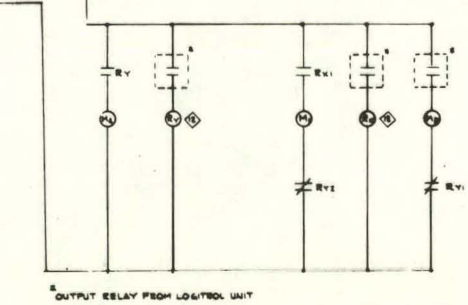
1. NON-AUTOMATIC CIRCUIT BREAKER G.E. CO. #TJJ426Y400 IN NEMA 3R ENCLOSURE 250 VDC, 400A., REMOTE AT SOLAR ARRAY.
2. NON-AUTOMATIC CIRCUIT BREAKER G.E. CO. #TFJ226Y225 IN NEMA 3R ENCLOSURE 250 VDC, 400A., REMOTE AT SOLAR ARRAY. (REMOVED.) △1
3. G.E. 550 LOGITROL, 12 VDC CONTROL POWER W/I.O. RACK, KWH DISPLAY, UNIT TO BE PROGRAMMED IN THE FIELD.
4. G.E. MILL TYPE DC CONTACTOR, 300A., 2P-NO W/2 AUX CONTACTS 135 VDC COIL W/1 SPARE COIL. G.E. CO. #IC2801AD211AB.
5. G.E. MILL TYPE DC CONTACTOR, 300A., 1P-NO W/2 AUX CONTACTS 135 VDC COIL W/1 SPARE COIL. G.E. CO. #IC2801AD201A.
6. THIS NOTE HAS BEEN DELETED.
7. G.E. 18L4NH DC SURGE CAPACITOR, 0-750 VDC.
8. 300A. DIODE, 200V, G.E. CO. #A190158H1ADZ.
9. NON-AUTOMATIC CIRCUIT BREAKER G.E. CO. #TJJ426Y400, 250 VDC, 400A.
10. THIS NOTE HAS BEEN DELETED.
11. 250 VDC, 200A-2P2F, NEMA 3R ENCLOSURE, FUSE W/200A. U.L. CLASS J. MOUNT ON EXTERIOR WALL OF CONTROL ROOM. PROVIDE ANGLE IRON RACK.
12. RELAY 135 VDC, COIL. G.E. CO. #IC2820A200B111CC
13. NEMA 3R JUNCTION BOX
14. 250 VDC, 60A-4P4F, NEMA 3R ENCLOSURE, FUSE 2 POLES W/35A. U.L. CLASS R FUSES. PROVIDE SOLID COPPER BUS FOR 2 POLES.
15. 250 VDC, 60A.-2PNF, NEMA 3R ENCLOSURE, SHORTING SWITCH.
16. PANEL CONNECTION JUNCTION BOXES, SEE DETAIL (2).
17. PHOTOVOLTAIC PANELS, SEE DETAIL (3) FOR PANEL WIRING.
18. #14/2 + GROUND, TYPE UF. 1'-6" BELOW GRADE. SEE DETAIL (1) FOR ELECTRICAL CONNECTIONS AT PANEL.
19. SERIES DIODE.
20. ZENER DIODE (TRANSIENT SUPPRESSORS) IN DC SWITCHBOARD. MOTOROLA-#MPZ5-180C. (DELETE) △1
21. 2 ZENER DIODES (TRANSIENT SUPPRESSORS) TO GROUND. MOTOROLA-#MPZ5-180C. (DELETE) △1
22. THIS NOTE HAS BEEN DELETED.
23. HALL EFFECT CURRENT TRANSFORMER
24. HALL EFFECT DC WATT HOUR METER

INSTRUMENTATION JB TYPE 2 - TERMINAL DESIGNATION

TERMINAL STRIP	CURRENT SENSING RESISTOR-PHOTOVOLTAIC PANEL NO.					
	PR. BLACK RED	PR. BLACK WHITE	PR. BLACK GREEN	PR. BLACK BLUE	PR. BLACK BROWN	PR. BLACK YELLOW
"A"	1A	2A	3A	4A	5A	SPARE
"B"	1B	2B	3B	4B	5B	SPARE
"C"	1C	2C	3C	4C	5C	SPARE
"D"	1D	2D	3D	4D	5D	SPARE
"E"	1E	2E	3E	4E	5E	SPARE
"F"	1F	2F	3F	4F	5F	SPARE
"G"	1G	2G	3G	4G	5G	SPARE
"H"	1H	2H	3H	4H	5H	SPARE
"I"	1I	2I	3I	4I	5I	SPARE
"J"	1J	2J	3J	4J	5J	SPARE
"K"	1K	2K	3K	4K	5K	SPARE
"L"	1L	2L	3L	4L	5L	SPARE

	TEMPERATURE SENSING TRANSDUCER					
TERMINAL STRIP	PR. BLACK RED	PR. BLACK WHITE	PR. BLACK GREEN	PR. BLACK BLUE	PR. BLACK BROWN	PR. BLACK YELLOW
M	ROW 1	ROW 1	SPARE	ROW 1	ROW 1	SPARE
N	ROW 2	ROW 2	SPARE	ROW 2	ROW 2	SPARE
O	ROW 3	ROW 3	SPARE	ROW 3	ROW 3	SPARE





LANNEAU GOLUCKE
ELECTRICAL
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EL PASO, TEXAS

REVISIONS

MARK	DATE	
△1	11-15-80	AS BUILT

SOLAR POWER SYSTEM FOR NEWMAN PLANT
EL PASO, TEXAS

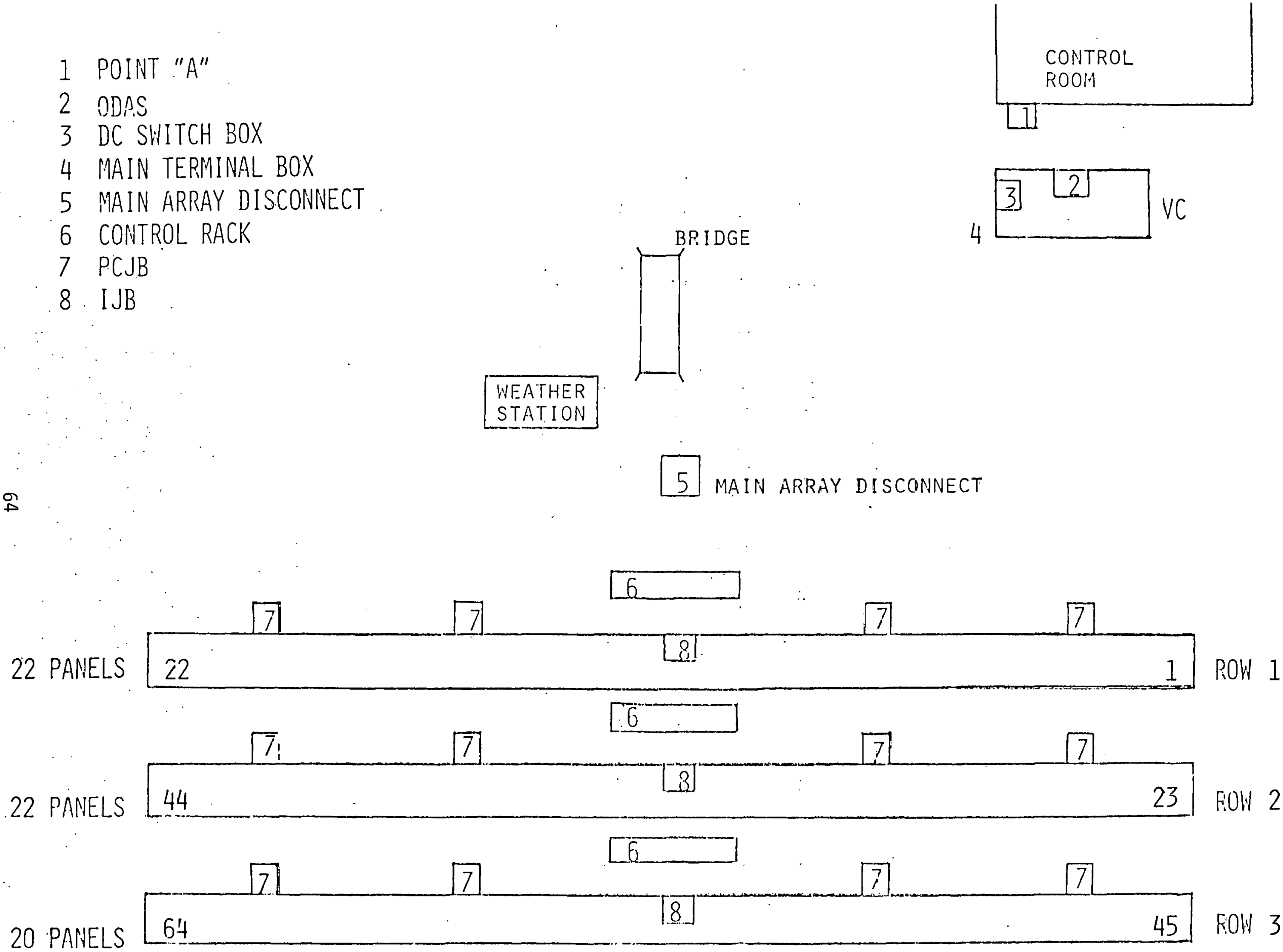
SHEET NO. 6

APPENDIX B

EL PASO TRAINING PROGRAM VISUAL AIDS

EL PASO PV SYSTEM

- DIRECT CONVERSION OF SOLAR ENERGY TO DC ELECTRICITY.
- UP TO 17 KW OUTPUT DEPENDING ON SOLAR INSOLATION.
- MAXIMUM DC VOLTAGE IN ARRAY FIELD IS $\sim$ 190 VOLTS.
- MAXIMUM DC CURRENT IN ARRAY FIELD IS $\sim$ 160 AMPS.
- ARRAY FLOATS - NO MANUAL GROUNDING OF POWER LINES.



1 POINT "A"
2 ODAS
3 DC SWITCH BOX
4 MAIN TERMINAL BOX
5 MAIN ARRAY DISCONNECT
6 CONTROL RACK
7 PCJB
8 IJB
CONTROL ROOM
VC
BRIDGE
WEATHER STATION
MAIN ARRAY DISCONNECT
22 PANELS
ROW 1
22 PANELS
ROW 2
20 PANELS
ROW 3

SAFETY

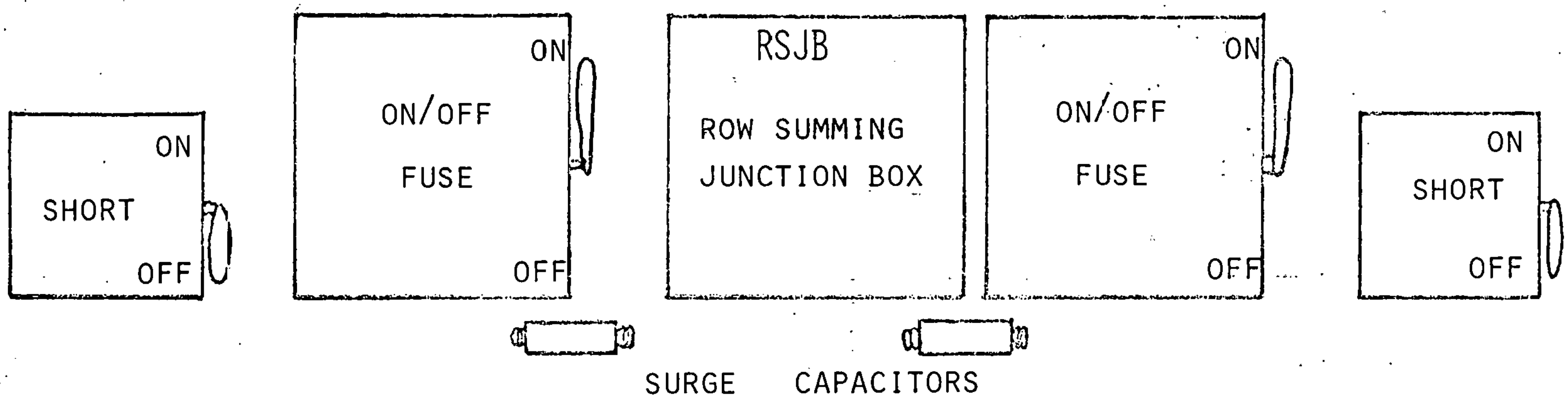
- PV ARRAY IS ELECTRICAL GENERATOR.
- OPENING ON-OFF/FUSE SWITCH REMOVES SUBARRAY FROM LOAD BUT PCJB AND MSJB STILL HAVE V_{OC}.
- SHORTING SWITCH ZEROS VOLTAGE IN SUBARRAY BUT HIGH CURRENT FLOWS.

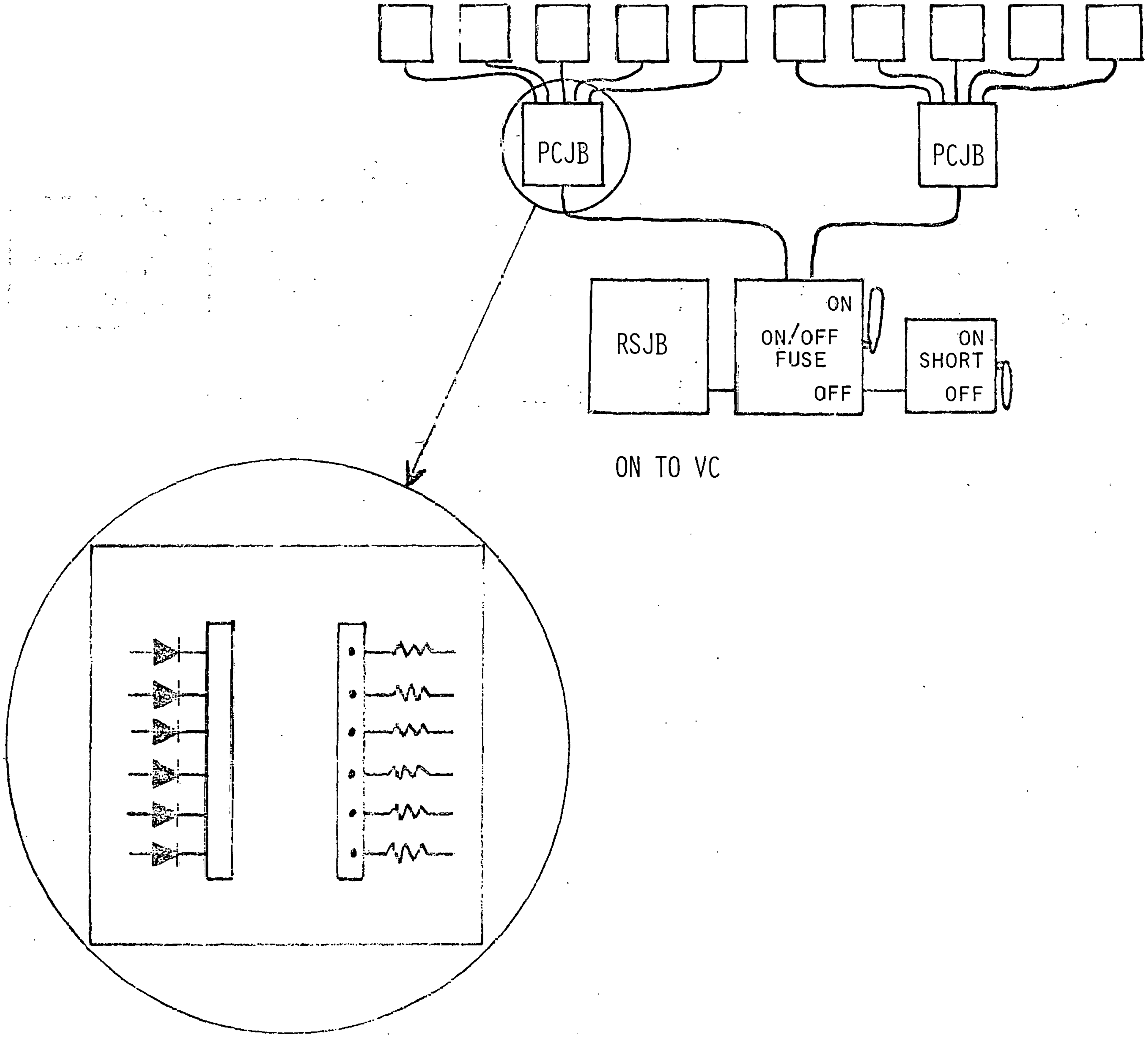
AT VC

- IN DC SWITCHBOARD ARRAY IS CONNECTED TO BUS.
- TO ISOLATE DC SWITCHBOARD BOTH MAIN ARRAY BREAKER AND CONTROL ROOM DISCONNECT MUST BE THROWN.
- AUTOMATIC SWITCHING OCCURS.

TO CHECK PANEL VOLTAGES

- OPEN SPECIFIC SUBARRAY SWITCH SHORTING SWITCH OPEN.
- AT PCJB TEST EACH PANEL OPEN CIRCUIT VOLTAGE (V_{OC}).
- SHOULD READ BETWEEN 165V - 190V DEPENDING ON WEATHER AND INSOLATION.
- IF A MEASUREMENT IS 8 - 20V BELOW AVERAGE IT INDICATES BAD PANEL.
- AT THE MODULE SERIES JB (MSJB) CHECK EACH MODULE OPEN CIRCUIT VOLTAGE.
- SHOULD FIND AT LEAST ONE WITH V_{OC} 8 - 20 VOLTS BELOW AVERAGE.
- TRACE WIRING AND RECORD MODULE SERIAL NUMBER.
- REPLACE MODULE.


SHORT
ON
OFF
ON/OFF
FUSE
ON
OFF
RSJB
ROW SUMMING
JUNCTION BOX
ON/OFF
FUSE
ON
OFF
ON
SHORT
OFF
SURGE CAPACITORS

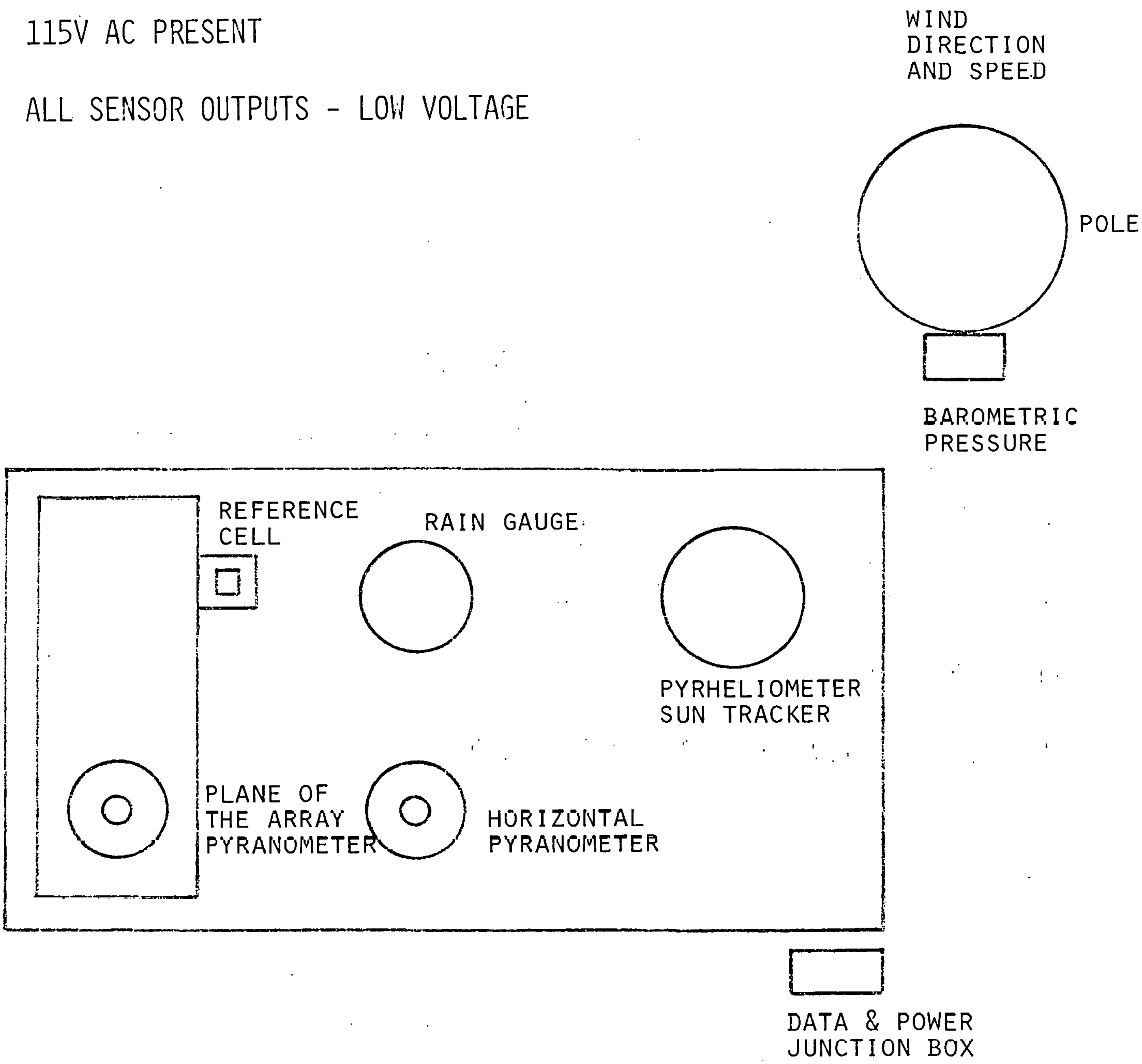

PCJB
PCJB
RSJB
ON
ON/OFF
FUSE
OFF
ON
SHORT
OFF
ON TO VC

HANDLING MODULES

- HANDLE AS YOU WOULD AN 18" x 42" PIECE OF GLASS - IT IS.
- HOLD MODULE BY THE EDGE ONLY.
- DO NOT PUT PRESSURE ON MODULE SURFACE.
- STORE MODULES ON EDGE.
- DO NOT LEAN, SIT OR CLIMB ON PANELS.

WEATHER STATION

- 115V AC PRESENT
- ALL SENSOR OUTPUTS - LOW VOLTAGE



- CLEANING - PYRANOMETERS AND PYRHELIOMETER
  DAILY WITH NON-ABRASIVE CLEANER (WINDEX TYPE)

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APPENDIX C

MODULE SPECIFICIATION AND HANDLING INFORMATION FROM SOLAR POWER CORPORATION

II. COMPONENTS SUSCEPTIBLE TO DAMAGE IN HANDLING

Because the module is unframed, there is no obvious means to handle the structure safely, and those elements which are susceptible to damage are much more exposed to the possibility of sustaining such damage unless special care is taken. Those components particularly susceptible to such damage are the glass superstrate, the silicon wafers (solar cells), and the terminal box and cable.

A. Glass Superstrate

The glass superstrate is the basic structural element of the module; but,in the unframed state it is simply a pane of glass, subject to the same susceptibility to damage in handling as any other bare pane of glass. It can be broken by an impact at any point. However, this pane of glass has been tempered, so it should be able to sustain a light impact on its front surface. (It has been tested to withstand 1 1/2 inch hailstones at their terminal velocity.) It is extremely sensitive to an impact on its edge, though. To minimize the chance of damage from edge impact, the rubber gasket which covers the edge should always be kept in place.

Because the glass is tempered, an impact at any point which results in a fracture completely destroys the entire pane of glass. Once a fracture is initiated, it propagates throughout the entire sheet of glass, resulting in a mass of tiny glass splinters held together only by the silicone rubber layer bonded to its back surface. Because its structural integrity is completely lost, the entire module has been destroyed. Care must be exercised in disposing of such a destroyed module because the small glass fragments are very sharp and can result in some nasty cuts on the hands. The use of heavy protective gloves is recommended.

B. Silicon Wafers

Silicon is a very hard, brittle material. The very thin silicon wafer solar cells are therefore quite fragile and easily broken. However, they are protected from the front by the glass sheet, and an impact on the front which does not break the glass will not break the cells. This is not true of impacts on the back surface. A sufficiently strong impact on the back, plastic-covered surface can cause a cell to crack, even though no visible damage to the packaging materials may be detected. The shock of the impact can be transmitted through the soft silicone rubber encapsulant and result in a cracked cell. An excessive concentration of pressure behind a cell can also cause it to crack. Sufficient pressure to crack a cell can come about by "pinching" the module front-to-rear between the fingers and thumb. Therefore the temptation to lift a module in this way must be resisted.

Degradation of module performance due to a cracked cell may not occur immediately if the electrode metallization remains intact. However, once a cell is cracked, the probability that the metallization will ultimately fail is greatly increased because the relative motion between the two parts of the cell during thermal excursions may ultimately fatigue the metal.

The "life" of such a cracked cell cannot be predicted, but in some cases may be on the order of years.

C. Terminal Box and Cable

The terminal box is held in place solely by the silicone rubber potting compound. It was not designed as a structural element, so excessive stress on the box can lead to failure of its bond to the module. With an unframed module the temptation to use the terminal box or output cable as a handle for lifting the module may be hard to resist. Nevertheless, since this action can damage the module, this temptation must be resisted.

UNPACKING

Modules are normally shipped 10 to a carton having outside dimensions approximately 18 x 21 x 46 inches. Any obvious damage to cartons as received should immediately be brought to the attention of the deliverer and noted for possible claims for shipping damage to modules inside. Each carton will have its own identification number, and as far as practical, each carton will contain modules from the same output current classification. A letter code stamped on the back of each module near the terminal box indicates the current classification as follows:

LETTER CODE	SHORT CIRCUIT CURRENT RANGE
D	1.90 - 1.99 A
E	2.00 - 2.09 A
F	2.10 - 2.19 A
G	2.20 - 2.29 A
H	2.30 - 2.39 A

The 10 modules in each carton are divided into 5 groups of 2. Each group of 2 is wrapped in a single cardboard sleeve. The glass fronts of the 2 modules face each other, cushioned from each other by the rubber perimeter gaskets. The back surfaces which face out are therefore protected by the cardboard sleeve. Each terminal box protrudes through a slot in the sleeve, and the output cables are taped to the outside surfaces of the sleeve. Within each carton, the 5 groups of sleeved modules are separated from each other by foam spacers. These foam spacers also keep all parts of any module at least one inch away from all inside walls of the carton. Therefore, cartons can be opened safely as long as tools do not penetrate more than one inch into the carton. When the carton has been opened, each sleeved group of 2 modules can then be removed as a unit. A separate envelope containing the current - voltage output data for each of the 10 modules is also included in the carton.

Each cardboard sleeve enclosing a group of 2 modules is a wraparound type having a seam near the center of one of the broad faces. The seam is held together by tape which must be cut or peeled away in order to unwrap the sleeve and remove the modules. If the tape is to be cut, care must be taken to insure that the knife does not penetrate too deeply and slash the back surface of the module. Use a special cutting tool whose blade does not extend more than 1/16 inch beyond the hilt. The sleeves must be unwrapped to remove the modules. Do not try to slide modules out of the sleeves.

WARNING: After the sleeve has been removed, the unframed modules are susceptible to the types of damage discussed in Section III. Refer to Section V for proper handling procedures.

HANDLING

The unframed module is particularly susceptible to damage in handling as described in Section III. The best way to avoid chance of damage is to avoid handling the module. This means that procedures which minimize the amount of handling required should be thought out and set up. Ideally, a single handling step which transfers the modules directly from the shipping carton to the finished frame might be possible. If temporary intermediate storage is necessary, the number of times a module is transferred into and out of storage should be reduced to an absolute minimum.

When unframed modules must be handled, obeying the following rules wil] greatly reduce the chance of damage.

1. Pick up and carry modules only by their edges (but do not pinch front to back - especially critical in cell area).

2. Alternatively, pick up and carry modules by means of vacuum cup lifters on the front glass surface.

3. Do not, under any circumstances, lift modules by their terminal box or output cable.

4. While carrying the module, be careful to avoid all obstacles which might accidently knock against the module.

5. If the module must be set down temporarily during transport, let it lean against some object such that only the rubber perimeter gasket (or the terminal box) rests against the object. Never allow contact between any foreign object and the back surface of the module. Keep all other traffic away from the area.

6. When installed in frames, use cable ties to secure the cable from flapping in the wind. (NOTE: Some plastic cable ties will deteriorate in outdoor service.)

I. STORAGE

To store unframed modules for any extended period of time, a protective covering should be used to guard them against accidental impacts. The back surface is especially vulnerable. The cardboard sleeves used in shipping can be reused for this purpose. Protected modules should be stacked upright (standing on end), but may be allowed to lean against each other. Do not lay modules flat and stack them on top of each other.

For very temporary storage where it is not expedient to provide protective covering, modules may be stacked unprotected. Again, modules should stand upright (standing on end). The first module should lean against some sturdy object (e.g., a wall) such that only the rubber perimeter gasket (or the terminal box) makes contact. Subsequent modules may lean against each other such that contact is made only between terminal box and glass. Be gentle in stacking modules this way. Since the stack of unprotected modules is vulnerable to impact damage, traffic in the storage area should be restricted.

II. CLEANING

Once the modules are mounted in frames and arrayed, only the top glass surface is susceptible to soiling which can result in degradation of electrical output. Because the surface is glass, natural cleaning from normal rainfall is relatively efficient. This natural cleaning is enhanced by increasing the tilt angle of the array. Experience indicates that some equilibrium level of soiling will be reached and maintained, the level depending on the amounts of particulate pollution in the atmosphere relative to the amount of precipitation. In most suburban and rural areas this equilibrium level corresponds to less than 10% degradation of electrical output, but in some urban areas the level may be much greater, in some cases exceeding 30% degradation.

To wash the glass surfaces, use any means normally used to clean glass. They can be hosed down with water and scrubbed with a mild detergent. Any other commercially available glass cleaning solution is also acceptable. For scrubbing, a soft cloth or sponge is recommended. For safety, the section of the array being washed should be short circuited.

There should be no reason to clean the underside of arrayed modules. If some unforeseen reason arises, use only a soft damp cloth or sponge and wipe gently. Again, make sure that section of the array is short circuited.

III. SAFETY OF PERSONNEL

Three or more modules connected in series can result in lethal voltages at the terminals. Therefore, great care must be exercised when wiring modules into a high voltage system. The voltage is present even on dark, overcast days. Ideally, individual modules should be plugged into connectors after all interconnect wiring is completed and sealed. Alternatively, some scheme may be devised to insure that modules are short circuited while the interconnections are being made, and then provide for a safe means to remove the short circuits.

It is advisable that all personnel handling modules wear safety glasses for protection in the event of breakage.

The safety aspects of broken module disposal was discussed in Section III A. The main concern is to avoid cuts from the sharp fragments of broken glass. Protective gloves should be worn when handling the shattered-glass module.

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