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Subcontractor Report

Development of a Fully Integrated PV System for Residential Applications

Phase I Annual Technical Report February 27, 1998 — August 31, 1999

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National Renewable Energy Laboratory

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PREFACE

This is the Annual Report on technical progress for Phase I of a two-phase effort to focus on the design, assembly, and testing of a novel roof top PV panel attachment and interconnection process and a fully integrated multi-functional dc-ac/ac-dc power collection, conversion, and control unit. A third focus of effort will be an optional battery energy storage unit designed to plug into the Power Unit and provide a dependable supply of energy for critical household loads. It summarizes work performed from February 27, 1998 to August 31, 1999 under DOE/NREL subcontract # ZAX-8-17647-02.

The following personnel at Utility Power Group, Inc. have contributed to the efforts covered in this report.

Jerry Aufang	Gilbert Duran	Gary Fourer	Kevin Mackamul
Dave Metcalf	Mike Stern	Rick West	Will Whalen

In addition, Utility Power Group, Inc. has been supported by John Wiles of the Southwest Technology Development Institute.

EXECUTIVE SUMMARY

Utility Power Group ("UPG") has completed Phase I of a two-year Photovoltaic Manufacturing Technology (PVMaT) work. During this period, UPG started work on the design, fabrication, testing and demonstration of a modular and fully integrated residential roof top-mounted PV power system. The three key and innovative components which are being developed are a PV Array, a Power Unit and Energy Storage Unit.

<u>PV Array</u> : Includes all PV modules (either crystalline or thin-film), panels, structural support equipment and materials, dc electrical equipment and materials, and installation labor and equipment required to secure and wire the fully functional dc PV array from the roof-top to the input of the Power Unit.

<u>Power Unit:</u> Includes all materials, components, and equipment required to perform all dc-ac/ac-dc power collection, conversion, and control functions from the output of the PV Array to the interconnection to utility service for power ranges from 8 - 12kW.

<u>Energy Storage Unit:</u> Includes a battery string, and all structural, mechanical, electrical materials and equipment required to provide a source of stored dc energy to be delivered to an input of the Power Unit. This may be an optional "plug and play" product in which multiple units can be paralleled by the customer for additional energy storage capacity, or it may integrated with the Power Unit.

UPG has made significant progress in the PV Array structural support design, the Power Unit power/control circuit design, the electro-mechanical layout and the Energy Storage Unit electro-mechanical design.

INTRODUCTION

Utility Power Group (UPG), in response to accelerating deregulation of the America's electric power industry and President Clinton's Million Roofs Initiative, is developing a low cost highly reliable multi-functional roof-top photovoltaic power processing system. The performance specifications of the system are being created in consultation with a number of electric utilities, PV module manufacturers, and potential end users and will set the standard for small PV power systems in the 21st century. These participants in UPG's creation of the system specifications are also participating in the work effort to make the system a reality.

The combined effect of deregulation and the Million Roofs Initiative has created both a historic market opportunity and a major technical challenge to the PV industry. The major technical challenge is to accelerate both the reduction in the installed cost and the improvement in the reliability of small rooftop PV power systems. In many ways, reliability is more important than cost in that if PV power systems are perceived by the public to be unreliable, they will not purchase such systems for their homes or businesses regardless of the price. Interestingly, the reliability of small PV systems must be considerably higher than that for large PV systems since the failure of a small portion of large system will result in merely a small decrease in output whereas the failure of a small system will result in a total loss of output.

UPG pioneered the concept of total system integration with the development of the Model 16500C Integrated Single Axis Solar Tracking PV Power System which was designed for grid-connected applications requiring a power output in blocks of 15kW. All of the Model 16500C Systems installed to date have operated without failure and UPG had installed over 100 such units by the end of December, 1999. The system now under development will represent a more advanced version of the technology utilized within the Model 16500C and will possess a number of advanced market driven capabilities which do not exist in any commercially available power processing product.

This work effort has focused on the design, assembly, and testing of a novel roof top PV panel attachment and interconnection process and a fully integrated multi-functional dc-ac/ac-dc power collection, conversion, and control unit. Utilizing a unique voltage mirror topology, the Power Unit will achieve the high power conversion efficiencies typically associated only with high voltage operation while never exceeding the relatively low voltage of typical household electric service. A third focus of effort is an optional low cost battery energy storage unit designed to plug into the Power Unit and provide a dependable supply of energy for critical household loads.

Utility Power Group has worked to develop and demonstrate this PV power system designed for exceptional reliability and the features listed below:

- Low Cost
- Compliance with all NEC, UL, IEEE, and Utility Interconnection Codes and Standards.
- High Efficiency.
- Adaptable to a Wide Range of Roof Types.
- Remotely Dispatchable.
- Silent.
- Rugged All-weather Electrical Packaging.
- Energy Storage.
- High Power Quality.

The goal of this work effort is to reduce by at least 30% the installed cost of grid-connected roof-top PV power systems, and improve their reliability by a factor of 5.

BACKGROUND

Photovoltaic ("PV") power systems generate electricity via the direct conversion of sunlight into electrical energy; requiring no fuel, creating no effluents, producing no noise, and therefore serving as an environmentally benign means of generating electrical energy. Although PV power systems are ideally suited for remote locations not served by a traditional electricity grid, their use as distributed generators in grid connected applications will allow PV technology to begin to displace conventional electrical generation technologies during peak electricity demand periods. Despite their obvious environmental value and over twenty years of use in both space and terrestrial applications, PV power systems are currently supplying less than one thousandth of one percent of the world's electricity. The dominant factor limiting the use of PV power systems in both grid and non-grid connected applications today is the life cycle cost of the total installed power system with respect to the annual kilowatt hours of energy generated.

Utility Power Group ("UPG") provides PV power system design, assembly, construction, installation, testing, and start-up services to electric utility, governmental, and industrial organizations. Since 1989, UPG has installed more than 2 megawatts of grid and non-grid connected PV power system in the United States. In 1997, UPG successfully demonstrated the concept of total PV power system integration with the Model 16500C Integrated Single Axis Solar Tracking PV Power System which was designed for grid-connected ground mount applications requiring a power output in excess of 15 kW.

UPG has become the recognized low-cost provider of PV power systems by manufacturing simple yet high quality turn-key PV power systems from a carefully specified and optimized set of components and raw materials. To date, 90% of the PV power systems manufactured by UPG have utilized a single axis-solar tracking ground mounted configuration with the remaining 10% utilizing a fixed axis rooftop mounting configuration. UPG expects that over the next five years, the proportion of rooftop mounted PV power systems will significantly increase.

As a capital intensive generation technology with no fuel cost, the life cycle cost of a PV power system is dominated by the initial installed cost and subsequent operation and maintenance expenses. Thus, the two key factors in establishing the life cycle cost of PV power systems are manufacturing cost and reliability. UPG's PVMaT work effort combines all that has been learned by UPG about component manufacturing, system integration, and customer requirements into a singular focus on reducing the manufacturing cost and increasing the performance and reliability of small rooftop PV power systems.

"System integration" and "modularity" are no longer concepts or goals. They are simply an absolute requirement of any cost effective and reliable PV power system that all components, materials, equipment, and labor associated with the installation of a PV system be properly sized, utilized, and assembled. UPG clearly demonstrated the substantial cost savings which could be attained for its ground mounted tracking system when the functions of several discrete components were integrated into a single modular unit. There is a point however, where the level of system integration, like PV module area, may reach a point of diminishing returns. For example, a very large area 2 kW PV module with an integrated UL and NEC compliant module scale inverter may not be more cost effective than a similarly sized system integrating an optimized module, panel, and inverter. Factors such as manufacturing yield, electrical conversion efficiency, and system installation flexibility, may all affect the economics of integration.

UPG's approach towards optimizing system integration and modularity issues for small roof top PV power systems was derived from a thorough analysis of every aspect of a complete PV power system from component performance to roof installation and from building code compliance to PV module I-V curve shape. UPG has received inputs from a number of module and inverter manufacturers as well as electric utility companies, end users, electrical contractors, building inspectors, and "green" energy marketing firms. The primary problems with today's commercially available grid connected roof top PV power systems including those marketed by UPG are summarized in Table 1 below:

TABLE 1: CONVENTIONAL ROOF-TOP PV POWER SYSTEMS
High cost ($5.75-$7.50 per watt)
Low inverter efficiency (85-93% @ full load)
Low System Efficiency (82-90% @full load)
Poor reliability (10% fail/yr)
Noisy Operation
No Energy Storage
Non Compliance with UL, IEEE, and Utility Interconnection Standards
Not easily Adaptable to Different Roof Types
Not Remotely Dispatchable
Inadequate All-Weather Packaging of Electrical Components
Grid Dependent

The result of this survey led UPG to develop a low cost multi-functional roof-top photovoltaic power processing system under the PVMaT Program. UPG's work effort addresses each of the problems associated with current small roof-top PV power systems and its successful completion will result in their solution. The PV power system will be comprised of three primary elements, which for simplicity will be named the PV Array, the Power Unit, and the Energy Storage Unit.

The PV Array includes all PV modules, panels, structural support equipment and materials, dc electrical equipment and materials, and installation labor and equipment required to secure and wire a fully functional dc PV array from the roof-top to the input of the Power Unit.

The Power Unit includes all materials, components, and equipment required to perform all dc-ac/ac-dc power collection, conversion, and control functions from the output of the PV Array to the interconnection to utility service.

The Energy Storage Unit includes a battery string, and all structural, mechanical, electrical materials and equipment required to provide a source of stored dc energy to be delivered to an input of the Power Unit.

Substantiation of the problems associated with the current manufacturing technology of roof top PV power systems is itemized below and presented with a description of the rational and approach to their solution:

High Cost

The installed cost of roof top PV power systems is the single largest contributing factor to life cycle cost and the primary barrier to widespread commercialization of PV technology. Although PV modules represent over 50% of the total system cost, they are outside of the scope of UPG's PVMaT work effort. Considering the current fluctuation in the price of PV modules and the promise of new modules and increased manufacturing capacities from a number of manufacturers, UPG is not including module cost or price in its analysis of system cost. All other system costs, however, from design through installation and final testing, are included. As of the date of this report, UPG has been offered modules ranging in efficiency from 5% to 14% and at prices from $2.25/watt to $4.50/watt. Rather than focus exclusively on one module type or manufacturer, UPG's low cost multi-functional roof-top photovoltaic power processing system will be designed with sufficient flexibility to accommodate most module types.

All cost data is presented in arbitrary monetary units for each cost element and includes direct materials, fabricated components and fully burdened direct labor. Area and power related cost elements are separated to allow comparison of module area efficiency on total system cost. Table 2 itemizes the major cost elements required to supply (procure, fabricate, assemble, install, test) a grid-connected roof-top PV power system based upon pre-PVMaT system technology development. Tables 3 and 4 itemize the materials/components and labor, respectively, which constitute the cost elements of Table 2.

TABLE 2: MAJOR COST ELEMENTS: Pre-PVMaT Technology	Costs (Arb. Units)
Area Related	
1. Design of Electrical Sub-System	43
2. Design of Mechanical and Structural Sub-Systems	43
3. Assemble Panels	193
4. Installation of Roof Brackets	86
5. Attachment of Panels to Roof Brackets	27
6. Conduit and Wiring From Panel to Panel	22
Power Related	
1. Installation of Combiner Boxes	70
2. Conduit and Wiring From Panels to Combiner Boxes	22
3. Conduit and Wiring From Combiner Boxes to Inverter/Grid	27
4. Installation of Inverter	450
5. Test Source Circuits	5
6. Test Inverter	8
7. System Start-Up	4
TOTAL	1000

TABLE 3: MATERIALS AND COMPONENTS: Pre-PVMaT Technology	Costs (Arb. Units)
Area Related	
Panel Rails	82
Module Mounting Adhesives	19
Conduit, Flex	22
Interconnect Wire	5
Combiner Boxes	48
Roof Brackets	38
Roof Sealing Materials	11
Mechanical Fasteners	12
Electrical Connectors	5
Conduit, IMC	13
Conduit Fittings and Accessories	9
Ground Wire	9
DC Collection Wire	17
Power Related	
Inverter	430
TOTAL	720

TABLE 4: LABOR: Pre-PVMaT Technology	Costs (Arb. Units)
Area Related	
Design & Documentation	86
Panelization	80
Roof Bracket Installation	27
Panel Attachment	20
Panel to Combiner Box Wiring	11
Conduit and Wire Installation	21
Power Related	
Inverter Installation	20
System Testing	15
TOTAL	280

Low Inverter Efficiency

Due to performance characteristics of the discrete power semiconductor switching devices within the inverter, high efficiency power conversion typically requires high dc voltage inputs. This effect applies to PV power systems of all sizes and is evidenced by the tendency of utility companies to prefer high voltage arrays when "behind the fence" rules apply. NEC and UL standards compliance dictates that PV system voltages be held below 480 Volts, but most customers with roof-top applications will not accept that high level of voltage. In such cases, the alternative is a low voltage (48 Volts) configuration which offers enhanced safety but at the expense of increased system cost due to higher amperage requirements and lower inverter efficiency due to conduction losses in the switching devices and I^2R losses in other components. UPG's proposed approach to the solution of this problem is the development of a medium voltage transformerless inverter utilizing a unique voltage mirror topology to achieve a full power conversion efficiency of over 96% while reducing the voltage level to that of the typical residential utility service.

Noncompliance with UL, IEEE, and Utility Interconnection Standards

No commercially available inverter is in full compliance with all applicable codes and standards on all federal, state, and local levels. Although some specific utility companies or local municipalities may have interconnection standards which will adversely impact the cost effectiveness of the overall system, the UPG Power Unit will be designed and tested to comply with all such codes and standards for every municipality in Arizona, California, Nevada, New Mexico, and Texas with populations over 50,000 people.

For clarification purposes, a distinction should be made between standards, and standardization. While it is of critical importance for the PV industry that nationally and internationally recognized standards for performance and reliability for all PV system components (modules, inverters, wire, conduit etc.) exist, it would be detrimental to the PV industry to establish a "standard" system design or configuration. Automobiles must meet certain safety standards, but the size, shape, and design of the vehicles required to meet those standards are left to the individual manufacturers to decide.

Poor Reliability

Reliability is a key component in the life cycle cost of a PV power system. Current failure levels of roof top PV systems are unacceptably high and faults within the inverter constitute 80% of those failures. Combiner boxes, module interconnection, and modules themselves make up the remaining 20% of system failures. Workmanship during installation is the cause of most non-inverter failures, while poor design and manufacture are the causes of most inverter related failures. UPG's solution to these problems is 1) To design and manufacture a rugged Power Unit based upon UPG's advanced power conversion technology and submit it to a barrage of stress and performance tests prior to field deployment and 2) To reduce and simplify the number of structural and electrical components required to install a roof-top system and shift certain tasks from being performed in the field to being performed in a factory environment. One of the simple approaches to be utilized by UPG to enhance the reliability of the inverter section of the Power Unit is to provide generous headroom in terms of continuous and peak power rating. In UPG's experience, the competition between outside suppliers of PV inverters has caused a shrinking of headroom to drive the down the cost per watt as calculated at the system level. With overall system reliability responsibility, UPG is focused on total system cost and reliability first and component cost second.

Noisy Operation

Many commercially available inverters operate at switching frequencies which are in the audible range and are not appreciated in a residential environment. UPG's Power Unit is designed to perform all power processing functions at a switching frequency of 20.48 kHz. High frequency operation reduces capacitor and magnetics cost, increases conversion efficiency and provides silent operation in all environments. In addition, voltage regulation is the standalone mode is greatly simplified and improved, eliminating look-up table regulation.

Inadequate All-Weather Packaging Of Electrical Components.

Few commercially available inverters provide low-cost and rugged all weather protection for an inverter with fully integrated dc/ac interface components. The highly efficient high frequency operation of UPG's proposed Power Unit will allow smaller capacitors, magnetics and heat exchangers, and will eliminate the need for 60 Hz transformers. These features will enable UPG to provide a relatively compact, all weather, enclosure in compliance with all applicable standards. A key feature of UPG's proposed PV Array is that the rail/runner concept act as a load bearing electrical raceway system to provide simplified panel installation and interconnection processes. In addition, the concept will facilitate UPG's plan to obtain UL listing for the entire PV power system as a single product.

No Energy Storage

Potential customers for roof-top PV power systems widely assume that one of the benefits of such a system is that it will provide electricity during brownouts, blackouts, or other times of trouble with the utility service. The fact that no pre-engineered, pre-packaged UL listed system exists to provide this capacity will significantly limit the penetration of PV technology into the consumer marketplace. The low cost multi-functional roof-top photovoltaic power processing system being developed by UPG is designed with a continuous rating of 8 – 12 KW and a peak rating of 19 kW to supply critical household or small commercial loads. A modular Energy Storage Unit will provide a minimum of one hour of standalone backup at the continuous power level and enables the Power Unit to act as a household UPS (Uninterruptible Power Supply). The Power Unit will charge the Energy Storage Unit from either the PV Array or from the grid.

To summarize, UPG's multi-functional roof-top photovoltaic power processing system is designed to solve the problems previously described through the development of the following:

- A simplified and adaptable roof mounting and electrical interconnection process for large area factory assembled PV panels.

- A low cost bi-directional multi-functional high efficiency power processing system.

OBJECTIVE

The overall objective of this subcontract is to reduce the total installed cost and increase the reliability of residential roof top-mounted PV power systems. The secondary objective is to increase U.S. PV power system production and installed capacity. UPG is working to achieve a 30% reduction in total non-module related system costs through the development of a PV Array and Power Unit with direct material and direct labor costs below $\$4/ft^2$ and \$0.45/W, respectively. The roof-top system will consist of a PV array, an 8 - 12 kW Power Unit and an optional Energy Storage Unit.

TECHNICAL ACCOMPLISHMENTS

TASK 1 - PV ARRAY

UPG significantly improved the conventional means and methods required to structurally interface PV modules to the roofs of single family residential houses and to electrically interconnect these PV modules to a power conversion unit. UPG focused on the design and test of a PV Array based upon the highly efficient utilization of materials and labor. Design criteria included cost, structural integrity, electrical safety, reliability, conformance with applicable standards and building and seismic codes, and adaptability to a wide range of roof materials for both existing and retrofit roof applications.

Applicable Codes and Standards for PV Arrays

The standards listed in Appendix A are applied by various organizations to the design, construction, and installation of PV power systems in residential and commercial locations.

The titles of these standards may not directly relate to PV systems, but the contents of the various standards are applicable to the areas of interest and may be used by listing agencies or inspection officials in investigating the design or installation of such systems.

Mechanical and Structural Design

The two techniques investigated for attaching the "Rail" to the "Runner" were:

1. the pushnut technique
2. the snap/slide latch mechanism

The pushnut approach requires a shaft (threaded or smooth) to be attached to the runner and a pushnut made with a strong spring-like material attached to the rail. Although the pushnut approach is an easy-on/difficult-off installation method, for repair and maintenance purposes it would be preferred if the rail/panel were more easily removed from the runner. In addition, the long term reliability of the pushnut to maintain its springlike characteristics was questioned. Although the pushnut approach of attaching the rail to the runner would be simple to use, the problems associated with it led to an alternative approach.

The alternative approach investigated utilizes a snap/slide latch mechanism to attach the "Rail" to the "Runner". In this approach the "Rail" would have a slide latch attached to it which would mate with the solid metal stud attached to the "Runner". The stud on the "Runner" would slip into the slide latch of the "Rail", slide down and snap into position. It would require both an upward and an outward force to remove the Panel from the "Runner". See Drawing Numbers 1 through 6 in Appendix C.

Grounding Considerations

The two techniques considered for grounding the PV Array were:

1. Snap Slide Latch mechanical attachment between Rail and Runner and attaching one continuous ground wire from Runner to inverter ground
2. Pigtail/Braid linking each Rail with the lower Runner, attached with either sheet metal screws, nuts & bolts, or rivets. The lower Runner will then be grounded with a continuous wire to the inverter ground.

The Mechanical and Structural Design includes an attachment method which will secure the metal Rail to the metal Runner. Article 250-136 of the NEC allows for equipment secured to grounded metal supports as equipment considered effectively grounded. The Rail will be secured to and in electrical contact with a metal rack or structure (the Runner) provided for its support and grounded by attaching a grounding wire to the Runner with a sheet metal screw and running the grounding wire to earth ground.

Electrical Interconnection

The various options for electrically interconnecting the modules into panels and the panels into the array include: individual module junction boxes, a junction box attached to each Rail/Panel, a junction box integral to the Runner, or by using high-reliability wire-nuts or butt connectors. Although the J-Box techniques are the traditional approach, it is costly both in terms of materials and the labor required for installation. Although this approach is useful when diodes and/or fuses are used at the module or panel level, it was decided to centralize all diodes and fuses within the power unit to facilitate operation and maintenance. Although wire costs are increased, the approach of centralizing the diodes and fuses in the power unit allows the use of UL-listed silicone-filled wire-nuts or butt connectors to connect the two or three wires forming the series/parallel circuits of the array within the Rail and Runner.

Source Circuit Design

Included in this report are drawings describing the source circuit designs utilizing either Energy Photovoltaic EPV-40 modules or Siemens Solar Industries (SSI) SP-75 modules. A major difference in the two module types is the level of voltage produced by each module. The EPV-40 has an open circuit voltage (V_{OC}) of 62.2 volts while the SSI SP75 has a V_{OC} of 21.7 volts. Each panel is composed of two modules and therefore the two modules of the EPV panel are wired in parallel while the two modules of the SSI panel are wired in series in order to supply the necessary voltage to the Power Unit. The EPV module is provided with positive and negative pigtail leads, while the SSI module has an integral J-Box with a bypass diode. See Drawing Numbers 7 and 8 in Appendix C.

PV Array Testing

UPG performed wind equivalent loading tests on the prototype PV Array by first mounting the panel to a rigid test structure. The panel was then instrumented and monitored throughout the test to detect any open circuit or ground faults during the test. An essentially uniform load of 50 lb/ft^2 was applied normal to the panel surface and left in place for 30 minutes. The load was removed and reapplied to the opposite surface for 30 minutes. These two loadings were repeated for three cycles. The panels exhibited neither open nor short-circuit conditions during the test.

PV Array Cost Analysis

The PV Array Cost Analysis is based on a residential roof-top system utilizing 60 modules with a unit module area of 8.5 ft^2 for a total array area of 510 ft^2. An array this size will generally produce approximately 2,000 watts using the thin-film modules that are currently commercially available and will cost less than \$5.00/ft^2 of module area for non-module materials and installation labor. The modules are assembled into panels consisting of two modules, sheet metal Rails, wire and required adhesive material. The Runners are attached to the roof using lag screws and standoff hardware. The panels are mounted onto Runners using a slide and lock mechanical attachment technique that is an integral part of the Rail and Runner. Each set of two Runners supports five panels. Each cost category is broken down in terms of Direct Labor and Direct Materials.

TABLE 5: MAJOR COST ELEMENTS: Phase 1 Results	Costs (Arb. Units)
Area Related	
1. Design of Electrical Sub-System	43
2. Design of Mechanical and Structural Sub-Systems	43
3. Assemble Panels	155
4. Installation of Roof Brackets	73
5. Attachment of Panels to Roof Brackets	11
6. Conduit and Wiring From Panel to Panel	12
Power Related	
1. Conduit and Wiring From Panels to Inverter/Grid	25
2. Installation of Inverter	345
3. Test Source Circuits	5
4. Test Inverter	8
5. System Start-Up	4
TOTAL	724

TABLE 6: MATERIALS AND COMPONENTS: Phase 1 Results	Costs (Arb. Units)
Area Related	
Panel Rails	63
Module Mounting Adhesives	15
Conduit, Flex	19
Interconnect Wire	5
Roof Brackets	28
Roof Sealing Materials	11
Mechanical Fasteners	12
Electrical Connectors	5
Conduit, IMC	13
Conduit Fittings and Accessories	9
Ground Wire	9
DC Collection Wire	17
Power Related	
Inverter	325
TOTAL	531

TABLE 7: LABOR: Phase 1 Results	Costs (Arb. Units)
Area Related	
Design & Documentation	86
Panelization	40
Roof Bracket Installation	12
Panel Attachment	8
Conduit and Wire Installation	12
Power Related	
Inverter Installation	20
System Testing	15
TOTAL	193

TASK 2 - POWER UNIT

Utility Power Group designed and tested a high efficiency, low cost, high reliability prototype power conversion unit which included all materials, components, equipment, and software required to perform all dc-ac/ac-dc power collection, conversion, and control functions between the output of the PV Array and the interconnection to the electrical grid service of single family residences. The goal of this task was to develop a Power Unit capable of meeting the preliminary specifications outlined in Table 8 and conforming to the draft specifications of IEEE PAR 929 and UL 1741.

TABLE 8: POWER UNIT PERFORMANCE SPECIFICATION

Utility Interface / Generator, 120/240 split phase	
Continuous Power Rating (@25degC)	8.0 kW - 12.0 kW
Peak Power Rating, (10sec)	12 kW - 20 kW
Nominal Utility Voltage, line-line	240 Vac, split phase
Utility Voltage Range, 86%-106% of nominal	206-254 Vac
Frequency, nominal	50/60 Hz
Power Factor, 25%-100% load, grid-tied	> .99
Current Distortion, grid-tied	< 3% THD, IEEE 519-1992
Disconnect	visible, load break

Utility Interface / Generator, 120 Vac	
Continuous Power Rating (@25degC)	8.0 kW – 12.0 kW
Peak Power Rating, (10 sec)	12 kW - 20 kW
Nominal Utility Voltage, line-line	120 Vac, single phase
Utility Voltage Range, 86%-106% of nominal	103-127 Vac
Frequency, nominal	50/60 Hz
Power Factor, 25%-100% load, grid-tied	> .99
Current Distortion, grid-tied	< 3% THD, IEEE 519-1992
Disconnect	visible, load break

Photovoltaic Interface	
Configuration	bipolar
Maximum Current	24 Amps
Operating Voltage, nominal	220 Vdc
Max Power Tracking Window	190 to 250 Vdc
Max Open Circuit Voltage	600 Vdc
Disconnect	visible, non-load break

Battery Interface	
Nominal Voltage, bipolar configuration	+\- 192 Vdc
Maximum Current, charge or discharge	48 Amps
Disconnect	visible, non-load break

Performance	
Efficiency, grid tied, 25%-100% load	> 94%, nominal conditions
Switching Frequency	20.5 kHz
Standby Losses	< 10 Watts
Max Power Tracking Accuracy	+/- 1%
Auto Start (wakeup) Algorithm	Array Current Sense
Low Power Shutdown Algorithm	Array Power < 50 Watts
Battery Charging Algorithm	3 stage, temp compensated

Reliability	
Failure Rate (specification non-compliance)	2 in 100 per year

Fault Detection / Diagnostics	
Overtemperature	$T_{junction,\ IGBT}$ > 100degC
System Trouble	UV control power supply
DC Ground Fault Trip Point	$I_{leakage}$ > 1 Adc
DC Ground Fault Interrupt Method	Open circuit array disable
DC Ground Fault Alarm	Audible, piezo electric
Synchronization / Frequency Fault	PLL lock loss, nom freq +1.0 Hz, -1.5 Hz
Utility Under/Over Voltage, 240 V config.	206 Vac > $V_{l\text{-}l}$ > 254 Vac
Overpower	P_{array} > 7000 Watts
Overcurrent	I_{line} > 110%

Packaging / Environmental	
Dimensions	22″W x 33″T x 11″D
Weight	190 lbs
Operating Temperature	-25degC to 50degC
Humidity	0-100%
Integrity, interface compartment	NEMA 3R equivalent
Integrity, electronics compartment	NEMA 12 equivalent
Cooling	isolated forced convection
Finish	polyester powdercoat over zinc rich primer

Front Panel Controls / Metering / Alarms / Remote Controls (all optional)	
Comprehensive Display and Programming	keypad and LCD
Battery Capacity Indicator	LCD
Primary Power Loss Alarm	communication terminals for remote piezo alarm
Low Battery Capacity Alarm	communication terminals for remote piezo alarm
Generator Start (low battery)	relay contacts to communication terminals

Power Unit Electro-Mechanical and Circuit Design

UPG has designed the electrical and electronic circuitry of key elements of the Power Unit, including the Voltage Mirror, Split-Phase Bridge, and the Power Conductor Interface. These circuits incorporate high-speed, low-loss power IGBT modules manufactured by UPG. These IGBT modules allow operation at 20 kHz to reduce acoustical noise and provide a reduction in magnetics size, thereby reducing the overall size of the Power Unit. In addition, UPG developed a specification defining I/O signals and timing requirements of a microprocessor to provide the user interface and run the Current/Voltage Regulation Algorithms required to perform power conversion and active line harmonic cancellation. UPG's primary design criterion is to be manufacturable for low-cost production and high reliability. See Drawing Numbers 9 through 14 in Appendix C.

Power Unit Testing

Power Unit Subassemblies Test Report

All printed circuit boards subassemblies were tested for schematic verification per test plans. Much of this work involved verification of correct component values for agreement between parts list, schematic and correct circuit function. All printed circuit boards were verified for mechanical interference and mounting considerations. All changes have been documented. Burn-in tests were performed on all power circuits where applicable.

Table 9 is a list of Power Unit subassembly tests results. The list outlines all modifications to the original electrical design other than those listed in the preceding paragraph.

Power Unit Cost Reduction

The cost of materials and direct labor based on 100 piece production quantities is $0.34/watt, outperforming the Phase 1 goal of $0.50/watt.

Table 9: Power Unit Subassembly Test Results

Test Performed	Results of Tests and Improvements Needed
Bridge Assembly, B05100A	Snubber values changed Neutral connections reconfigured
Contactor Assembly, B05200A	No changes required
PV Combiner Assembly, B05300A	No changes required
Differential Capacitor Assembly, B5400	No changes required
Control Board Assembly, B05500	PROM code changed Cut and jump PCB changes made Via to trace shorts removed Voltage regulation phase changed Current control compensation values changed Sinewave references rescaled Comparator differential clamp diodes added Start timing delays changed
Operator Interface Assembly, B05550	Resistor networks changed
Crowbar Subassembly, B05600	No changes required
Power Supply Assembly, B05650	PWM chip start circuit changed Feedback compensation values changed Cut and jump modifications for PCB ground plane swell error Transformer gap changed Snubber values changed Push-pull current limit changed Fan controller circuit values changed
Drive Subassembly, B05700	IGBT drive resistor values changed Dead time component values optimized
EMI subassembly, B05800	No electrical changes required

Following is the test plan for the electrical, mechanical and thermal tests performed on the Power Unit:

Power Unit Electrical, Mechanical and Thermal Test Plan

1.0 Electrical Test Plan

1.1 Troubleshooting - Visually inspect PCB's for registration errors and solder bridges. Connect low voltage power supplies and verify power to all IC's. Check circuit function per schematic. *Typical problems are missing or erroneous circuit board connections and incorrect component values. Some of the circuitry will not make the transition from paper working hardware. In this case portions of the circuit will have to be redesigned.*

1.2 Specification Conformance – Vary loads, input supply voltage and output line-tie voltage to test specification conformance.

1.3 Circuit Optimization – Improve conversion efficiency by adjusting IGBT gate drive and IGBT snubber values. Simplify and delete extraneous circuitry.

1.4 Documentation Update – During the above subtasks "redline" changes on schematics, PCB layouts and parts lists. Upon completion of the first three subtasks, make changes to all formal documentation.

2.0 Mechanical Test Plan

2.1 Fit – Assemble prototype to verify design clearances, parts alignment and hole tolerances.

2.2 Documentation Update – Incorporate "red lined" changes to formal drawings.

3.0 Thermal Test Plan

Place thermocouple probes on heatsink and on power modules. Setup normal operational configuration of prototype with all access plates secured and front door closed. Run unit at full power. When temperatures have stabilized record readings. Record ambient temperature. Determine IGBT junction temperature margin extrapolated to 50deg ambient.

Following is the test plan for the anti-islanding tests:

Plan for Anti-Islanding Performance Test

The anti-islanding performance test will be done according to UL1741, *Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems*, and without exception. UL1741 is currently the definitive standard for anti-islanding tests.

TASK 3 - ENERGY STORAGE UNIT

Utility Power Group designed and tested a low cost, modular, self-contained, low maintenance, all weather, battery-based Energy Storage Unit designed to interface with the Power Unit to provide back-up electricity to supply critical household loads in the event of utility grid failure. The Energy Storage Unit includes a battery string and all structural, mechanical, and electrical materials and equipment required to provide a source of stored dc energy to be delivered to an input of the Power Unit. UPG designed this unit as a "plug and play" option in which multiple units can be easily paralleled for additional energy storage capacity or integrated with the Power Unit. See Drawing Number 15 in Appendix C. The goal of this task was to develop an Energy Storage Unit which met the preliminary specifications outlined in Table 10 and conforms to applicable IEEE and UL Standards.

Applicable Codes and Standards for Energy Storage

The standards listed in Appendix B may be applied by various organizations to the design, construction, and installation of battery energy storage systems (including engine-driven charging systems) in residential and commercial locations.

The titles of these standards may not directly relate to batteries, but the contents of the various standards are applicable to the areas of interest and may be used by listing agencies or inspection officials in investigating the design or installation of such systems.

Energy Storage Unit Battery Selection

The battery technology choice for the PVMaT development was not made strictly from the standpoint of dollars/kilowatt-hour of energy storage capability. Safety and liability drove the final selection criteria.

From a cost and performance perspective, there were two basic battery types considered for this application; flooded lead acid and sealed maintenance free types.

Flooded lead acid types were determined to be unsafe for high voltage battery strings in residential applications. Leakage of electrolyte from a battery in a high voltage battery string can easily cause arcing to the grounded battery enclosure. In addition, the end user could be expected to accurately tend to the "make-up" watering maintenance requirements. Additionally, the possibility of explosion during a catastrophic event is much more likely with the flooded battery types.

The batteries chosen were valve regulated lead acid (VRLA) employing absorbed glass mat (AGM) technology. Some characteristics and comparisons with other battery types are given below.

- The electrolyte is absorbed in a glass mat (AGM) separator in the valve regulated lead acid (VRLA) batteries and it is spillable in the flooded/vented battery type.

- The cells have pressure relief safety valves with flame arrestors in the VRLA batteries that are designed to keep positive pressure in each cell. The flooded type battery cells are open to the atmosphere through the vent cap holes. Should the vented battery be tilted or inverted the result can be electrolyte (sulfuric acid & water mixture) spilled, creating a potentially dangerous condition.

- The cell groups in the vented type batteries are loosely packed and thus have high plate separation. In contrast, the VRLA has every square inch of positive and negative plate material tightly packed and compressed with the AGM and supported by each cell wall. Because of this type of construction the VRLA batteries have much lower internal resistance and greater energy density. Additionally, this support provides a much higher degree of shock and vibration resistance than the flooded type batteries.

- The flooded electrolyte electric storage batteries consume water in service because the battery generates hydrogen from the negative plate and oxygen from the positive plate when on charge, a process known as electrolysis. During the electrolysis process the flooded battery can generate ignitable and explosive amounts of hydrogen gas into the air. Also, the hydrogen and oxygen gases that escape through the vent holes must be replaced periodically by adding water that is consumed.

Operational Theory

The VRLA design is a recombinant gas, absorbed electrolyte battery. The cells are sealed using pressure relief safety valves with flame arrestors that provide a positive pressure within the battery. The plates are sandwiched with a microfibrous silica glass mat consisting of a blend of glass fibers of varying length and diameter that have superior wicking characteristics and promote retention of the electrolyte. Electrolyte is absorbed and held by the capillary action between the fluid and the glass mat fibers. The mat is over 90% saturated with electrolyte. By design it is not totally saturated with electrolyte, a portion is filled with gas. This void space provides the channels by which oxygen travels in its path from the positive to the negative plate during charging. The void spaces allow the freshly generated gases, which are in their atomic state and very reactive, to recombine rapidly and safely. The recombination passivates the negative slightly, reducing electrolysis and ultimately eliminating the need to add water, which makes the battery truly maintenance free.

Gelled Electrolyte Problems

A major limitation of all gelled electrolyte batteries is the immobility of the electrolyte. These batteries are manufactured using a silica gell/acid mixture. The gelled electrolyte is highly viscous and recombination of the gases generated on charge occurs at a much slower rate than with the VRLA-AGM batteries. This effectively increases the time it takes to recharge a gel battery and limits the charging current. Further, the gel batteries lose capacity over their life. During the charge cycle minute voids develop within the gell matrix to allow passage of gases. However, because of the viscosity of the gelled electrolyte, these voids (channels) do not always refill. Over time these voids keep increasing in size and number. As these voids continue to increase, more and more plate surface area is left dry and unable to provide a path for ionic flow, progressively reducing the capacity of the gel battery.

CHARGE RETENTION

VRLA batteries retain charge five to ten times better than flooded type batteries. Depending on the specific battery series selected self discharge is one to three percent per month.

SAFETY

By design, VRLA-AGM batteries produce no more than 1% hydrogen gas during severe overcharge at elevated temperatures. In recent testing by the U.S. Navy the batteries were tested to MIL –B-8565J for hydrogen gas emission. For flammability in air a hydrogen concentration of 4.1% or greater is required. The MIL Spec. requires a concentration of 3.5% or less to pass the test. The VRLA-AGM batteries produced no more than 1% during test.

Further, the VRLA-AGM batteries have been tested by Underwriter Laboratories for compliance to UL 924 and UL 1989. These batteries are a UL recognized system component.

Energy Storage Unit Specification

UPG evaluated battery storage capacity requirements for various system configurations by reviewing typical household load profiles and determining an average critical load profile. UPG determined the economic value of on-peak/off-peak load shifting and utility dispatch capability as part of this assessment to select between float or deep cycling operation. UPG and SWTDI researched and compiled national codes, and select state/local safety, building and seismic codes and standards for lead acid battery installations. The shape, weight and structural integrity of the Energy Unit was considered with respect to the expected transport and installation methods.

TABLE 10: ENERGY STORAGE UNIT SPECIFICATION

Nominal Voltage	+/- 192 Volts
Configuration	Bipolar, center tap neutral
Capacity, 8 hour rate	11.5 kW-hr
Capacity, 20 hour rate	12.7 kW-hr
Disconnect	Load break, visible separation
Overcurrent Protection	60A fuses
Maximum Voltage (equalize)	+/- 240 Vdc @ 0° C
Battery Type	Absorbed Glass Mat, Valve Regulated
Battery Electrolyte	Lead Acid
Enclosure Type	Tamperproof, freestanding
Weight	1000 lbs.
Overall Dimensions	50"L x 25"W x 37"T

Energy Storage Power Management

Charging Method

There are three stages to the charge cycle. The battery management circuitry will automatically step through each of these three stages whenever charging current is available and the battery has been discharged to below the float voltage.

1. Bulk Charge: The charging circuitry is in current source mode, limited by the available power of the maximum allowable current (current limit point) of the charging circuit. This cycle concludes when the battery voltage reaches the Absorb Cycle Voltage. Any time that the bulk charge cycle is initiated and lasts for at least 5 minutes, this cycle is followed by the Absorb Cycle. In order to conserve power and avoid unnecessary heating of the batteries, the charging circuitry will divert directly to the Float Mode if a bulk charge cycle lasts for less than 5 minutes and the charge cycle has been completed within the last 48 hours.

2. Absorb Cycle: The charging circuitry is in voltage source mode, regulating the charging voltage to the Absorb Cycle Voltage. This mode is maintained for 3 hours. At the conclusion of this cycle, the Float Mode is initiated. Absorb Cycle Voltage = (229 – 0.36(T-25)) VDC ±0.5%. T is the battery temperature in degrees Centigrade.

3. Float Mode: The charging circuitry is in voltage source mode, and is reduced to the Float Voltage. It is not necessary to maintain charger operation for the batteries to maintain this voltage. Float Voltage = (214 - 0.36(T-25)) VDC 60.5%.

Monitoring the State of Discharge

In order to alert the user to low battery conditions and to maintain long battery life, the following discharge conditions will be monitored:

1. A discharge alarm will alert the user when the battery voltage reaches the Alarm Voltage. The remaining power available at this point varies with the discharge rate and temperature, and is typically 33% of the system capacity

2. The unit will shut off at the Discharge Voltage. Some battery capacity remains at this point, but battery life will be compromised if discharge continues below this point.

3. The unit may be used in Emergency Override when operating in stand-alone mode, and will operate until the battery voltage reaches the Emergency Shutdown voltage.

Alarm Voltage = 192 VDC.

Shut-Off Voltage = 184 VDC

Emergency Shutdown Voltage = 168V

Energy Storage Unit Testing

Following is the test plan for the electrical, mechanical and thermal tests performed on the Energy Storage Unit:

Structural/Mechanical, Electrical and Thermal Test Plan

Structural/Mechanical Tests

“Test” prototype assembly against all applicable national, state and local safety, building and seismic codes and standards for lead acid battery installations as delineated in deliverable D2.3.1.

Electrical Tests

Connect ESU (Energy Storage Unit) to Power Unit. Record each "12V" battery voltage within the series string. With the Power Unit sourcing power into the grid, discharge the ESU to +/-184Vdc or 1.92V/cell at 50% of rated current. Record kilowatt-hours delivered to the grid. Record each "12V" battery voltage. Fully recharge the ESU from the grid per charge algorithm. Record kilowatt-hours delivered from the grid. Record each "12V" battery voltage. Repeat the charge/discharge cycle until remaining ESU capacity is 10% of fresh battery capacity. Compare the total kilowatt-hour lifetime of the ESU to the manufacturer's specifications. This test is intended to prove the nominal ESU energy capacity at recommended depth of discharge and at an ambient temperature of 25degC.

Thermal Test Plan

Connect one thermocouple to each of the 32 battery units. The measurement point shall be in precisely the same place on each battery case. Place thermocouples in the four interior corners of the ESU. Place one thermocouple at the ambient air intake of the fan. Temperature measurements shall be made and recorded during the electrical test given above. The purpose of this thermal mapping is to verify the effectiveness of the enclosure air circulation system. The battery temperatures within the series string must be keep the same to prevent charge disparity between "12V" units.

Following is the test plan for the stress-cycling tests performed on the Energy Storage Unit:

Stress Cycling Test Plan

Connect ESU (Energy Storage Unit) to Power Unit. Block air intake vent to produce a 20degC interior temperature rise over temperatures recorded at 25degC ambient. Record each "12V" battery voltage within the series string. With the Power Unit sourcing power into the grid, discharge the ESU to +/-168Vdc or 1.75V/cell at full of rated current. Record kilowatt-hours delivered to the grid. Record each "12V" battery voltage. Fully recharge the ESU from the grid per charge algorithm. Record kilowatt-hours delivered from the grid. Record each "12V" battery voltage. Repeat the charge/discharge cycle until remaining ESU capacity is 10% of fresh battery capacity. This test is intended to define the worst case ESU energy capacity under deep discharge conditions and at a simulated ambient temperature of 45degC.

Connect one thermocouple to each of the 32 battery units. The measurement point shall be in precisely the same place on each battery case. Place thermocouples in the four interior corners of the ESU. Place one thermocouple at the ambient air intake of the fan. Temperature measurements shall be made and recorded during the electrical test given above. The purpose of this thermal mapping is to check for large battery unit temperature deltas or thermal "runaway" due to overcharging the highest temperature batteries.

ACKNOWLEDGMENT

The authors wish to acknowledge the role of the U.S. Department of Energy in the support of NREL's PVMaT Program, without which the development, demonstration, and commercialization of UPG's novel roof top PV panel attachment and interconnection process and a fully integrated multi-functional dc-ac/ac-dc power collection, conversion, and control unit would not have been possible. In particular, the authors appreciate the support and guidance provided by the NREL/SNL Technical Monitoring Team consisting of H. P. Thomas (NREL), B. D. Kroposki (NREL), and W. Bower (SNL).

The authors also wish to thank John Wiles of the Southwest Technology Development Institute for his support in the development of UPG's design approach.

Appendix A

Applicable Codes and Standards for PV Arrays

Applicable Codes and Standards for PV Arrays

1. National Fire Protection Association
   1 Batterymarch Park
   POB 9101
   Quincy, MA 02269
   800-344-3555

NFPA 70 *National Electrical Code* (1990-1999 in various jurisdictions)

The following Articles in the NEC relate to PV arrays:

Article 690 Solar Photovoltaic Systems
Article 511 Commercial Garages, Repair and Storage
Article 700 Emergency Systems

Other articles in the NEC that relate to electrical power systems will also apply.

The National Electrical Code Handbook provides additional detail and interpretations of the above listed sections of the NEC.

Other NFPA publications of interest are:

NFPA 37 *Installation and Use of Stationary Combustion Engines and Gas Turbines*
NFPA 58 *LP-Gas Code*
NFPA 73 *Residential Electrical Maintenance Code for One and Two Family Dwellings*
NFPA 110 *Emergency and Standby Power Systems*
NFPA 111 *Stored Electrical Energy Emergency and Standby Power Systems*

2. Underwriters Laboratories (UL)
   333 Pfingsten Road
   Northbrook, LI 60062
   847-272-8800

UL 198 B-L Fuses
UL 248 1-16 Low-Voltage Fuses
UL 977 Fused Power Circuit Devices
UL 1741 Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems
UL 1703 Flat-Plate Photovoltaic Modules and Panels

3. IEEE
   445 Hoes Lane
   Piscataway, NJ 08855
   800-678-4333

   IEEE 928 Recommended Criteria for Terrestrial Photovoltaic Power Systems

   IEEE 929 Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic (PV) Systems

   IEEE 1001 Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems

   IEEE 1374 Guide for Terrestrial Photovoltaic Power System Safety

4. Building Codes

The Uniform Building Code, Southern Building Code, International Congress of Building Officials, other regional codes, and local building and electrical codes impose regional and local standards.

For example, Sections 1301 and 2603.14 of the Uniform Building Code impose fire standard ratings for Solar Collectors installed on the roofs of buildings. Volume 2, Chapter 16, Division III of the UBC covers Earthquake Design that may apply to heavy battery banks, inverters, and PV systems mounted on the roof.

Appendix B
Applicable Codes and Standards for Energy Storage

Applicable Codes and Standards for Energy Storage

1. National Fire Protection Association
   1 Batterymarch Park
   POB 9101
   Quincy, MA 02269
   800-344-3555

NFPA 70 *National Electrical Code* (1990-1999 in various jurisdictions)

The following Articles in the NEC relate to battery installations:

Article 480 Storage Batteries
Article 690 Solar Photovoltaic Systems
Article 511 Commercial Garages, Repair and Storage
Article 513 Aircraft Hangers
Article 700 Emergency Systems
Article 701 Legally Required Standby Systems
Article 625 Electric-Vehicle Charging System Equipment

Other articles in the NEC that relate to electrical power systems will also apply.

The National Electrical Code Handbook provides additional detail and interpretations of the above listed sections of the NEC.

Other NFPA publications of interest are:

NFPA 37 *Installation and Use of Stationary Combustion Engines and Gas Turbines*
NFPA 58 *LP-Gas Code*
NFPA 73 *Residential Electrical Maintenance Code for One and Two Family Dwellings*
NFPA 110 *Emergency and Standby Power Systems*
NFPA 111 *Stored Electrical Energy Emergency and Standby Power Systems*

2. Underwriters Laboratories (UL)
333 Pfingsten Road
Northbrook, LI 60062
847-272-8800

UL 198 B-L	Fuses
UL 248 1-16	Low-Voltage Fuses
UL 583	Electric-Battery-Powered Industrial Trucks
UL 977	Fused Power Circuit Devices
UL 924	Emergency Lighting and Power Equipment
UL 1263	Battery Chargers for Charging Engine-Starter Batteries
UL 1564	Industrial Battery Chargers
UL 1741	Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems
UL 1703	Flat-Plate Photovoltaic Modules and Panels
UL 1778	Uninterruptible Power Supply Equipment
UL 1989	Standby Batteries
UL 2089	Vehicle Battery Adapters

3. Battery Council International
401 North Michigan Ave.
Chicago, IL
312-644-6610

This is an industry group that establishes standards for use and testing.

Battery Technical Manual - 1998
Battery Service Manual - 1995

4. IEEE
445 Hoes Lane
Piscataway, NJ 08855
800-678-4333

IEEE 450 Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations

IEEE 484 Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations

IEEE 928 Recommended Criteria for Terrestrial Photovoltaic Power Systems

IEEE 929 Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic (PV) Systems

IEEE 937 Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems

IEEE 1001 Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems

IEEE 1013 Recommended Practice for Sizing Lead-Acid Batteries for Photovoltaic (PV) Systems

IEEE 1361 Recommended Practice for Determining Performance Characteristics of Lead Acid Batteries for Use in Small Photovoltaic (PV) Systems

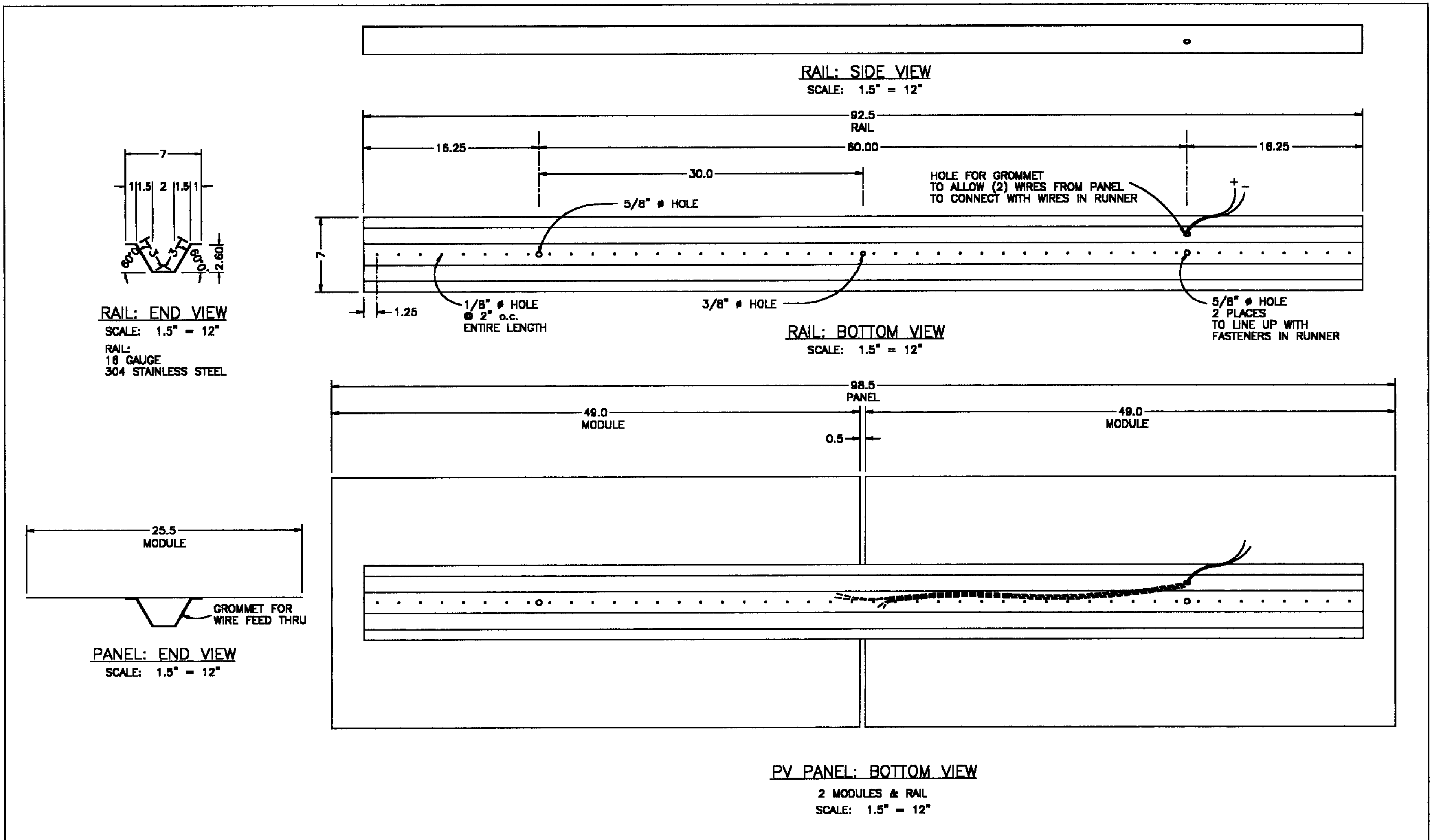
IEEE 1374 Guide for Terrestrial Photovoltaic Power System Safety

5. Building Codes

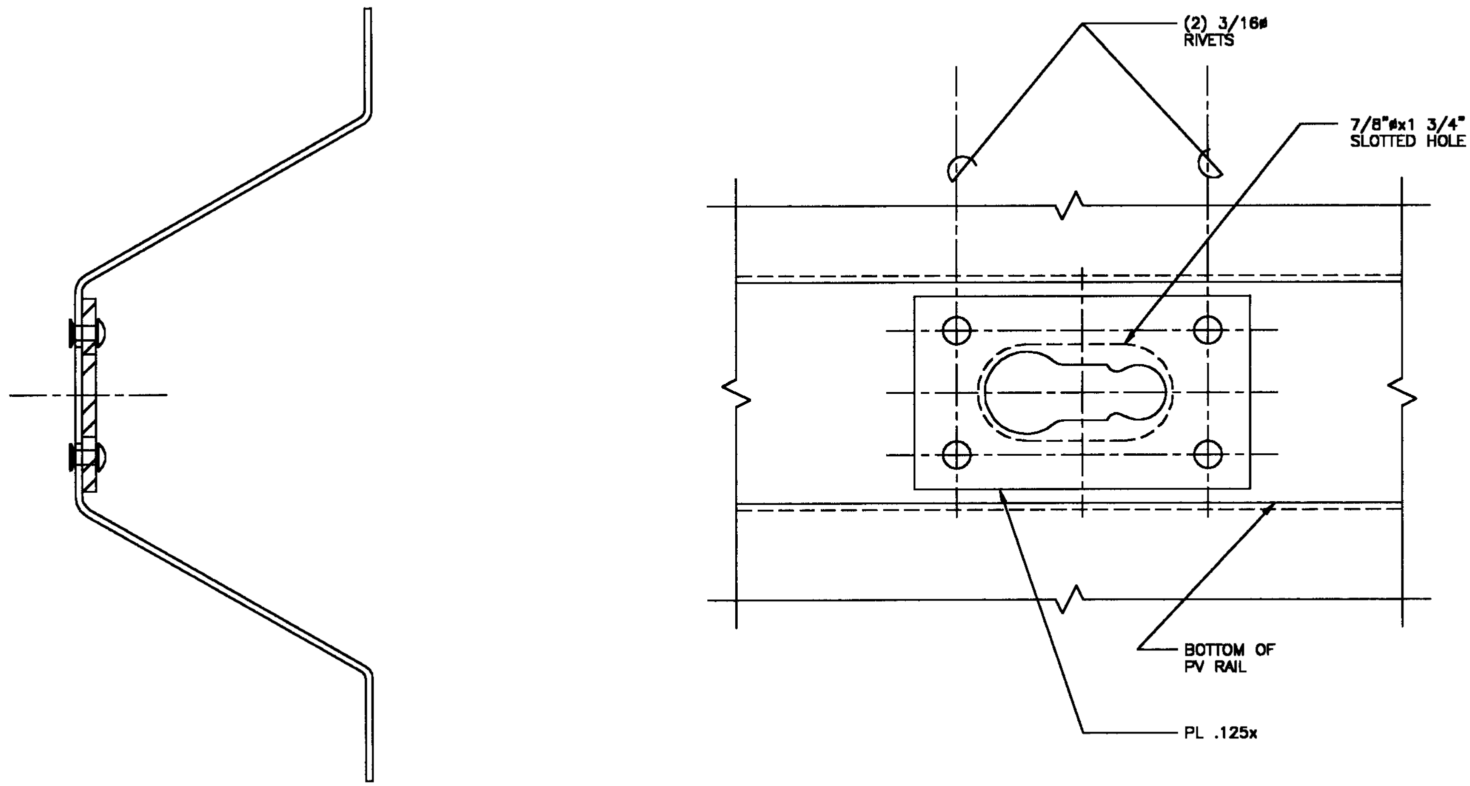
The Uniform Building Code, Southern Building Code, International Congress of Building Officials, other regional codes, and local building and electrical codes impose regional and local standards.

For example, Sections 1301 and 2603.14 of the Uniform Building Code impose fire standard ratings for Solar Collectors installed on the roofs of buildings. Volume 2, Chapter 16, Division III of the UBC covers Earthquake Design that may apply to heavy battery banks, inverters, and PV systems mounted on the roof.

Appendix C
Drawings



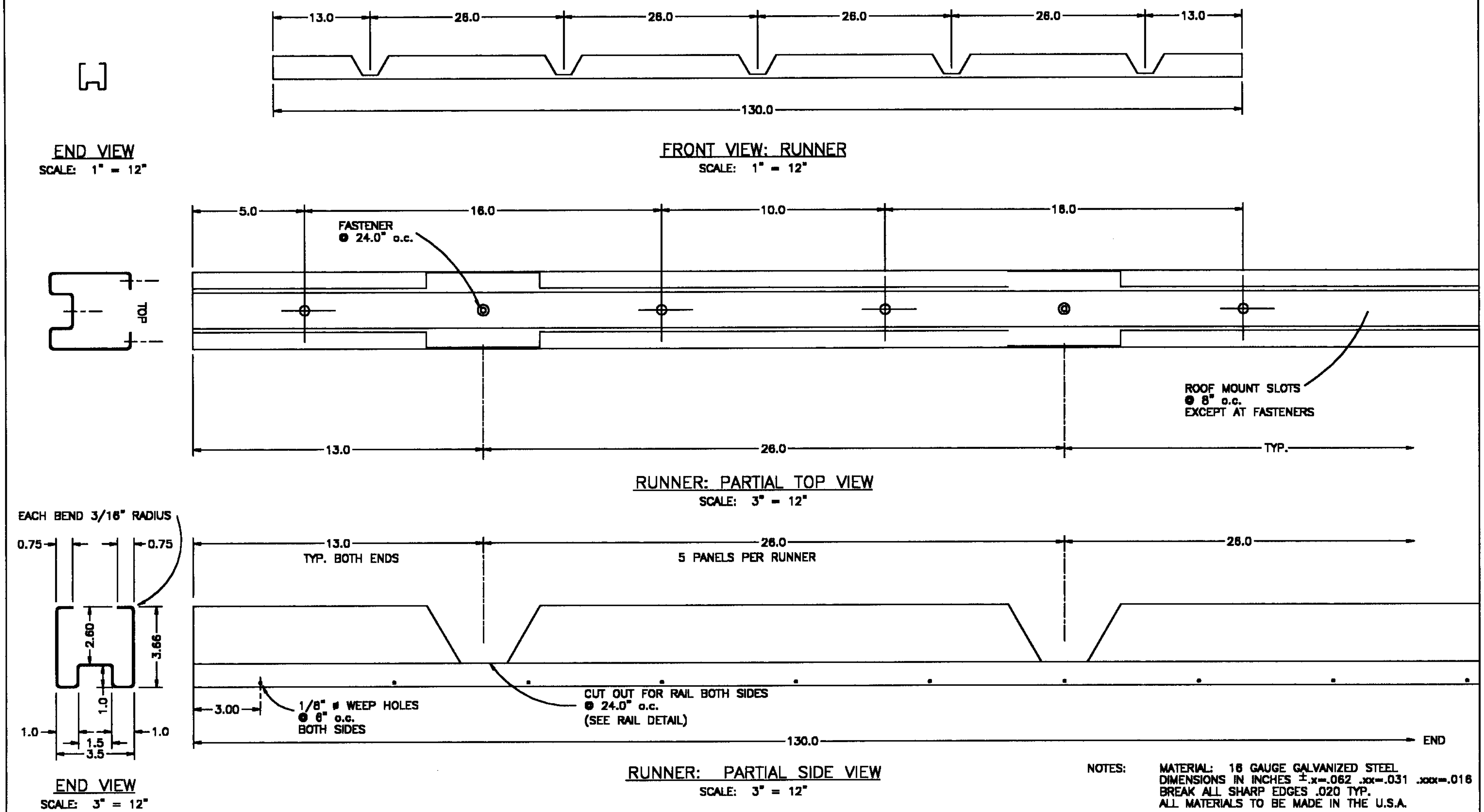
DATE: 5 MAR 99 ACAD FILE: DRAWN BY: ZB	Drawing No. 1: PANEL & PANEL RAIL	UPG UTILITY POWER GROUP 9410-G DeSOTO AVENUE CHATSWORTH, CA 91311



DATE: 5 MAR 99
ACAD FILE:
DRAWN BY: ZB

Drawing No. 2: RAIL STIFFENER PLATE

UPG UTILITY POWER GROUP
9410-G DeSOTO AVENUE
CHATSWORTH, CA 91311

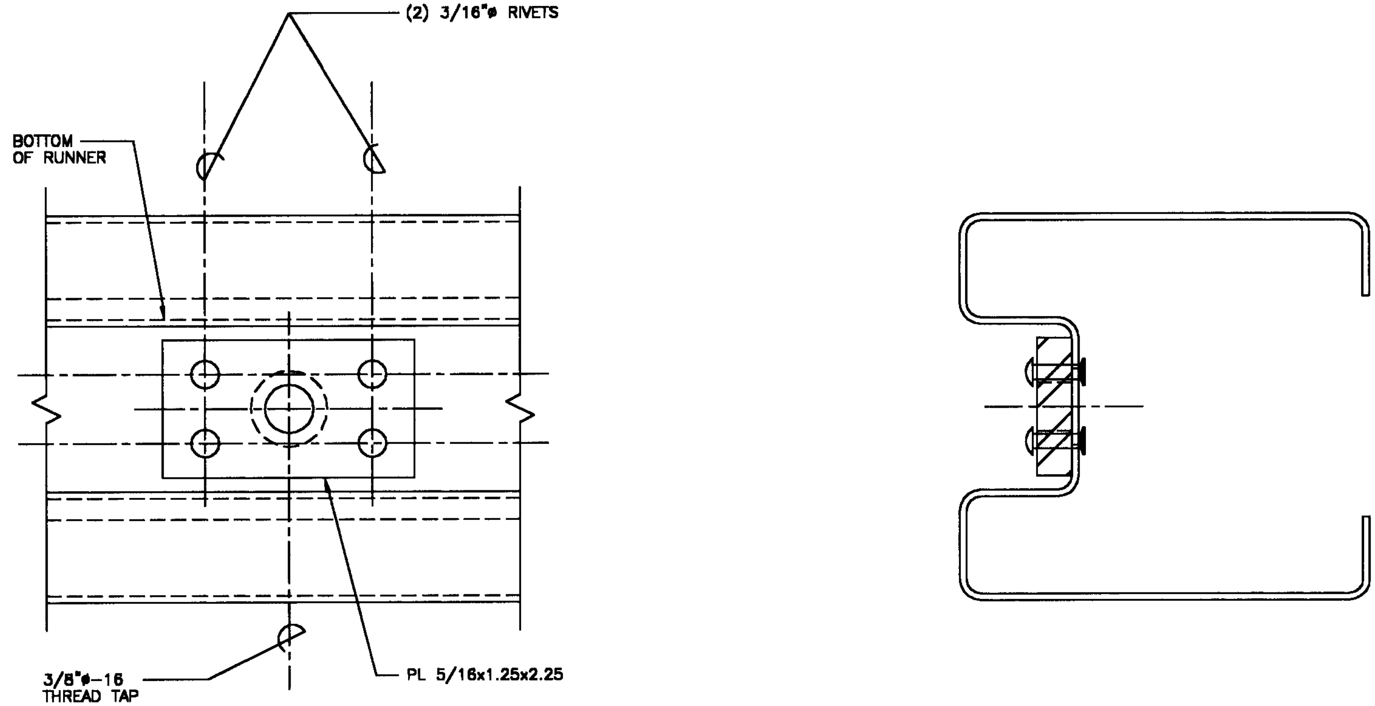


NOTES: MATERIAL: 16 GAUGE GALVANIZED STEEL
DIMENSIONS IN INCHES ±.x=.062 .xx=.031 .xxx=.016
BREAK ALL SHARP EDGES .020 TYP.
ALL MATERIALS TO BE MADE IN THE U.S.A.

DATE: 5 MAR 99
ACAD FILE: RUNNER.dwg
DRAWN BY: S. McArthur

Drawing No. 3: RUNNER

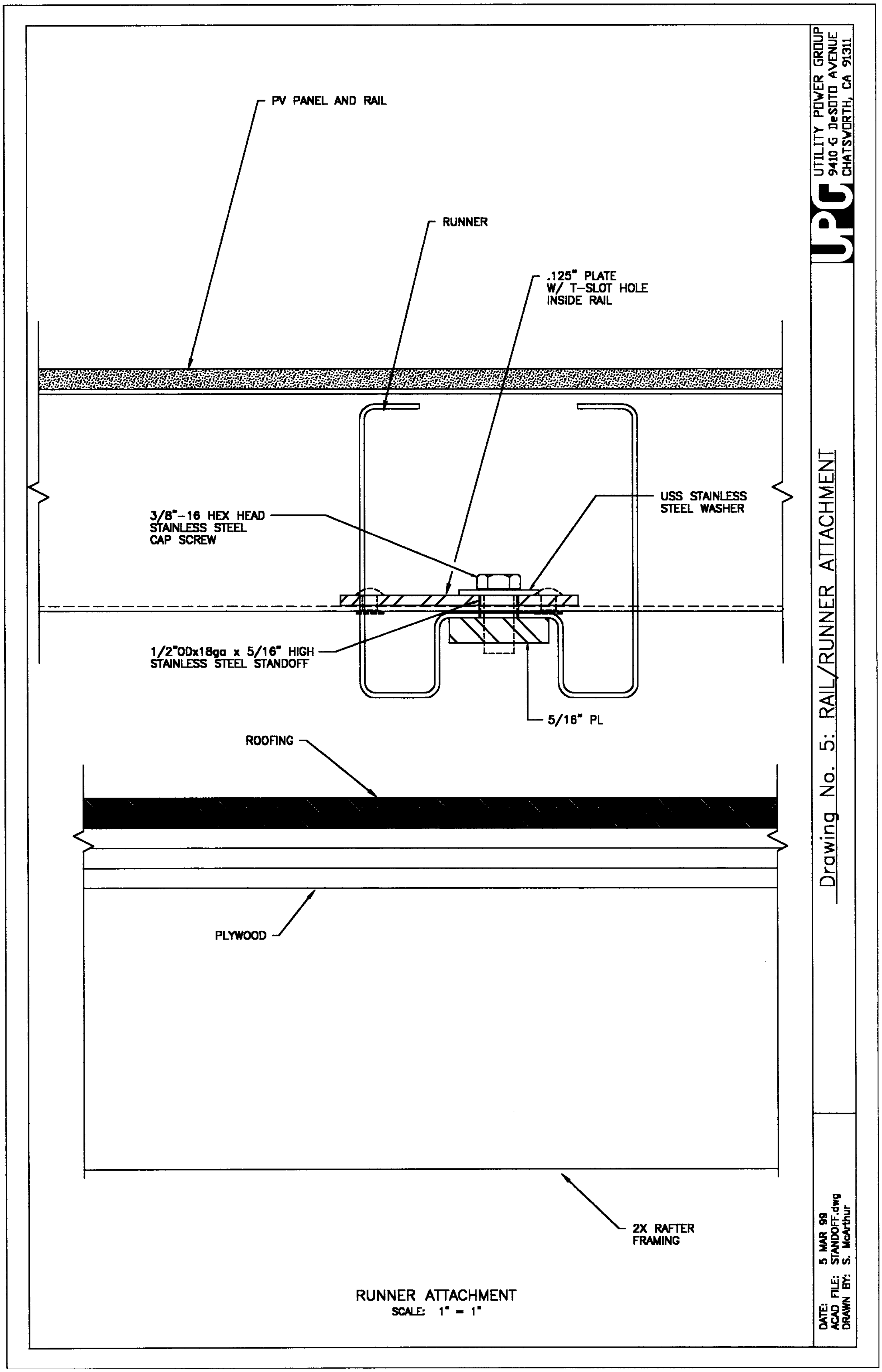
UPG UTILITY POWER GROUP
9410-G DeSOTO AVENUE
CHATSWORTH, CA 91311



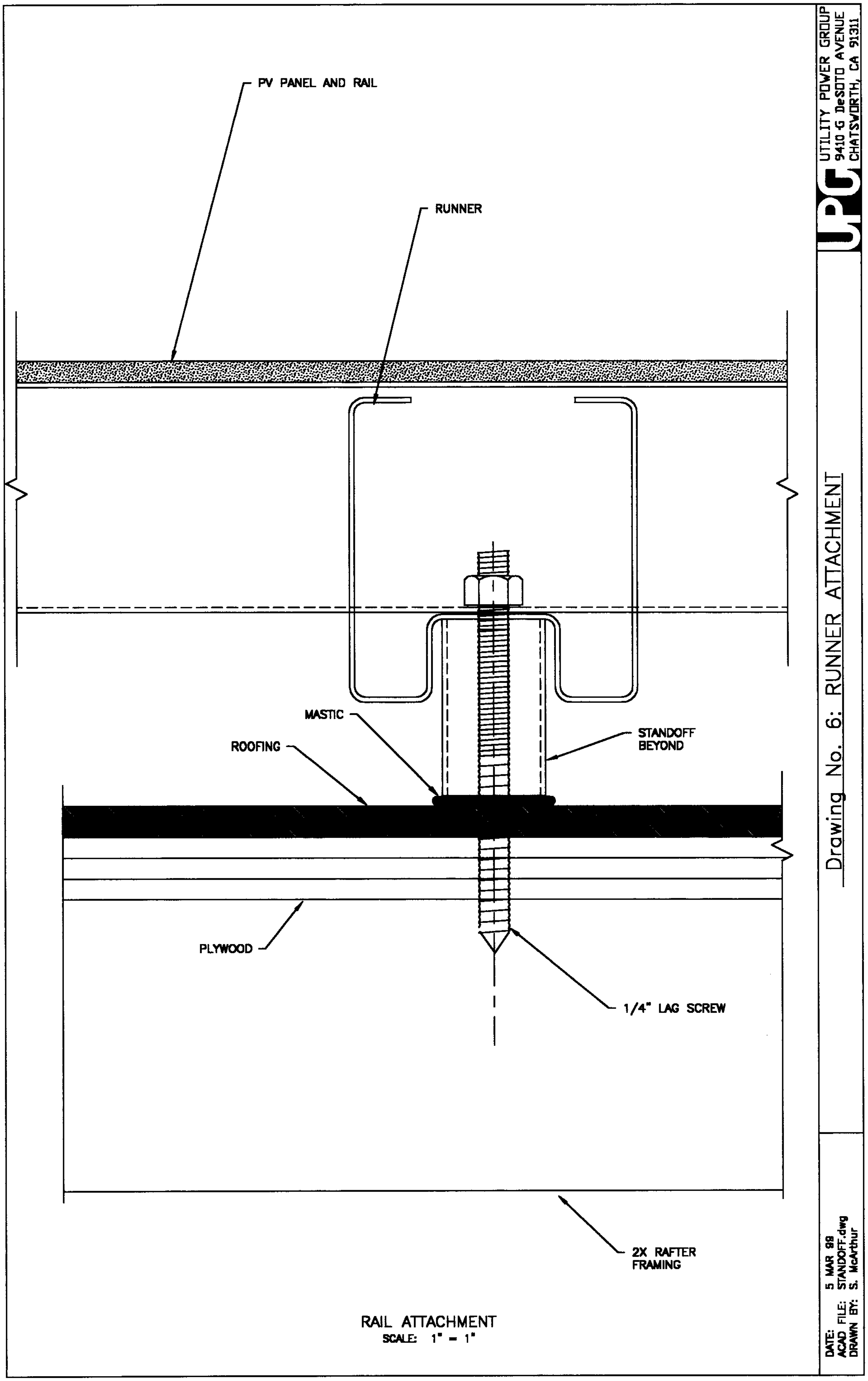
DATE: 5 MAR 99
ACAD FILE:
DRAWN BY: ZB

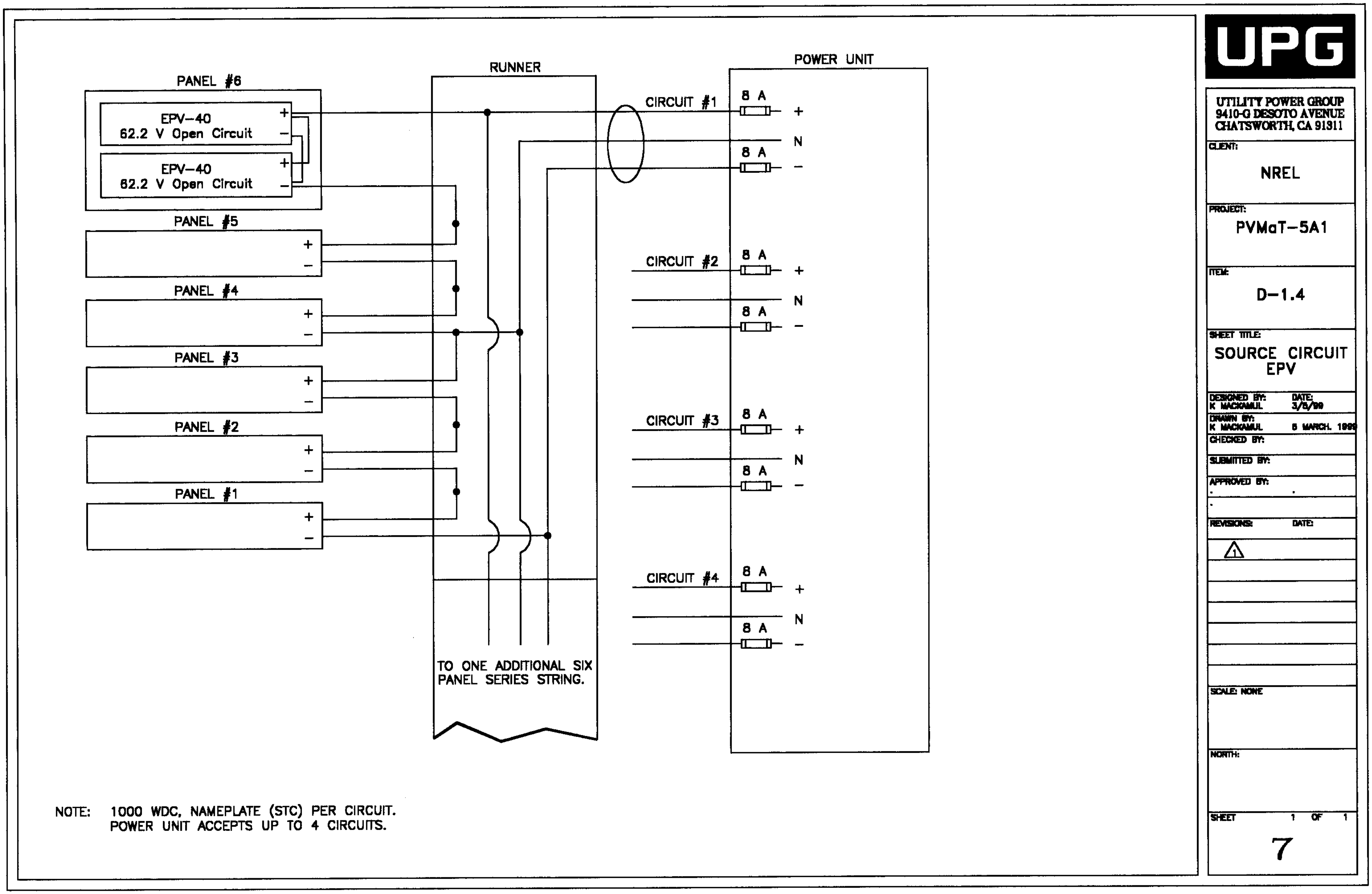
Drawing No. 4: RUNNER STIFFENER PLATE

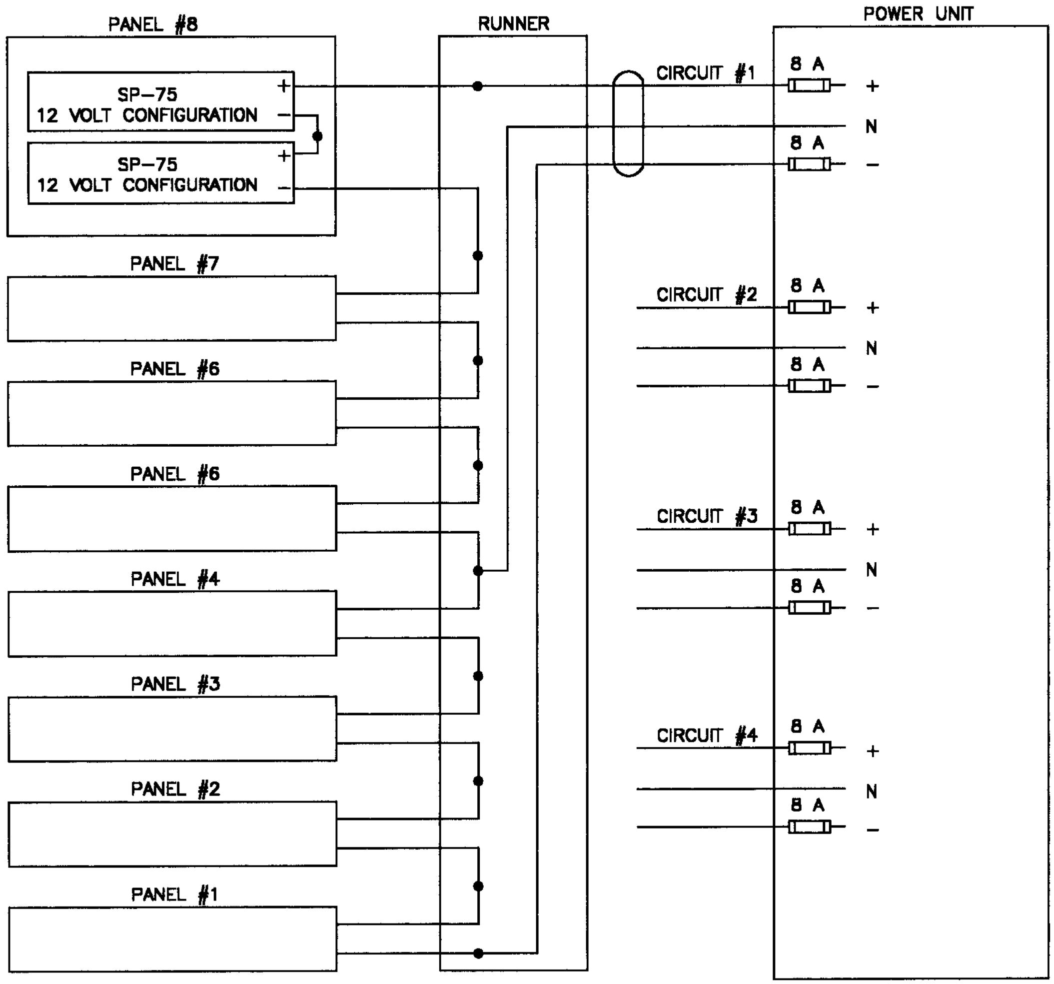
UTILITY POWER GROUP
9410-G DeSOTO AVENUE
CHATSWORTH, CA 91311



RUNNER ATTACHMENT
SCALE: 1" = 1"


PV PANEL AND RAIL
RUNNER
MASTIC
ROOFING
STANDOFF BEYOND
PLYWOOD
1/4" LAG SCREW
2X RAFTER FRAMING
RAIL ATTACHMENT
SCALE: 1" = 1"
Drawing No. 6: RUNNER ATTACHMENT
UPG
UTILITY POWER GROUP
9410-G DeSOTO AVENUE
CHATSWORTH, CA 91311
DATE: 5 MAR 99
ACAD FILE: STANDOFF.dwg
DRAWN BY: S. McArthur


PANEL #6
EPV-40
62.2 V Open Circuit
EPV-40
62.2 V Open Circuit
PANEL #5
PANEL #4
PANEL #3
PANEL #2
PANEL #1
RUNNER
TO ONE ADDITIONAL SIX PANEL SERIES STRING.
POWER UNIT
CIRCUIT #1
CIRCUIT #2
CIRCUIT #3
CIRCUIT #4
8 A
N
NOTE: 1000 WDC, NAMEPLATE (STC) PER CIRCUIT.
POWER UNIT ACCEPTS UP TO 4 CIRCUITS.
UPG
UTILITY POWER GROUP
9410-G DESOTO AVENUE
CHATSWORTH, CA 91311
CLIENT:
NREL
PROJECT:
PVMaT-5A1
ITEM:
D-1.4
SHEET TITLE:
SOURCE CIRCUIT EPV
DESIGNED BY: K MACKAMUL
DATE: 3/5/99
DRAWN BY: K MACKAMUL
5 MARCH. 1999
CHECKED BY:
SUBMITTED BY:
APPROVED BY:
REVISIONS:
DATE:
SCALE: NONE
NORTH:
SHEET 1 OF 1
7



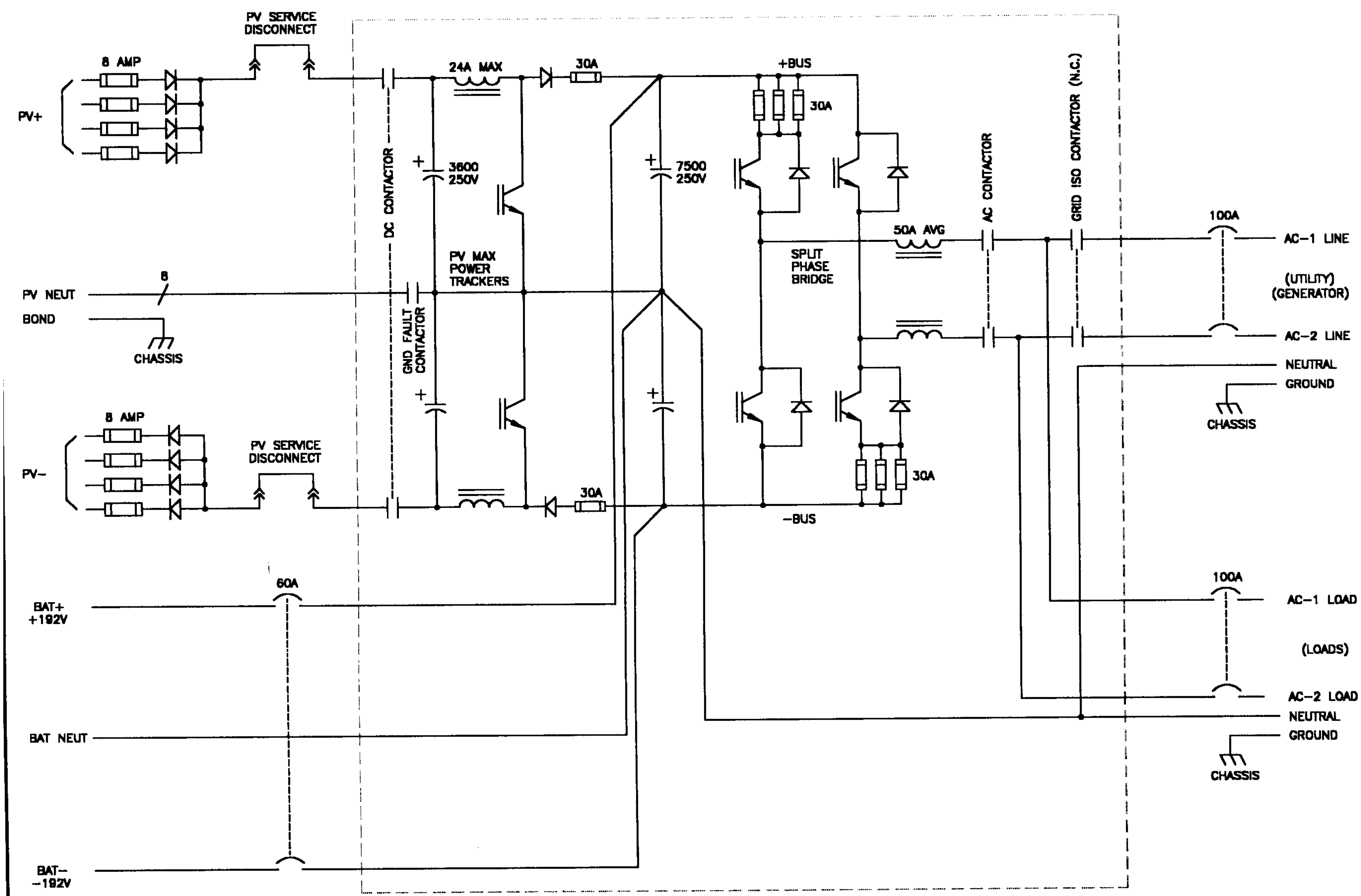
NOTE: 1200 WDC, NAMEPLATE (STC) PER CIRCUIT.
POWER UNIT ACCEPTS UP TO 4 CIRCUITS.

UPG

UTILITY POWER GROUP
9410-G DESOTO AVENUE
CHATSWORTH, CA 91311

CLIENT: NREL	
PROJECT: PVMaT-5A1	
ITEM: D – 1.4	
SHEET TITLE: SOURCE CIRCUIT SSI	
DESIGNED BY: G FOURER	DATE: 1 MAR. 1999
DRAWN BY: G FOURER	5 MAR. 1999
CHECKED BY:	
SUBMITTED BY:	
APPROVED BY:	
REVISIONS:	DATE:
1	
SCALE: NONE	
NORTH:	
SHEET 1 OF 1	

8



TRACE TECHNOLOGIES

3547-C HIGUERA STREET
SAN LUIS OBISPO
CALIFORNIA 93401

MODEL: 5000

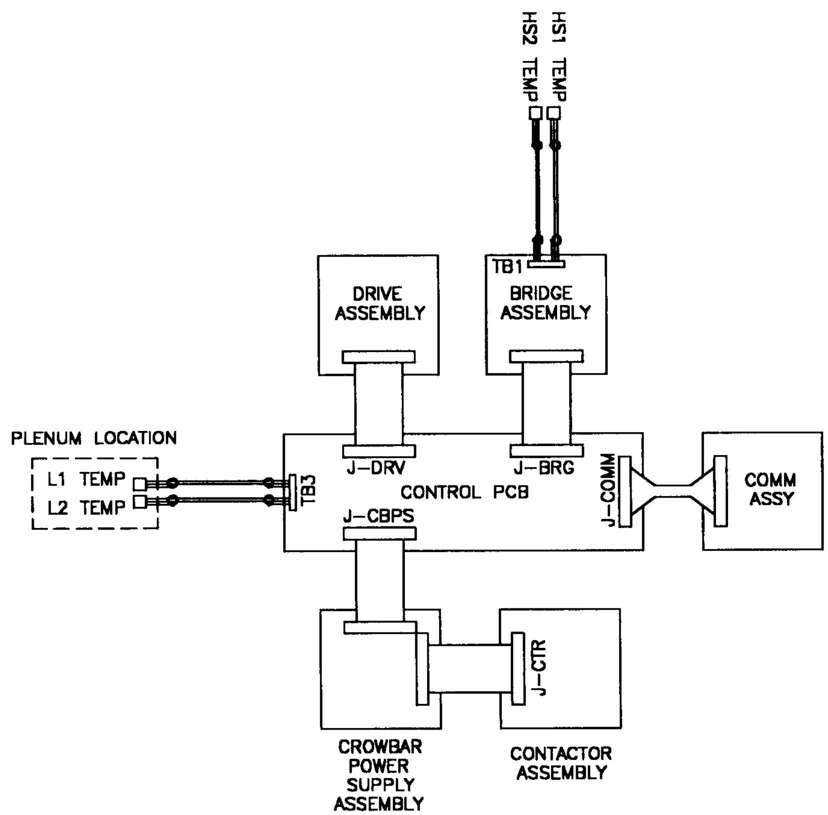
SHEET TITLE: POWER PATH COMPONENTS

DESIGNED BY: R. WEST DATE: 9 JUNE 1998
DRAWN BY: R. WEST 9 JUNE 1998
CHECKED BY:
SUBMITTED BY:
APPROVED BY:
/ACLT/PVMAT/D1.1D.DWG
REVISIONS: DATE:

SCALE: NONE

SHEET OF
D1.1F

CONTROL PCB ASSEMBLY CONTROL CABLES



UPG

UTILITY POWER GROUP
9410-G DESOTO AVENUE
CHATSWORTH, CA 91311

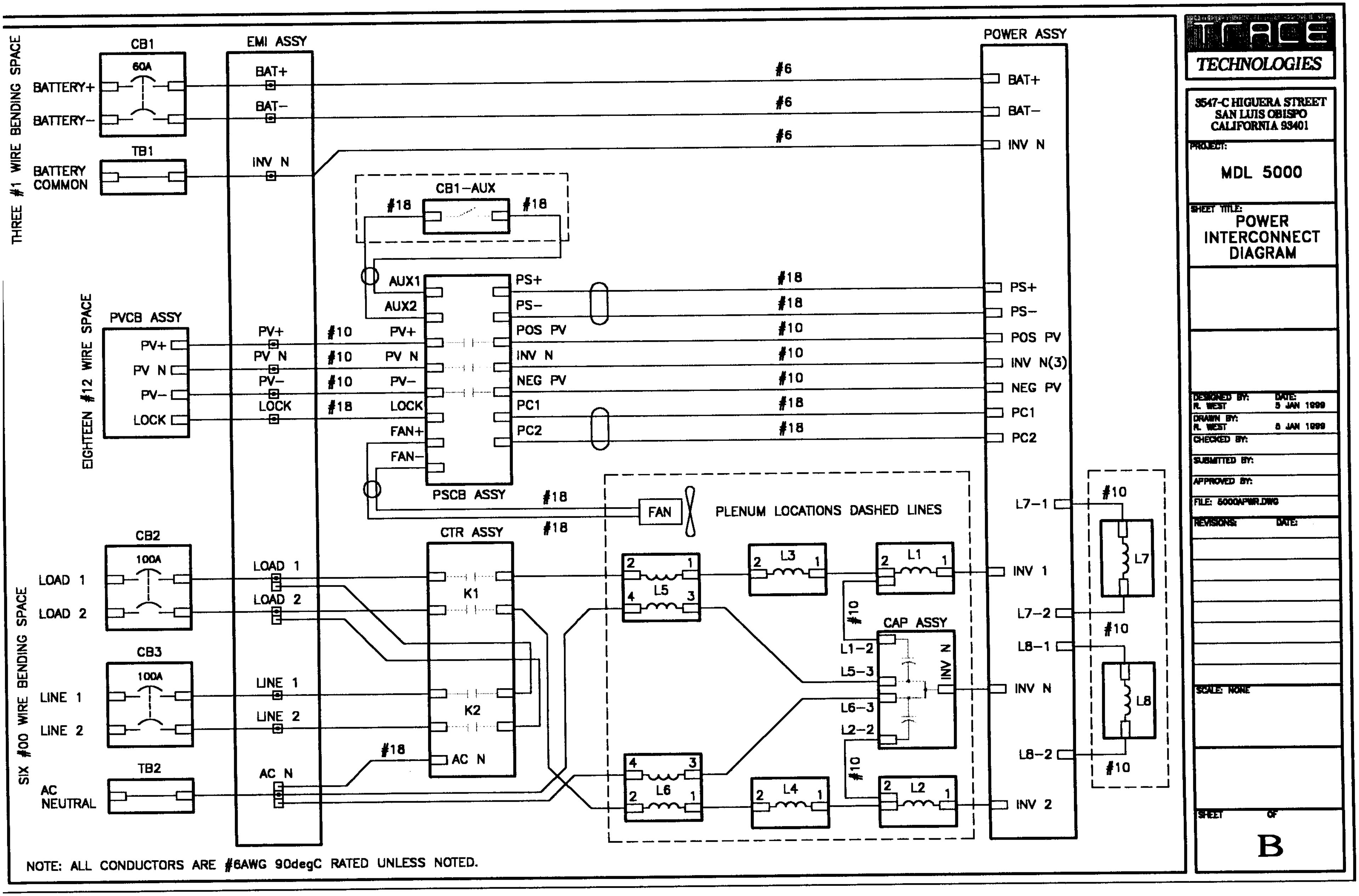
PROJECT:
PVMAT5A

SHEET TITLE:
SIGNAL INTERCONNECT DIAGRAM

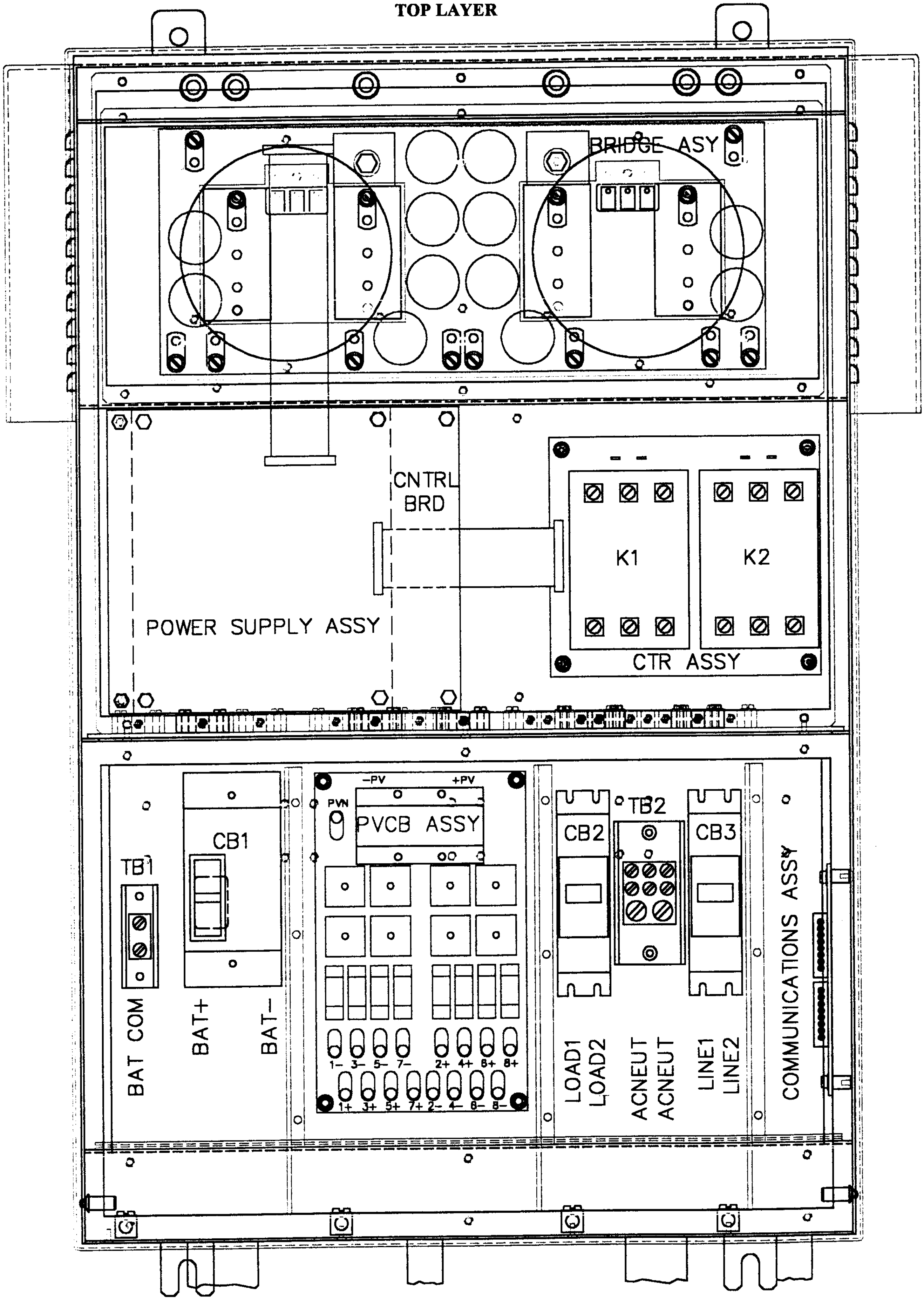
DESIGNED BY: R. WEST	DATE: 5 JAN 1999
DRAWN BY: R. WEST	6 JAN 1999
CHECKED BY:	
SUBMITTED BY:	
APPROVED BY:	
FILE: 5000CONB.DWG	
REVISIONS:	DATE:
A	5 MAR 99
b	4 AUG 99

SCALE: NONE

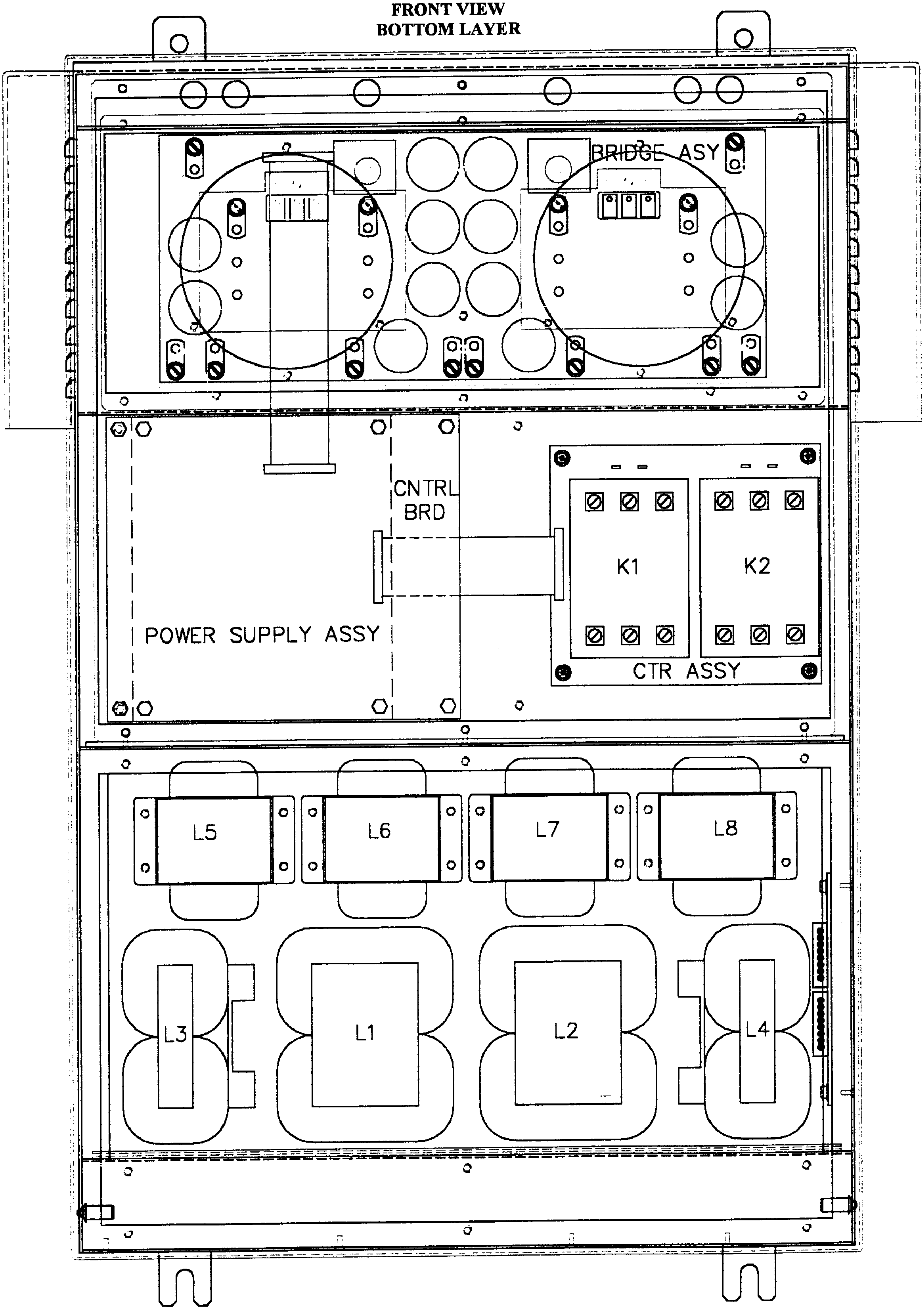
SHEET 1 OF


THREE #1 WIRE BENDING SPACE
CB1
60A
BATTERY+
BATTERY−
TB1
BATTERY COMMON
EMI ASSY
BAT+
BAT−
INV N
#6
#6
#6
POWER ASSY
BAT+
BAT−
INV N
CB1−AUX
#18
#18
AUX1
AUX2
PV+
PV N
PV−
LOCK
FAN+
FAN−
PSCB ASSY
PS+
PS−
POS PV
INV N
NEG PV
PC1
PC2
#18
#18
#10
#10
#10
#18
#18
PS+
PS−
POS PV
INV N(3)
NEG PV
PC1
PC2
EIGHTEEN #12 WIRE SPACE
PVCB ASSY
PV+
PV N
PV−
LOCK
#10
#10
#10
#18
FAN
PLENUM LOCATIONS DASHED LINES
#18
#18
L7−1
L7−2
L8−1
L8−2
#10
#10
#10
L7
L8
CTR ASSY
K1
K2
AC N
SIX #00 WIRE BENDING SPACE
CB2
100A
LOAD 1
LOAD 2
CB3
100A
LINE 1
LINE 2
TB2
AC NEUTRAL
LOAD 1
LOAD 2
LINE 1
LINE 2
AC N
#18
L5
L3
L1
L6
L4
L2
CAP ASSY
INV N
L1−2
L5−3
L6−3
L2−2
#10
#10
INV 1
INV N
INV 2
NOTE: ALL CONDUCTORS ARE #6AWG 90degC RATED UNLESS NOTED.
TRACE TECHNOLOGIES
3547-C HIGUERA STREET
SAN LUIS OBISPO
CALIFORNIA 93401
PROJECT:
MDL 5000
SHEET TITLE:
POWER INTERCONNECT DIAGRAM
DESIGNED BY: R. WEST
DATE: 5 JAN 1999
DRAWN BY: R. WEST
8 JAN 1999
CHECKED BY:
SUBMITTED BY:
APPROVED BY:
FILE: 5000APWR.DWG
REVISIONS:
DATE:
SCALE: NONE
SHEET
OF
B

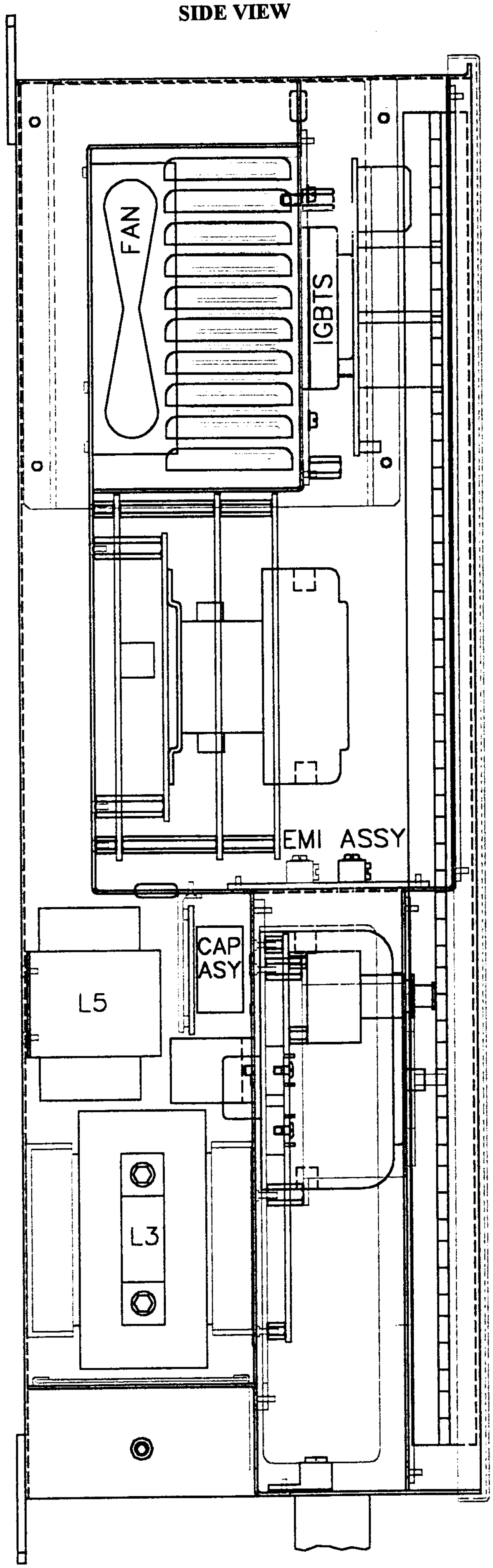
POWER UNIT
FRONT VIEW
TOP LAYER

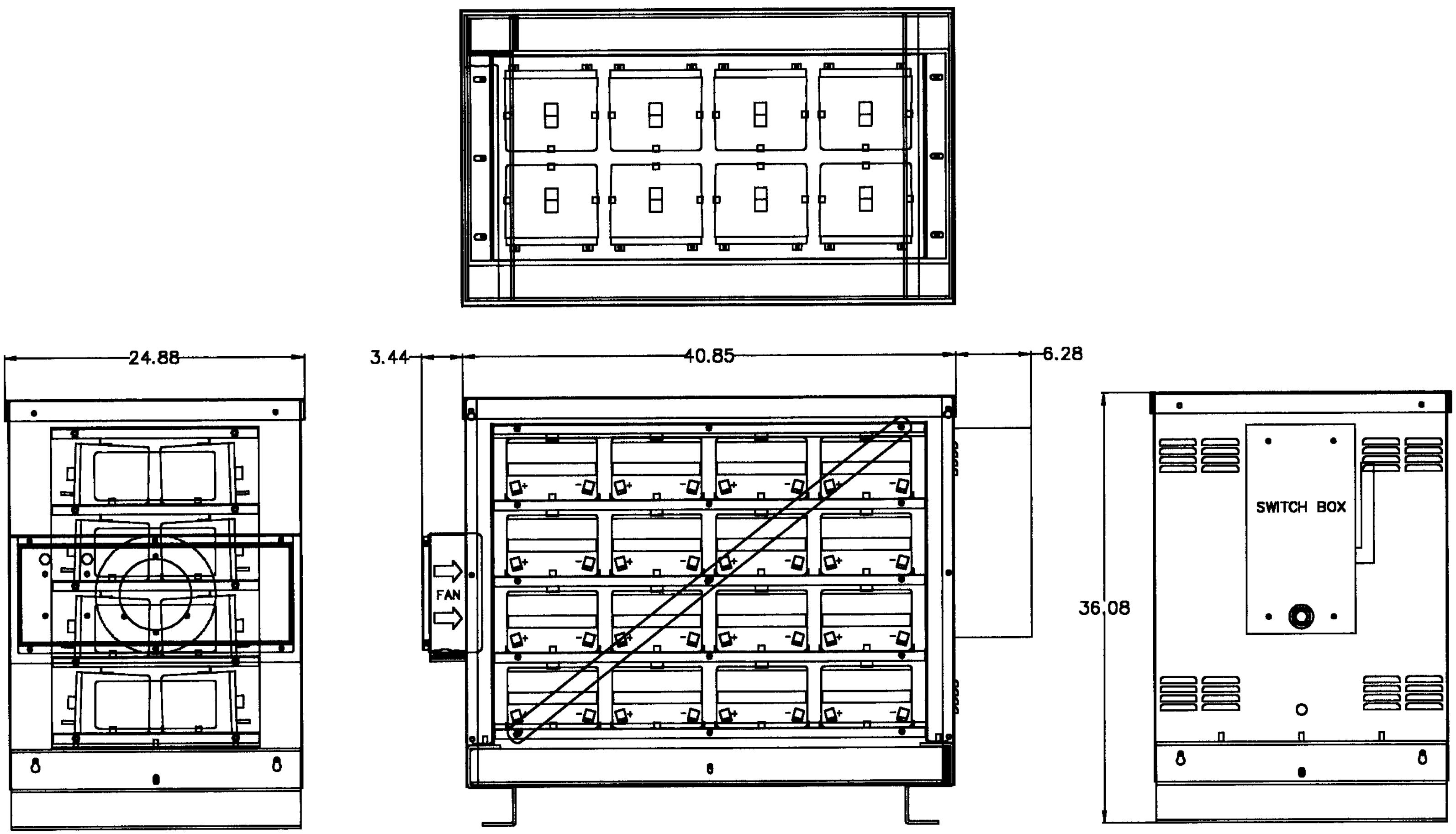


POWER UNIT
FRONT VIEW
BOTTOM LAYER



POWER UNIT
SIDE VIEW





UPG

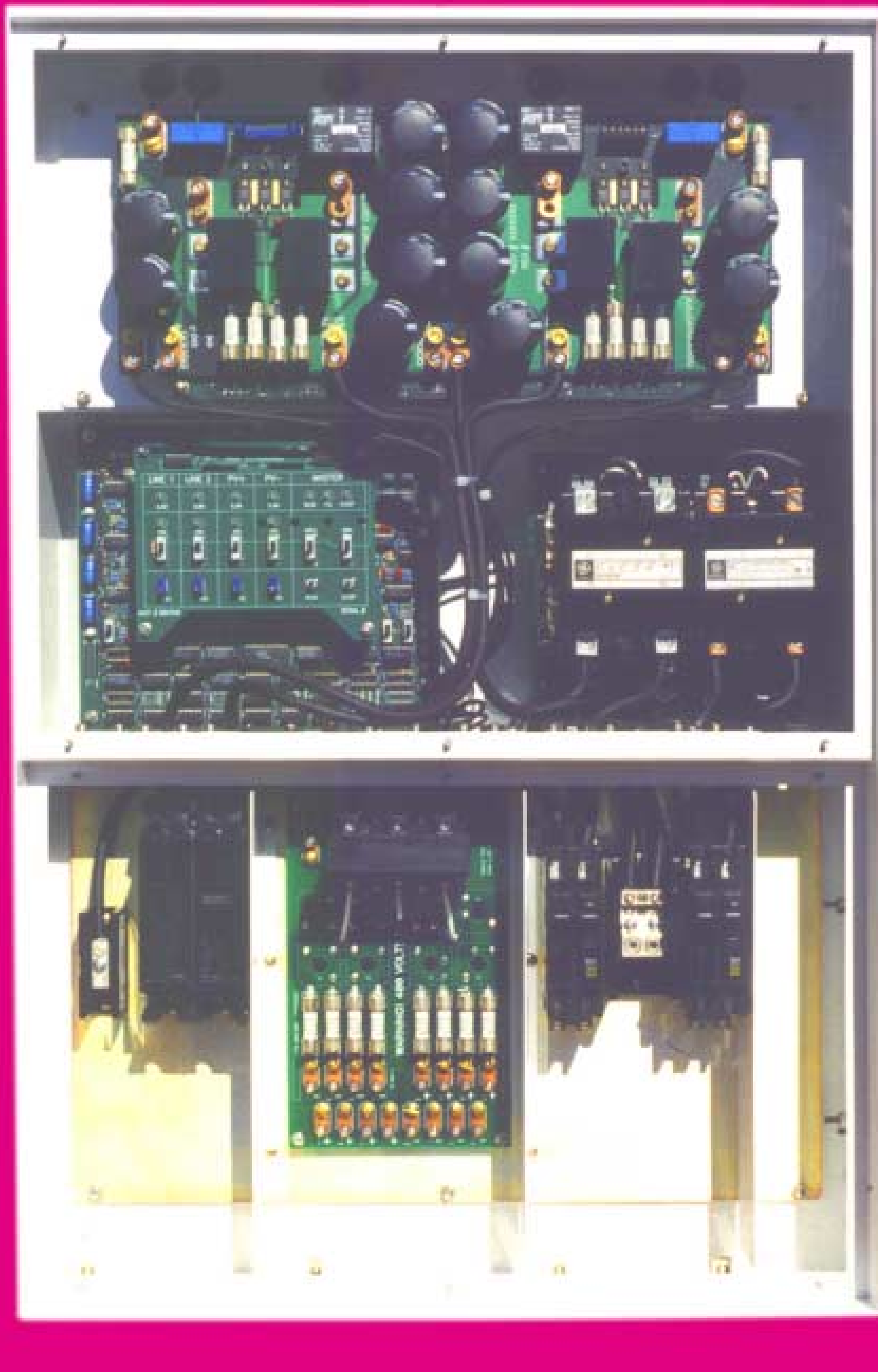
UTILITY POWER GROUP
9410-G DESOTO AVENUE
CHATSWORTH, CA 91311

CLIENT:	NREL
CONTRACT:	ZAX-8-17647-02
PROJECT:	PVMaT5A1
ITEM:	D-1.7
TITLE:	ENERGY STORAGE UNIT ESU13
DESIGNED BY: ARCHAMBAULT	DATE: 02/01/99
DRAWN BY: ARCHAMBAULT	02/01/99
CHECKED BY:	
SUBMITTED BY:	
APPROVED BY: WEST	04/01/99
FILE NAME: SK1.DWG	
REVISION:	DATE:
SCALE:	1:1
SHEET:	Drawing 15

Appendix D
Photographs

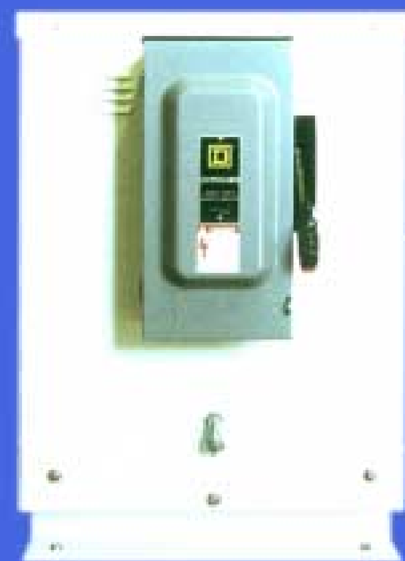
D-1.10 POWER UNIT PHOTOGRAPH

SHOWN WITH FRONT DOOR AND INTERIOR PANELS REMOVED



D-1.12 PHOTOGRAPH OF ENERGY STORAGE UNIT

SHOWN WITH INSULATION AND COVER PANEL REMOVED



SHOWN WITH ACCESS PANEL REMOVED

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13. ABSTRACT *(Maximum 200 words)*
This report describes Utility Power Group's (UPG's) technical progress for Phase I of a two-phase effort to focus on the design, assembly, and testing of a fully-integrated residential PV power system, including storage. In the PV Array Task, UPG significantly improved the conventional means and methods required to structurally interface PV modules to the roofs of single-family residential houses and to electrically interconnect these PV modules to a power conversion unit. UPG focused on the design and test of a PV array based on the highly efficient use of materials and labor. Design criteria included cost, structural integrity, electrical safety, reliability, conformance with applicable standards and building and seismic codes, and adaptability to a wide range of roof materials for both existing and retrofit roof applications. In the Power Unit Task, UPG designed and testing a high-efficiency, low-cost, high-reliability prototype power conversion unit that included all materials, components, equipment, and software required to perform all DC-AC/AC-DC power collection, conversion, and control functions between the output of the PV array and the interconnection to the electrical grid service of single-family residences. In the Energy Storage Unit Task, UPG designed and tested a low-cost, modular, self-contained, low-maintenance, all-weather, battery-based Energy Storage Unit designed to interface with the Power Unit to provide back-up electricity to supply critical household loads in the event of utility-grid failure. The Energy Storage Unit includes batteries and all structural, mechanical, and electrical equipment required to provide a source of stored DC energy for input of the Power Unit. UPG designed the storage unit as a "plug and play" option, where multiple units can be easily paralleled for additional energy storage capacity.

14. SUBJECT TERMS
photovoltaics ; Photovoltaic Manufacturing Technology ; PVMaT ; fully-integrated systems ; residential applications ; PV arrays, ; power units ; energy storage units

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