INSTALLING AND INSPECTING SOLAR PHOTOVOLTAIC (PV) SYSTEMS FOR CODE COMPLIANCE

A Workshop sponsored by the Hawaii State Energy Office, Hawaiian Electric Company, and the City & County of Honolulu

WHO: Building Officials, plan checkers, and inspectors; photovoltaic system installers; interested electricians

WHEN: April 8, 2003, 10:30 AM to 2:30 PM

WHERE: 1001 Bishop Street, American Savings Bank Tower (formerly Pacific Tower), 8th floor, Training Room 2.

FOR MORE INFORMATION: Call Maria Tome at 587-3809 or email mtome@dbedt.hawaii.gov

WORKSHOP AGENDA

- PV System Basics
- Introduction to Relevant Codes & Standards
- Summary of PV Installation Issues
- PV-Critical Issues in the NEC
- Inspector Checklist for PV Systems
- Questions & Answers

ABOUT THE WORKSHOP:

As the costs, appearance, and value of photovoltaic (PV) electrical systems have improved, and interest in renewable energy has grown, the demand for PV systems has increased. State law also mandates the net metering of solar electric systems. Building officials need to be familiar with these systems since increasing numbers of these systems will be installed in their jurisdictions. This workshop provides building officials with the basic background needed to properly inspect the PV system installations they will encounter. It reviews the pertinent national standards and codes related to these systems including relevant articles of the National Electrical Code (NEC), Institute of Electrical and Electronic Engineers (IEEE) standards, and Underwriters Laboratories (UL) standards for these types of systems. These codes and standards contain detailed requirements for the proper design and installation of PV systems. This workshop is a must for those responsible for code enforcement and keeping up with the latest code requirements.

ABOUT THE SPEAKER:

Bill Brooks, of Endecon Engineering, provides PV training of inspectors for the California Energy Commission. A member of several technical review committees, including those for IEEE-929 (PV Utility Interconnection) and for NEC Article 690 (Solar Photovoltaic Systems), he holds B.S. and M.S. degrees in Mechanical Engineering from North Carolina State University and is a registered professional engineer in North Carolina and California.

INSPECTING SOLAR PHOTOVOLTAIC (PV) SYSTEMS FOR CODE-COMPLIANCE

Presented by

Bill Brooks, PE
Endecon Engineering

Sponsored by
the Energy, Resources, and Technology Division of the
Department of Business, Economic Development, and Tourism
for the State of Hawaii

PV System Basics

Difference between PV and Thermal

- Photovoltaic (photo = light; voltaic = produces voltage) or PV systems convert light directly into electricity using semi-conductor technology. (@ 10% efficiency)
- Thermal systems (hot water, pool heaters) produce heat from the sun’s radiation (@ +40 % efficiency)
- Large difference in value of energy types.

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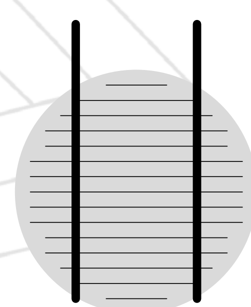
Definitions: PV Cell

- **Cell:** The basic photovoltaic device that is the building block for PV *modules*.



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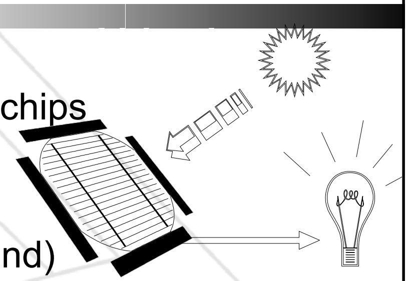
What Are Solar Cells?

- Thin wafers of silicon
  - Similar to computer chips
  - much bigger
  - much cheaper!
- Silicon is abundant (sand)
  - Non-toxic, safe
- Light carries energy into cell
- Cells convert sunlight energy into electric current- they do not store energy
- Sunlight is the “fuel”

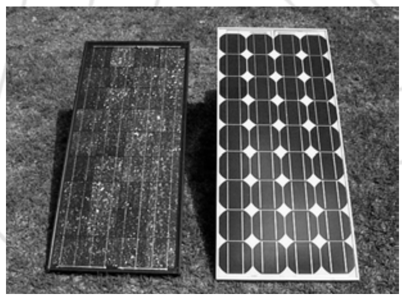


Connect Cells To Make Modules

- One silicon solar cell produces 0.5 volt
- 36 cells connected together have enough voltage to charge 12 volt batteries and run pumps and motors
- Module is the basic building block of systems
- Can connect modules together to get any power configuration

Definitions: PV Module

- **Module:** A group of PV *cells* connected in series and/or parallel and *encapsulated* in an environmentally protective *laminate*.



Solarex MSX60
60 watt polycrystalline

Siemens SP75
75 watt single crystal

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Definitions: Junction Box

- **Junction Box:** An enclosed terminal block on the back of PV modules which allows the module to be connected in the electrical system.

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Definitions: PV Panel

- **Panel:** A group of *modules* that is the basic building block of a PV *array*.

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Definitions: PV Array

- **Array:** A group of *panels* that comprises the complete direct current PV generating unit.

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Definitions: Balance of System (BOS)

- **BOS:** The balance of the equipment necessary to integrate the PV array with the site load (building). This includes the array circuit wiring, fusing, disconnects, and power processing equipment (inverter).

AC Module - All BOS Wiring is AC

Real World Example

- Where's the sun?

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Where's the SHADE!

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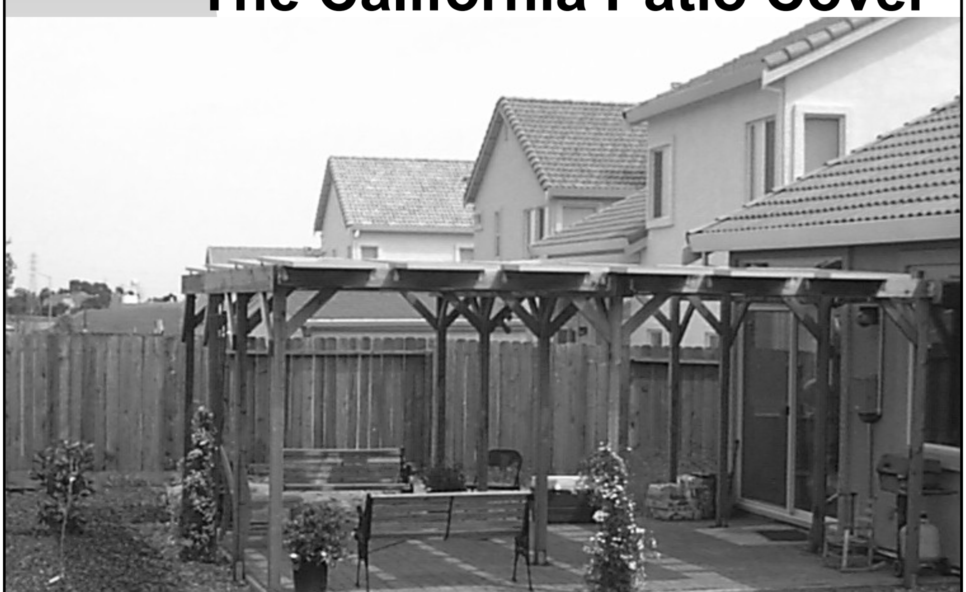
There it is

From the top

The California Patio Cover



Trace 5548 Power Module

- 5.5kW ac rating
- 44-60V dc input
- 120Vac output
- Batteries and controls all in the same cabinet
- Up to 12 kWh in storage cabinet. (this shows 8 kWh option)
- Unit backs up all 120V house loads

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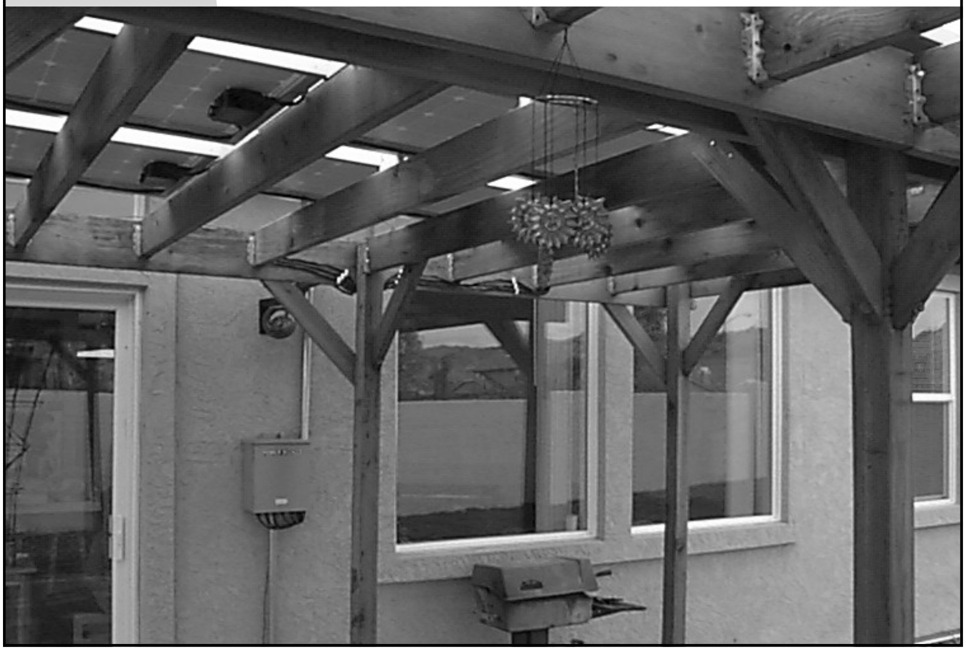
The Battery Shrine

- 48 Volt, 450 amp-hr (21 kWh battery) of AGM construction—potential 20 year life if treated properly in float application.
- Rack includes seismic bracing and airflow around all cells.

Every home needs one!!

Letting the sun do the work



The Manual Disconnect (and, more importantly, the backwards turning meter)

System produces all the electricity needed by the home on an annual basis

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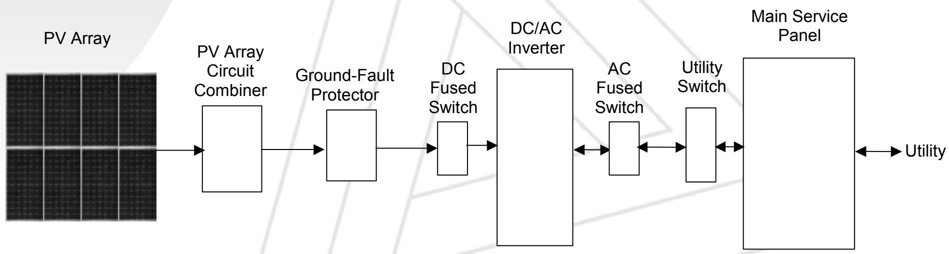
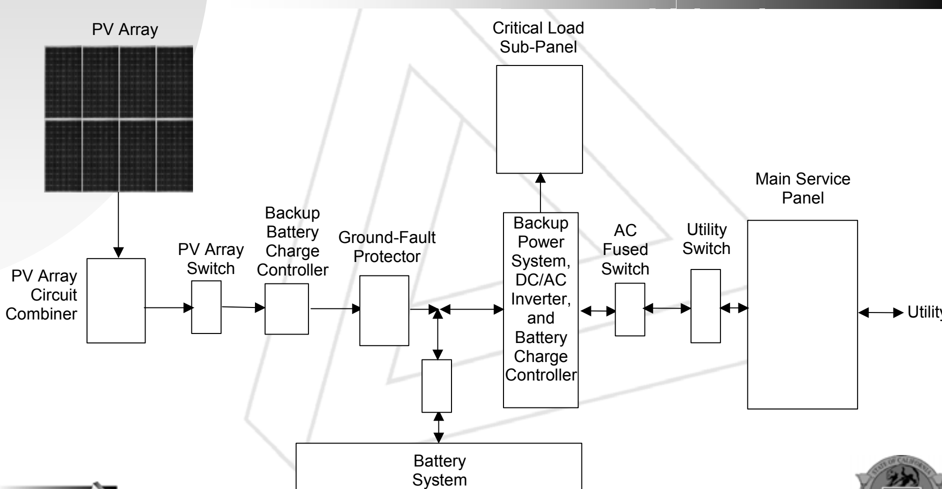
Block diagram of PV system without battery backup



Block diagram of PV system with battery backup



PV Codes and Standards 101

What are the applicable codes and standards for PV systems?

- NEC Article 690 - Solar Photovoltaic Systems - Building codes - UBC, SBC, BOCA, local codes
- UL Standard 1703, Flat-plate Photovoltaic Modules and Panels
- IEEE 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems (approved in January 2000)
- UL Standard 1741, Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems (published in May 1999-Required November 2000)

IEEE 929-2000

- Passed by IEEE Standards Board in January, 2000.
- Represents an excellent primer on PV inverter interconnection issues.
- One area of concern is when building officials have required utility approval before issuing a permit.

P929 Draft 11c January 2000

P929
Recommended Practice for Utility Interface of Photovoltaic (PV) Systems

Prepared by the Utility Working Group of
Standards Coordinating Committee 21, on Photovoltaics

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UL 1741 Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems

- First released in May of 1999
- Currently being revised to match IEEE 929-2000
- Compliance with revised document was required by November 7, 2000)
- New title reads “Standard for inverters, converters, and controllers for use in Independent Power Systems.”(Nov 8, 2000)

Underwriters Laboratories Inc.®

Subjects 1741

333 Pfingsten Road
Northbrook, IL 60062
March 3, 1999

TO: Industry Advisory Group of Underwriters Laboratories Inc. for Power Conditioning Units for Use in Residential Photovoltaic Power Systems,
Electrical Council of Underwriters Laboratories Inc.,
Subscribers to UL's Listing Services for Photovoltaic Charge Controllers (QIBP),
Subscribers to UL's Listing Services for Photovoltaic Power Systems Accessories (QIIO),
Subscribers to UL's Listing Services for Power Conditioning Units for Use in Residential Photovoltaic Power Systems (QIKH), and
Subscribers to UL's Listing Services for AC Modules (QHYZ)

SUBJECT: Request for Comments on the Proposed First Edition of the Standard for Static Inverters and Charge Controllers, UL 1741; PROPOSED EFFECTIVE DATE

Attached as Appendix A for your review and comment are proposed requirements for UL 1741. Questions regarding interpretation of requirements should be directed to the responsible UL Staff. Please see Appendix B of this bulletin regarding designated responsibility for the subject product categories.

Please note that proposed requirements are of a tentative and early nature and are for review and comment only. Current requirements are to be used to judge a product until these requirements are published in final form. **PROPOSED EFFECTIVE DATE**

The proposed requirements will necessitate a review and possible retest of currently Listed products. Therefore, UL proposes that the new requirements become effective 18 months after publication. This is intended to provide manufacturers with sufficient time to submit modified products for investigation and to implement the necessary changes in production. Please note that this also includes the time that will be needed by UL to conduct a review of the modified product.

RATIONALE

The first edition of the Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems, UL 1741, was proposed in the subject bulletin dated August 1, 1997. The proposed Standard has been significantly revised since then. The revisions are a result of the comments UL received from industry members regarding the proposed draft. In addition, the revisions were made to align the proposed Standard with the Ninth Draft of Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, P929, and other UL Standards. This bulletin proposes the revised first edition of the Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems, UL 1741.

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What is UL 1741 and how does it relate to IEEE 929?

- UL 1741 is the UL test standard that is used for the listing of PV inverters, charge controllers, and other BOS equipment.
- "Final" version just released. It will be revised as all new standards are over the first several years of implementation.
- 1741 incorporates the testing required by IEEE 929 (frequency and voltage limits, power quality, non-islanding inverter testing)
- 1741 testing includes design (type) testing and production testing.

Primary Concerns for the Building Official

- Mounting structurally sound
- Roof properly weather proofed
- Electrical equipment correctly specified and installed according to Electrical Code.

Mounting Structurally Sound

- Two main types of loading to consider
  - dead load (typically 3-5 lbs./ft^2 for standard standoff install and 2-12 lbs./ft^2 for integrated products)
  - wind load (25 lbs./ft^2 maximum in California (higher in select mountain regions)
- Structure must be capable of supporting dead load and attachment method must be capable of keeping the PV array on the roof (or relevant structure).

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Mounting Structurally Sound (cont.)

- Most modern truss roofs are capable of handling the extra 3-5 lbs./ft^2 dead load provided that the roof is not masonry. Masonry roofs often require a structural analysis or removing the existing product and replace it with composite in the area of PV array.
- Attachment method must be capable of keeping the PV array on the roof (or relevant structure).

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Fastener Withdraw Loads-Wood (safety factor already applied)

		Allowable Withdraw (lb./in)		
Screw Size		Redwood	Spruce	Doug Fir
#8		64	72	87
#10		74	100	119
#14 (1/4")		94	113	152
#18 (5/16")		114	154	194
#20 (3/8")		124	168	207

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Sample Structural Calculations

- 2kW system
- 2 x 4 truss roof on 24” centers with composite shingle roof (acceptable for 5 psf added weight)
- 32 modules @ 8 sq.ft. per module = 256 sq.ft.
- 24 mounting brackets
- 3” fastener depth in Doug Fir
- 25 psf uplift force

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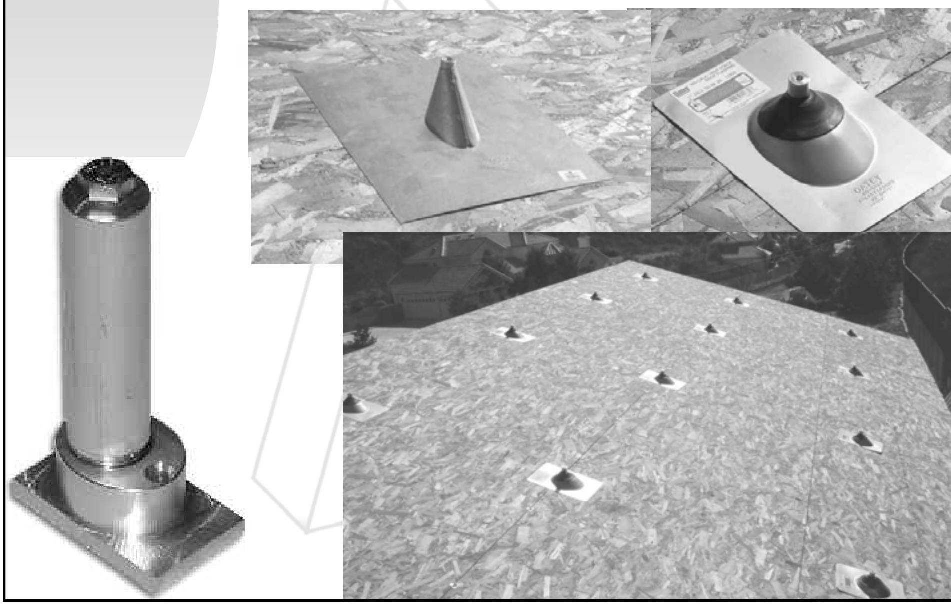
Sample Calculations

- 256 sf x 25 psf = 6,400 lb (total uplift)
- 6,400 lb /24 brackets = 266 lb per mount
- 194 lb/in x 3 in depth = 582 lb (more than twice as strong as necessary)

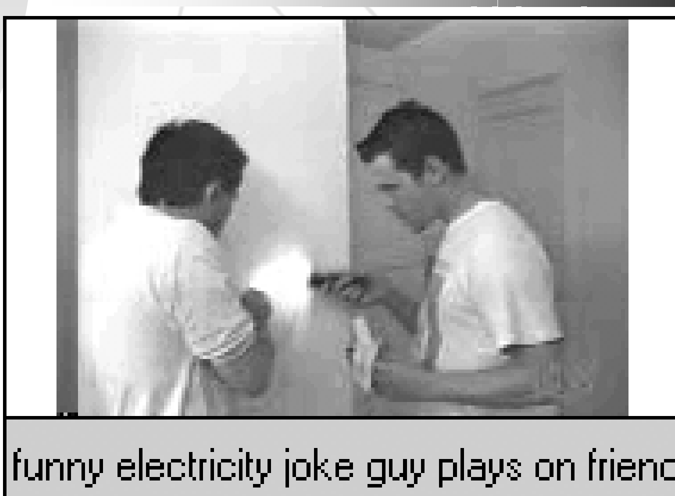
Weather Proofing of Roof

- Attachments must be properly sealed to preclude leakage.
- Urethane caulks such as Sikaflex 1a are both temperature and UV resistant. Silicones and roofing tars are less durable and can leak over time.
- Post and flashing method provides excellent weather proofing

Post and flashing method



Electrical Safety is no joke…



Differences Between PV and Conventional Electrical Systems

- PV systems have *dc circuits* which require special design and equipment.
- PV systems can have *multiple energy sources*, and special disconnects are required to isolate components.
- Energy flows in PV systems may be *bi-directional*.

Differences Between PV and Conventional Electrical Systems

- PV systems may require an interface with the ac utility-grid and special considerations must be adopted.
- As the maximum current in a PV array is short-circuit limited, a fault may not generate currents high enough to clear fuses. This is normal for PV systems but abnormal for many other electrical systems.

PV System Electrical Design: Common Problem Areas

- *Insufficient* conductor ampacity and insulation
- Excessive *voltage drop*
- *Unsafe* wiring methods
- *Lack of or improper* placement of overcurrent protection and disconnect devices
- *Use of unlisted*, or improper application of listed equipment (e.g. ac in dc use)
- *Lack of or improper* equipment or system grounding
- *Unsafe* installation and use of batteries

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Electrical Code Compliance: Issues

- Many PV systems may not comply with the NEC because:
  - Designers/installers have little experience with dc electrical systems.
  - Listed equipment is not widely available for PV components and dc hardware.
  - Suggestions that PV systems are easily designed/installed by untrained personnel.

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Disconnect Requirements

- Required to isolate major system components, e.g., the PV array, inverter, battery, and load.
- Switches or circuit breakers may be used. Use appropriate dc rated components.
- Maximum of six (6) disconnect devices are allowed for equipment shutdown, must be marked and labeled.

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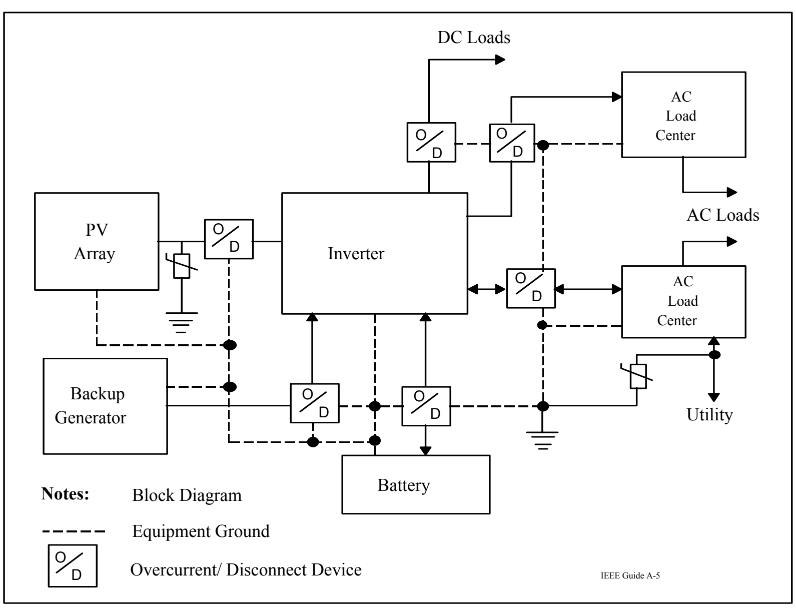
Stand-Alone and Grid-Connected System



INSP-55

Battery System Design Considerations

- Overcurrent protection and disconnects have appropriate DC ratings and Ampere Interrupt Ratings (minimum of 20,000 amps).
- Battery enclosure
  - Corrosion resistant
  - Flame resistant
  - Vented
    - (e.g. power-coated aluminum, fiberglass, plywood lined with flame-retardant material)

Trace 5548 Power Module

- 5.5kW ac rating
- 44-60V dc input
- 120(240)Vac single-phase
- Batteries and controls all in the same cabinet

Checklist for Photovoltaic Power System Installations

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CONDUCTORS **(General)**

- Standard building-wire cables and wiring methods can be used [300-1(a)].
- Wet-rated conductors should be used in conduits in exposed locations [100 Definition of Location, Wet].
- DC color codes should be same as ac color codes—grounded conductors are white and equipment grounding conductors are green or bare [200-6(a), Ex 5].

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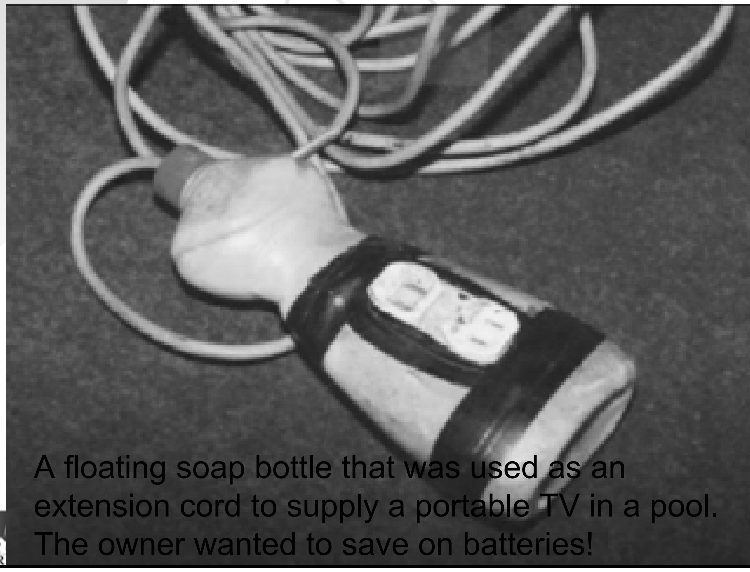
Make sure conductors are wet-rated--No Darwin Awards please



Conductors

- Conductor type—USE-2, if exposed [690-31(b)]; RHW-2, THWN-2, or XHHW-2 in conduit [310-15]. 90°C, wet-rated conductors are necessary.
- Conductor insulation rated at 90°C [UL-1703] to allow for operation at 71°C or above.
- Temperature-corrected ampacity calculations should be based on 125% of short-circuit current (Isc), and the corrected ampacity must also be greater than rating of overcurrent device (156% Isc -see below) [690-8,9].

Conductors

- Suggest correction factors for 61°C for modules tilted above roof pitch, and 71°C for modules mounted parallel with roof surface be used for ampacity calculations.
- Portable cords are allowed only on moving tracker connections [690-31(c), 400-3].
- Strain reliefs/cable clamps or conduit should be used on all cables and cords [300-4, 400-10].

Types of Conductors in PV Systems

Application	Wire Type
Array Wiring	USE-2, TC (holds THWN-2 or THWN), (sun resistant-check temp rating) THWN-2 (only in conduit)

- Note: roof mounted systems must use 90ºC wet-rated wiring since temperatures can exceed 70ºC.

Application	Wire Type
BOS Interconnects	THWN (only in conduit)
Interior Exposed	NM, NMC, UF (multi-conductor)
Battery Cables	RHW Flexible (multistranded)

Temperature Corrected Ampacity: Example

- A No. 10 AWG USE-2 cable has a 90°C rating and ampacity of 55 amps in ambient temperatures of 26-30° C.
- When the same conductor is used for module interconnect wiring for rooftop applications it may experience temperatures of 71-80° C. In this situation its temperature corrected ampacity is reduced to 22 amps.

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Conductors—Example: Voltage Drop Considerations

- Voltage drop is a major factor in low-voltage systems.
- Voltage drop *increases* with *increasing current* and *decreasing conductor size*.
- Remember that a 48-Volt system has 2.5 times the voltage drop of 120-Volt systems. (Example: 100-amps at 48V requires 4/0 Aluminum for a 90-foot run at 3% drop. Compared with 225’ for 120V)

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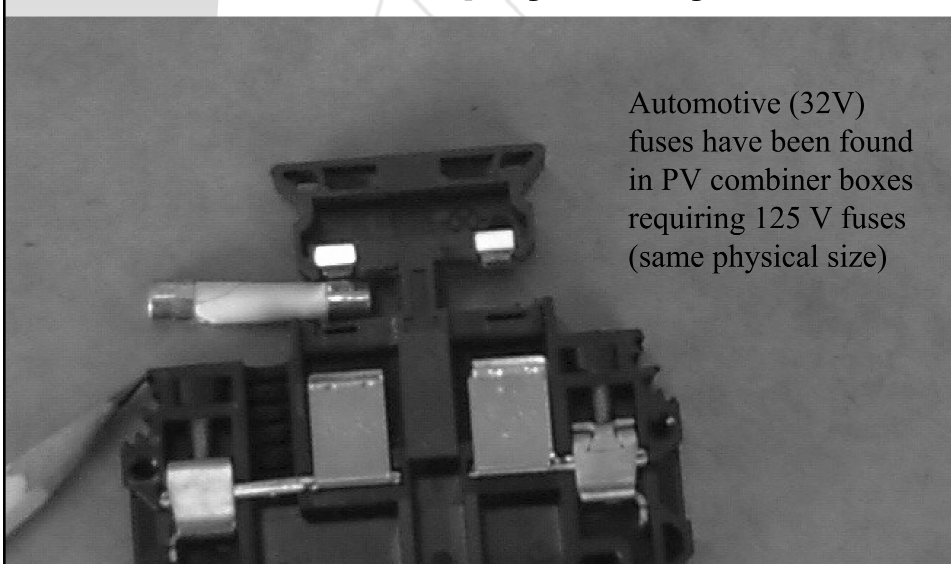
Overcurrent Protection

- DC-rated and listed fuses and circuit breakers are available from several sources. If device is not marked dc, then verify dc listing with manufacturer.
- Rated at 1.25 x 1.25 = 1.56 times short-circuit current from modules [UL-1703, 690-8, module instructions].

Underrated Fuse–Fuse appears to be physically stressed



Automotive (32V) fuses have been found in PV combiner boxes requiring 125 V fuses (same physical size)

Overcurrent Protection

- Size string fuses or circuit breakers according to UL max series fuse listing(to protect PV module).
- Size fuse holders for 1.25 times the open-circuit voltage (V_{oc}) (depends on Temp. in 1999 code).

Overcurrent Protection

- Located near the charge controller or battery [690-9(a) FPN].
- Must protect smallest conductor used to wire modules. Sources of overcurrent are parallel-connected modules, batteries, and backfeed through inverters [690-9(a)].

DISCONNECTS

- Listed, dc-rated devices are available: Square D QO breakers for 12-volt dc systems, Square D Heavy Duty Fused Safety Switches up to 600 volts dc.
- Listed PV Load Centers by Pulse, Trace, and others for 12, 24, and 48-volt systems contain charge controllers, disconnects, and overcurrent protection for entire dc system.
- Must provide disconnects for all current-carrying conductors [690-13] and equipment [690-17].

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INVERTERS (battery-based systems)

- Listed inverters are available from three manufacturers [110-3]. Three battery-based units available for utility-intertied systems
- DC input currents must be calculated for cable and fuse requirements: Input current = rated ac output in watts divided by lowest battery voltage divided by inverter efficiency [690-8(b)(4)].
- Cables to batteries must handle 125% of input currents [690-8(a)].
- Overcurrent devices should be located within 4-5 feet of batteries.

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INVERTERS (cont.)

- Overcurrent/Disconnects mounted near batteries and external to PV load centers are suggested if cables are longer than 10 feet to batteries or inverter.
- Listed, dc-rated fuses and circuit breakers are available. AIR should be at least 20,000 amps. Littelfuse marks dc rating, Bussmann and others sometimes do not [690-71(c), 110-9]. Verify listed, dc-rating with manufacturer if unmarked.
- 120-volt inverters connected to 120/240 load centers with multiwire branch circuits have the potential for neutral overloading in the branch circuit [100–Branch Circuit, Multiwire].

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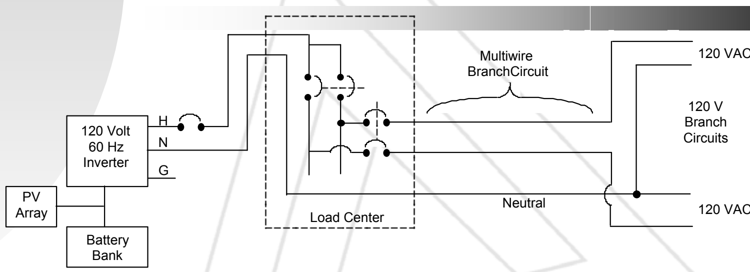
Safety Alert

Multiwire Branch Circuits and PV Systems



- Inverters—100 watt - 6 kW @ 120 volts
- Load Centers—120/240 v @ 100 - 200 amps
- Multiwire Branch Circuits—common
- Neutral Overload Possible

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multi-wire branch circuits--consider options

- install 240-Volt transformer on the output of the inverter to supply these circuits.
- rerun two separate runs to replace multi-wire branch circuits to be powered by inverter.
- stay away from those circuits. (laundry and furnace are on dedicated circuits in newer homes)

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Example: Inverter Circuit Conductors

- Inverter may draw sizable dc currents from the battery bank.
- Conductors must be rated to handle 125% of the maximum full load inverter dc current, may increase size for surge currents.

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Example (cont.): Inverters Require High DC Input Currents

- Example: Inverter rated to supply a resistive load of 5500 Volt-Amps AC at 120 volts at 80% efficiency. Battery voltage is 40 volts DC.
- DC input power level:
  - 5,500/0.80=6,875 watts DC
- DC input current at 40 volts:
  - 6,875/40 = 172 amps DC.
    (also should add RMS AC current of 28 amps– 172 + 28 = 200
- Battery cable rating
  - 200 amps x 1.25 = 250 amps

BATTERIES

- None are listed (although some are recognized).
- Cables should be building-wire type cables [Chapter 3]. Welding cables and auto battery cables don't meet NEC. Flexible USE/RHW cables are available. Article 400 cables OK for cell connections, but not in conduit or through walls [690-74, 400-8].
- Access should be limited [690-71(b)]. Install in well-vented areas (garages, basements, out-buildings, not living areas).
- Cables to inverters, dc load centers, and/or charge controllers should be in conduit [300-4].

INVERTERS (Utility-Interactive Systems)

- Listed units are available from at least four manufacturers and should be used for safety of utility personnel by eliminating the possibility of energizing unenergized utility lines.
- Must be on dedicated branch circuit [690-64].
- Must have external dc and ac disconnects and overcurrent protection [690-15,17].
- Connection made either at dedicated branch circuit breaker in service panel or on the line side of the panel service.

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Inverters— Example: AC Point of Connection

- Connection can be made through a breaker on a service panel.
- Connection can also be make on the line side of the main breaker (using double lugs or lugs that bolt through the insulation)
- Commercial construction must observe busbar rating since diversity of loads are less likely.

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GROUNDING

- Only one connection to dc circuits (ungrounded conductor) and one connection to ac circuits should be used for system grounding [250-21].
- AC and dc grounding electrode conductors should be connected to the same grounding electrode system (ground rod) [690-41,47].

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Grounding (Cont.)

- IMPORTANT!!!
  - There should be only be one point in the system where the grounding conductor is attached to the grounded conductor in the PV system. This eliminates the possibility of circulating ground currents under normal operating conditions.
  - The dc system grounding electrode shall be in common with or be bonded to the ac system grounding electrode. (this is NOT a separately derived system)

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Ground-Fault Protection

- NEC Article 690-5 requires ground-fault protection (GFP) for PV arrays mounted on the roofs of dwellings.

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Ground-Fault Protection Equipment

- New commercial equipment now exists.
- A GFP device will automatically:
  - sense excess ground-fault currents
  - interrupt the currents
  - open the circuit between the array and load

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1999 NEC Article 690 Changes

- Code Making Panel (CMP) #3 Is Responsible for Article 690
- CMP#3 Has Appointed an Industry Based Task Group to Examine Article 690 and to Propose Any Needed Changes to Make Article 690 Consistent with Current Photovoltaic Technology
- Significant Changes Were Agreed Upon by the SEIA Standards &Codes Committee for Task Group Action
- Virtually all of the more than 50 changes were accepted by CMP#3.

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The NEC requires a variety of Marking and Labeling

- Any fuse or circuit breaker that can be energized in either direction must be labeled as such. (NEC 690-17)
- UL listing covers markings on PV modules. (NEC 690-51)
- System Ratings: operating current, voltage, max voltage, and short-circuit current. (NEC 690-53)

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Marking and Labeling (cont.)

- Interactive Point of Connection (NEC 690-54)
- If system contains uninterruptible capabilities, provide a diagram of the location of the disconnects at the external house disconnect to notify fire officials.(702-8)

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Final Inspection and Acceptance

- System must first be inspected by the authority having jurisdiction
- Requires a contract with the serving utility company.
- Inverter must be acceptable to utility for interconnection.
- Utility may perform an acceptance test.

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