What are the applicable codes and standards for PV systems?

- Electrical codes - NEC Article 690 - Solar Photovoltaic Systems – NFPA 70
- Uniform Solar Energy Code
- Building Codes – ICC, ASCE 7
- UL Standard 1703, Flat-plate Photovoltaic Modules and Panels
- IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems
- UL Standard 1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources
Inspecting PV Systems for Code-Compliance

Current varies with irradiance

Siemens Solar Module SP75
Performance at Different Irradiances

Voltage varies with temperature

Siemens Solar Module SP75
Performance at Different Cell Temperatures
Inspecting PV Systems for Code-Compliance

Ain’t that purdy….

…and this is so much prettier...

Expedited Permit Process for PV Systems

available at www.Solarabcs.org/permitting

Why do we need Permit Guidelines?

- Variations in compliance requirements—some are insufficient to protect the public, others may not be consistent with established standards.
- Need a predictable process with uniform enforcement of code requirements for jurisdictional authorities and installing contractors.
Required Information for Permit

- Site plan showing location of major components on the property. This drawing need not be exactly to scale, but it should represent relative location of components at site (see supplied example site plan). PV arrays on dwellings with a 3' perimeter space at ridge and sides do not need fire service approval.
- Electrical diagram showing PV array configuration, wiring system, overcurrent protection, inverter, disconnects, required signs, and ac connection to building (see supplied standard electrical diagram).
- Specification sheets and installation manuals (if available) for all manufactured components including, but not limited to, PV modules, inverter(s), combiner box, disconnects, and mounting system.

Step 1: Structural Review of PV Array Mounting System

- Is the array to be mounted on a defined, permitted roof structure? Yes/No (structure meets modern codes)
- If No due to non-compliant roof or ground mount, submit completed worksheet for roof structure WKS1.

Roof Information:

- Is the roofing type lightweight (Yes = composition, lightweight masonry, metal, etc...).___________
  - If No, submit completed worksheet for roof structure WKS1 (No = heavy masonry, slate, etc...).
- Does the roof have a single roof covering? Yes/No
  - If No, submit completed worksheet for roof structure WKS1.
- Provide method and type of weatherproofing roof penetrations (e.g. flashing, caulk).___________

Mounting System Information:

- The mounting structure is an engineered product designed to mount PV modules? Yes/No
  - If No, provide details of structural attachment certified by a design professional.
- For manufactured mounting systems, fill out information on the mounting system below:
Mounting System Information:

a) Mounting System Manufacturer ___________ Product Name and Model# ____________

b) Total Weight of PV Modules and Rails __________ lbs

c) Total Number of Attachment Points ____________

d) Weight per Attachment Point (b÷c) __________ lbs (if greater than 45 lbs, see WKS1)

e) Maximum Spacing Between Attachment Points on a Rail __________ inches (see product manual for maximum spacing allowed based on maximum design wind speed)

f) Total Surface Area of PV Modules (square feet) __________ ft²

g) Distributed Weight of PV Module on Roof (b÷f) __________ lbs/ft²

- If distributed weight of the PV system is greater than 5 lbs/ft², see WKS1.

Site Diagram

- Drawing does not need to be to scale, but it should basically show were the major components are located.
- If array is ground mounted, it should show that it conforms with allowable setbacks.

Step 2: Electrical Review of PV System (Calculations for Electrical Diagram)

- In order for a PV system to be considered for an expedited permit process, the following must apply:

  1. PV modules, utility-interactive inverters, and combiner boxes are identified for use in PV systems.
  2. The PV array is composed of 4 series strings or less
  3. The Inverter has a continuous power output 13,440 Watts or less
  4. The ac interconnection point is on the load side of service disconnecting means (690.64(B)).
  5. The electrical diagram (E1.1) can be used to accurately represent the PV system.
One-line Diagram

- Should have sufficient detail to call out the electrical components, the wire types and sizes, number of conductors, and conduit type and size where needed.
- Should include information about PV modules and inverter(s).
- Should include information about utility disconnecting means (required by many utilities).
Section 1. Field Inspection Checklist for Array:

- a) Array matches plans
- b) Wire Management
- c) Module and Array Grounding
- d) Electrical enclosures on Roof Accessible and Connections Suitable for the Environment
- e) Array Fastened and Sealed According To Attachment Detail
- f) Conductor Ratings and Sizes

PV module model number matches plans and spec sheets
Get a digital photo of module label, if possible
Typical PV Module Label

Common Installation Mistakes with Array Modules and Configurations
- 1. Changing the array wiring layout without changing the submitted electrical diagram.
- 2. Changing the module type or manufacturer as a result of supply issues.
- 3. Exceeding the inverter or module voltage due to improper array design.
- 4. Putting too few modules in series for proper operation of the inverter during high summer array temperatures.

Inspection Checklist for Array:
   b) Wire Management
   - The most important safety issue is proper support and protection of conductors.

Wire Management
Proper Installation of Exterior Cables

- NEC 338.10(B)(4)(b) states how USE-2 is to be installed in exterior locations.
- PV Wire/Cable should follow the same installation methods as USE-2.
- Section 338.10 refers the installer on to Article 334.30 (NM Cable) for support methods.

Proper Installation of Exterior Cables—Article 334.30

1. Secured by staples, cable ties, straps, hangers, or similar fittings at intervals that do not exceed 4.5 feet.
2. Secured within 12 inches of each box, cabinet, conduit body, or other termination.
3. Sections protected from physical damage by raceway shall not be required to be secured within the raceway.
4. Cable shall closely follow the surface of the building finish or of running boards (NEC 334.15)—the analogous installation for USE-2 in PV arrays is for the conductors to follow support rails or module extrusions.
5. Protected from physical damage by raceway when necessary.

Wire Management—Proper

Wire Management—Room for Improvement
Wire Management—Support?

Common Installation Mistakes with Wire Management

• 1. Not enough supports to properly control cable.
• 2. Conductors touching roof or other abrasive surfaces exposing them to physical damage.
• 3. Conductors not supported within 12 inches of boxes or fittings.
• 4. Not supporting raceways at proper intervals.
• 5. Multiple cables entering a single conductor cable gland (aka cord grip)
• 6. Not following support members with conductors.

Proper cable glands into Combiner Box

Common Installation Mistakes with Wire Management—cont.

• 7. Pulling cable ties too tight or leaving them too loose.
• 8. Not fully engaging plug connectors.
• 9. Bending conductors too close to connectors.
• 10. Bending USE-2 cable tighter than allowable bending radius.
• 11. Plug connectors on non-locking connectors not fully engaged
Wire Management—Follow structural members & What the...?

What you can’t see won’t hurt you??

Inspection Checklist for Array: c) Module and Array Grounding

- Most common concern of field inspectors.
- Ungrounded module frames are a potential safety hazard.
- All array metal “likely to become energized” must be properly bonded together and grounded with lugs on each module and mounting rails or some equivalent equipment grounding method.

Module bonding and grounding methods

- 1. Some modules are designed to be grounded using a stainless-steel thread-forming screw threaded into the module frame holding the EGC at a grounding symbol. An isolating washer, such as a stainless cup washer is often used to isolate the copper conductor from the aluminum frame to prevent galvanic corrosion.
- 2. Some modules can be grounded to their mounting structures with stainless steel star washers placed between the module and the support structure. This creates an electrical bond while isolating the aluminum frame from dissimilar materials such as galvanized steel. The EGC is attached to an electrically continuous support member with a properly installed grounding lug.
Module bonding and grounding methods—cont.

3. Some modules can be grounded by properly installing a properly rated lay-in lug to the either the grounding point on the module, or any unused mounting hole. The EGC is run through this lay-in lug to bond the modules together.

4. For specific module mounting products (e.g. UniRac, ProSolar, DPW, etc...), there exists listed grounding clips to bond typical aluminum framed modules to the mounting structure. Only the proper clip can be used with each mounting structure. This allows the EGC to be connected to the electrically continuous rail. This method is consistent the NEC 690.43 and NEC 250.136.

5. Some modules can be grounded together using serrated clips that hold the module to the support structure and electrically bond with the module. One lug on any module can ground a whole row of modules.

Early module and structure grounding improvements

Identifying Grounding Clips

Notice slight gap caused by properly installed clip.
Common Installation Mistakes with Module and Array Grounding

- 1. Not installing a grounding conductor on the array at all.
- 2. Using cad-plated Tek screws to fasten ground wires or lugs to modules.
- 3. Using indoor-rated grounding lugs on PV modules and support structures.
- 4. Not protecting EGCs smaller than 6 AWG from physical damage.
- 5. Allowing copper EGC to come in contact with the aluminum rails and module frames.
- 6. Assuming that simply bolting aluminum frames to support structures provides effective grounding.

Nice Lugs! (poor fasteners)

Indoor lugs and Tek screws

Aluminum bolted to steel without isolation washers and no effective bond

Grounding Hardware and Components

Stainless hardware looks like new

Galvanized washer showing galvanic corrosion with aluminum contact
Inspection Checklist for Array:
d) Electrical enclosures on Roof Accessible and Connections Suitable for the Environment

- NEC 690.34 Access to Boxes. Junction, pull, and outlet boxes located behind modules or panels shall be so installed that the wiring contained in them can be rendered accessible directly or by displacement of a module(s) or panel(s) secured by removable fasteners and connected by a flexible wiring system.

Junction Boxes
- Connection between conductors in an outdoor location generally must be done within a rainproof junction box, NEMA 3R, or 4 (unless with approved connector)
- Junction boxes are commonly used to transition conductors from exterior to conduit conductors and for combining array source circuits.

Rooftop j-boxes in compliance with 690.34

Improper Connections
- Dry wirenut and not in a j-box
- Wire twisted together, wrapped in tape, and in the sun

Waterproof wirenuts must be in j-boxes
Common Installation Mistakes with Electrical Boxes, Conduit Bodies, and Disconnecting Means

- 1. Installing disconnects rated for vertical installation in a non-vertical application.
- 2. Installing improperly rated fuses in source combiners and fused disconnects.
- 3. Covering boxes or conduit bodies making them nearly inaccessible for service.
- 4. Not following manufacturer’s directions for wiring disconnect for 600 Vdc ratings.
- 5. Installing dry wire nuts in wet locations and inside boxes that get wet routinely.
- 6. Using improper fittings to bring conductors into exterior boxes.

Many disconnects like these require the ungrounded conductor to be broken twice in series to get the 600Vdc rating.
Inspecting PV Systems for Code-Compliance
Correct Fuses and Terminals?

Proper Current Rating?

Proper Current Rating?

Properly Rated Disconnects and Inverters

Inspecting PV Systems for Code-Compliance
Inspection Checklist for Array:
e) Array Fastened and Sealed According To Attachment Detail

- Roof penetrations must be properly sealed to preclude leakage.
- Do a hand pull test on a sample of lag screw attachments to make sure they are secured to rafters.
- Look in attic to see if lags are visible.

Proper and Improper Flashing

Common Installation Mistakes with Mounting Systems:

1. Not using supplied or specified hardware with the mounting systems.
2. Substituting Unistrut for special manufactured aluminum extrusions.
3. Not installing flashings properly.
4. Not using the correct roof adhesives for the specific type of roof.
5. Not attaching proper lag screws to roofing members.
6. Not drilling proper pilot holes for lag screws and missing or splitting roofing members.

Inspection Checklist for Array:
f) Conductor Ratings and Sizes

- Exposed Array Conductors—The only single-conductor cables allowed in 690.31(B) are USE-2 and PV Wire (Cable).
- Conductors in raceways on rooftops—Table 310.15(B)(2)(c) adds an additional 14°C-30°C to the ambient temperature. These high temperatures nearly always limit ampacity below the terminal temperature ampacity.
Conduit Exposed to Sunlight Above Rooftops — Table 310.15(B)(2)(c)

Common Installation Mistakes with Conductors:

1. Not accounting for high operating temperatures in rooftop conduit.
2. Specifying THHN conductors rather than wet rated conductors in drawings where raceways are clearly located outdoors.
3. Specifying or installing THWN conductors in raceways that may exceed 60°C without properly correcting the THWN conductors for this temperature.

Incorrect conductors and roof plumbing into combiner box

Improperly Rated Conductors
Section 2. Specifics For Ground-Mounted Arrays

- a) Foundation and mounting structure review
- b) Electrical bonding of structural elements
- c) Additional array electrode [690.47(D)]
- d) Attachment method according to plans
- e) Wiring not readily accessible
Wiring not readily accessible?

Readily accessible or not?

Common Installation Mistakes with Ground Mounting Systems:

1. Not using supplied or specified hardware with the mounting systems.
2. Substituting Unistrut for special manufactured aluminum extrusions.
3. No bonding of support structure or discontinuous grounding of support structure.
4. Dissimilar metals in contact with one another (e.g. aluminum and galvanized steel).
5. No bonding of aluminum structural elements to steel structural elements.
6. Array wiring readily accessible to other than authorized personnel.

Section 3. Appropriate signs installed

- Sign construction
- Photovoltaic Power Source
- AC point of connection
- alternative power system
Sign Construction

- The NEC is not extremely specific about what signs should be made of.
- NEC 110.21 states, “The marking shall be of sufficient durability to withstand the environment involved.”
- Electrical industry standards for outdoor signs is that signs should be metal or plastic with engraved or machine printed letters, or electro-photo plating, in a contrasting color to the sign background.

Indoor signs may allow more variety of construction

Photovoltaic Power Source Sign

Signs and Labels
Section 4. Check that equipment ratings are consistent with application and signs
Inspecting PV Systems for Code-Compliance
Guts—show and tell

Good Installation Practices

Good Installation Practices

Inspecting PV Systems for Code-Compliance
Good Installation Practices

Nice Work

Nice Work

Nice Work

Inspecting PV Systems for Code-Compliance