Solar Photovoltaic (PV) Fire Safety Training

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The New England Solar Cost-Reduction Partnership is a consortium of five New England states and the Clean Energy States Alliance (CESA), working to drive down the non-hardware “soft” costs for solar PV electricity systems. The Partnership consists of the following state agencies:

- CT: Connecticut Green Bank
- MA: Massachusetts Department of Energy Resources and the Massachusetts Clean Energy Center
- NH: New Hampshire Office of Energy and Planning
- RI: Rhode Island Office of Energy Resources and Rhode Island Commerce Corporation
- VT: Vermont Public Service Department

CESA, a national, nonprofit that advances state and local efforts to implement smart clean energy policies and programs, coordinates the Partnership.

www.cesa.org
The New England Solar Cost-Reduction Partnership is funded through the U.S. Department of Energy SunShot Initiative Rooftop Solar Challenge II program.

The SunShot Initiative is a national collaborative effort to make solar energy cost-competitive with other forms of electricity by the end of the decade.

Rooftop Solar Challenge aims to reduce the cost of rooftop solar energy systems through improved permitting, financing, zoning, net metering, and interconnection processes for residential and small commercial PV installations.

Solar Photovoltaic (PV) Safety for Firefighters

Clean Energy States Alliance

Matt Piantedosi

Tony Granato

Summer/Fall 2016
The views and opinions expressed in this presentation by the instructors are based upon their own experiences and understanding of the topic. They do not necessarily reflect the position of Cadmus, US DOE, CESA, or the participating states. Examples based on experiences are only examples. They should not be utilized in actual situations.
About Matt Piantedosio

• Senior Associate Engineer, Solar PV Inspector
  – The Cadmus Group
• BS Electrical Engineering
  – Western New England College
• Inspected over 500 residential/commercial PV systems
• Licensed Electrician in MA, NH, RI, and CT
• Working in the trade for over 16 years
• IAEI – Boston Paul Revere Chapter
  – Executive Board Member
About Tony Granato

• Hometown: South Glastonbury, Connecticut
• 24 years career fire service
  – 8 years at the rank of Lieutenant
• Certified Connecticut Fire instructor
• Licensed Connecticut Electrician
Outline

• Photovoltaics 101
  – Introduction to Photovoltaics & Electrical Theory (11)
  – Recognizing PV Systems and Components (37)
  – PV System Operation (59)
  – PV System Common Labels (64)

• PV Fire Safety
  – Planning, Size Up, and Tactical Considerations (80)
  – Disconnecting Methods & Rapid Shutdown (95)
  – Extinguishing a PV Fire/Hose Stream (128)
  – Personal Protective Equipment (PPE) (135)
  – Alternative Light Sources (140)
  – Electrical Hazards (147)
  – Other Hazards (171)
Photovoltaics 101
• The sun produces enough energy in 24 hours to supply our entire planet for over 4 years

• Solar technology rapidly evolved following the 1970’s era energy crisis

• Solar energy is renewable, pollution and noise free
“Photovoltaic”… what does it mean?

• A method of converting solar energy into direct current electricity using semiconducting materials that exhibit the “photovoltaic effect”

• Photo = Light
• Voltaic = Electricity
“Photovoltaic Effect”

• The “photovoltaic effect” is the creation of voltage or electric current in a material upon exposure to light.

• In 1839 French scientist Edmond Becquerel discovered the “photovoltaic effect” while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity conducting solution, electricity generation increased when exposed to light.
What is the difference between **AC** and **DC**

Alternating Current (**AC**)

- The direction of current flowing in a circuit is constantly being reversed back and forth.
- The frequency of repetition of this current is 60 Hertz (North America). The direction of the current changes sixty times every second.
- Power from grid is AC

![AC Circuit](image)

13
What is the difference between AC and DC

Direct Current (DC)

• The electrical current is only flowing in one direction in a circuit.

• Photovoltaic modules are DC sources of power.
PV Cells

• PV cells are thin layers of silicon or amorphous silicon
• Layered with Boron and Phosphorous.
• Boron needs an electron, Phosphorous has one.
• Sunlight photons makes the electrons move.
• Creates .5V/cell
How solar cells become a solar array

• Multiple PV cells are connected and become a Module.
How do they work?

• Specifications unique to make/model
• Current-limiting power source
  – Will never produce more current than their short-circuit current (Isc) rating
• Strung together in series to produce greater voltages
  – Similar to a DC battery
• Power depends on *sun exposure* and *temperature*
• Lower temperature, higher voltage
• A typical module: 50-72 cells measuring 5’x3’, produces 20-40V and 100-350 watts

• Residential systems commonly produce up to 600VDC per string

• Commercial can be up to 1000VDC per string

• A 20 module array can produce over 6,000 watts and weigh about 1,000 lbs.

• Constructing the array over 420 square feet of roof space produces an additional 2.5 lbs./square foot dead load
How solar cells become a solar array

- Modules are connected in series and to increase voltage and become *Strings*. 
How solar cells become a solar array

• Strings are tied into each other in parallel to increase amperage and become an *Array.*
Utility-Interactive Central Inverter System
Series - parallel - series/parallel

Series Connected Solar Panels

12V 4.0A

By series connecting gives higher voltage
Current remains same.

Parallel Connected Solar Panels

Parallel connected solar panels give more current (ampere)

24V 12.0A

Series and Parallel connecting solar panels

12V 4.0A

Series and Parallel connected Solar Panels gives higher
voltage and higher current.

24V 8.0A

Watts = Amps x Volts
Types of PV Modules

- Crystalline
- Frameless
- Solar Laminate
- Thin Film Solar Shingles
PV systems can be anywhere

Residential - Single family

A whole neighborhood
Many Fire Stations in the US have PV systems installed on their roofs.
Things are not always what they look like
No guarantee you’re walking on an asphalt shingle roof
Examples of Solar Shingles
Examples of Solar Shingles
Examples of Solar Shingles
Be aware of all roof covering materials
Combinations of different systems

Solar PV and Thermal Systems
Solar Thermal System

Typically 2-6 panels
Insulated piping coming from panels (as opposed to wiring) – typically copper

Solar thermal systems do not pose the same risk as solar photovoltaic systems. They typically contain a loop of water/glycol in the rooftop collectors, however there may be a scalding hazard.
Solar Thermal System

Thermal piping can be wrapped with insulation
Solar Thermal System
Recognizing PV Systems and Components
Modules
Roof-mounted residential

Parking areas

Ground-mounted

Building integrated shingles

Roof-mounted commercial

Building integrated walls
Typical pitched-roof mounting

- Panels are secured using an aluminum racking system

- Racking is secured to roof with lag screws drilled into structural rafters

- Mounting is designed to withstand wind loads for installation area requirements – making them very difficult to remove
Typical flat-roof mounting
String Combiners

Left: Typical Residential Combiner, Right: Typical Commercial Combiner
Inverters

• Convert DC power to AC to match building/grid electrical system

• 3 types of inverters:
  – Central Inverter
  – String Inverter
  – Microinverters

• All types stop converting power when utility power shuts down
Central Inverter System

- Larger inverters
- Typically located remotely from array
- Most-common for large-scale ground-mount or commercial rooftop systems
String Inverter System

- Mid-sized inverters
- Typically located adjacent to array on commercial rooftop systems
- Most-common type for residential rooftop systems, inverter will typically be located in basement or outside
Microinverter System

- Mini inverter under each module
- Most-common type for residential rooftop systems
- Typically not found on large commercial systems
- Minimum DC exposure
Utility-Interactive AC (Microinverter) System

NOTE: The grounding method shown is one of multiple allowable methods. A GEC (grounding electrode conductor) is required only for M21S-60-2LL. It is not required for M21S-60-2LL-IG.

Enphase Energy
FIELD WIRING DIAGRAM
240 VAC SINGLE PHASE
Utility-Interactive Central Inverter System
With DC Optimizers
Solar Optimizers
Disconnects

Disconnect switches can be integral to inverters or located remotely.
Electric Panels

Electrical panels can be used to combine multiple inverter outputs or to connect solar to the grid.
kWh Production Meters

PV systems may contain a production meter in addition to the existing utility meter
Larger PV systems may contain a DAS, that will remotely monitor power production.
PV System Operation

- Inverter monitors grid voltage/power quality
  - UL 1741 requires inverter to shut off within fraction of a second if power goes out of range, or completely off
  - Inverter will remain off until it detects 5 minutes of continuous power
  - Most PV systems today do not contain batteries or energy storage
PV System Operation

- During production times, power goes to grid if not completely used behind the meter
  - Typically there is no onsite energy storage (today)
PV System Basics

- At night, electricity is supplied by grid
Energy Storage Systems
(Battery Banks)

• Not common for most PV systems
• Lead acid batteries are used to store power produced.
• Newer technology - lithium ion batteries (Tesla Powerwall)
• Charge Controllers will also be present with Battery banks
PV system battery hazards

- Batteries can give off gas, both Oxygen and Hydrogen
- They should be in well ventilated areas with no combustibles present
- Can be located in basements, sheds, crawl spaces
- SCBA required for fires involving batteries
PV System Common Labels
PV System Labeling

- 690.31(G)(3) DC Raceway Label
- 690.13(B) DC Power Source
- 690.53 PV System Disconnect Line/Load Energized
- 705.12(D)(3) Multiple Sources
- 690.56(B) Service Disconnect Directory
- 690.54 AC Power Source
- 705.12(D)(2)(3)(b) PV Breaker "Do Not Relocate"
PV System Labeling

Materials used for marking shall be reflective, weather resistant and suitable for the environment. IEC 605.11.1.1.

The markings shall be of sufficient durability to withstand the environment involved. NEC 110.21

1. MAIN SERVICE DISCONNECT
   - WARNING: ELECTRICAL SHOCK HAZARD. TERMINALS ON BOTH LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION. NEC 690.17(F)
   - WARNING: TURN OFF PHOTOVOLTAIC AC DISCONNECT PRIOR TO WORKING INSIDE PANEL. NEC 110.27(C)
   - WARNING: ELECTRICAL SHOCK HAZARD. THE DC CONDUCTORS OF THIS PHOTOVOLTAIC SYSTEM ARE UNGROUNDED AND MAY BE ENERGIZED. NEC 690.3(F)
   - PHOTOVOLTAIC POWER SOURCE.
   - DC conduit, raceways, enclosures, cable assemblies and junction boxes. Use every 10', at every turn, above and below penetrations, and all DC combiner junction boxes per IEC 605.11.1.4 & NEC 690.31(E)(2)

2. Net Meter
   - WARNING: ELECTRIC SHOCK HAZARD. THE DC CONDUCTORS OF THIS PHOTOVOLTAIC SYSTEM ARE UNGROUNDED AND MAY BE ENERGIZED.
   - Per NEC 690.5(C)

3. Building/Structure
   - CAUTION: POWER TO THIS SYSTEM IS ALSO SUPPLIED FROM THE FOLLOWING PV SYSTEMS LOCATED AS SHOWN.
   - Per NEC 690.56(B)

4. Main Service Disconnect
   - MAIN PV SYSTEM DISCONNECT.
   - Per NEC 690.14(2)
   - WARNING: PHOTOVOLTAIC SYSTEM CIRCUIT IS BACKED. MAIN Disconnect UNDER LOAD.
   - Per NEC 690.33(E)(2)
   - Conductors at switch or circuit breakers (pull box) per NEC 690.4. Main circuit breaker and meter per NEC 691.17. Dual power source NEC 705.12(D)(4) and Backfeed prevents NEC 705.22.4 and NEC 690.64

5. AC Disconnect / Breaker / Points of Connection
   - PHOTOVOLTAIC AC DISCONNECT.
   - Per NEC 690.14(C)(C) & 690.15

6. Inverter
   - Per NEC 690.54

7. DC Disconnect/ Breaker
   - Per NEC 690.52
   - Per NEC 690.53

8. Inverter
   - Per NEC 690.54
PV System Labeling

Materials used for marking shall be reflective, weather resistant and suitable for the environment. IFC 605.11.1.1.

The label shall be suitable for the environment where it is installed. NEC 110.21

1. Main Disconnect
   - Per NEC 690.17(E)
   - Per NEC 110.27(C)

2. Conduit
   - NEC 690.31(G)(1) Where circuits are embedded under roofing and not covered by PV modules, they shall be clearly marked.

3. Building/Structure
   - Per NEC 690.56(A)

4. Net Meter
   - Per NEC 690.56(B)
   - Per NEC 690.5(C)

5. DC Disconnect/Breaker
   - Per NEC 690.53

6. Inverter
   - Per NEC 690.5(C)
   - Per NEC 690.31(I)

7. AC Disconnect
   - Per NEC 690.14(2)
   - Per NEC 705.12(D)(3)

8. Panel Breakers/Pull Boxes
   - Per NEC 690.15
   - Per NEC 690.33(E)(2)

9. Solar Disconnect
   - Per NEC 690.52

10. Photovoltaic System Equipped with Rapid Shutdown
    - Per NEC 690.55(B)

11. Photovoltaic Power Source
    - Per NEC 690.17(E)
    - Per NEC 690.35(F)

12. WARNING: Photovoltaic Power Source
    - The DC conductors of this photovoltaic system are ungrounded and may be energized.

13. WARNING: Electrical Shock Hazard
    - Do not touch terminal terminals on both line and load sides may be energized in the open position.

14. WARNING: Electrical Shock Hazard
    - Turn off Photovoltaic AC Disconnect prior to working inside panel.

15. WARNING: Electrical Shock Hazard
    - DC conduit, raceways, enclosures, cable assemblies and junction boxes. Use every 10', at every turn, above and below penetrations, and all DC combiner junction boxes per IFC 605.11.1.4 & NEC 690.31(G)(3)(4).

16. WARNING: Photovoltaic System Connected
    - Solar disconnect dual power source second source is photovoltaic system.

17. CAUTION: Solar Electric System Connected
    - Do not disconnect under load.
DC Raceway Label
NEC Article 690.31(G)(3)

• On or inside a building

WARNING: PHOTOVOLTAIC POWER SOURCE

- Minimum 3/8” CAPS
- White on Red
- Reflective

Required on all DC raceways, every 10 feet.
PV System Disconnect

NEC Article 690.13(B)

The utility may require specific wording on an AC disconnect. Article 690.13(B) still applies. It is important that this is not confused with the Service Disconnect.
PV System Disconnect
NEC Article 690.13(B)

The correct way: Label identifying disconnect as Solar PV disconnect.
Disconnect Line/Load Energized

NEC Article 690.17(E)

WARNING
ELECTRIC SHOCK HAZARD
DO NOT TOUCH TERMINALS.
TERMINALS ON BOTH THE LINE
AND LOAD SIDES MAY BE ENERGIZED IN THE
OPEN POSITION.
DC Power Source

NEC Article 690.53

Maintenance label showing DC system properties.
AC Power Source
NEC Article 690.54

Maintenance label showing AC system properties.
Dual Power Sources

NEC Article 705.12(D)(3)

Warning label indicating multiple sources of power present.
“Do Not Relocate”

NEC Article 705.12(D)(2)(3)(b)

Maintenance label for electrical connection in panelboard.
AC Combiner Panel
NEC Article 705.12(D)(2)(3)(c)

WARNING
THIS EQUIPMENT FED BY MULTIPLE SOURCES.
TOTAL RATING OF ALL OVERCURRENT DEVICES,
EXCLUDING MAIN SUPPLY OVERCURRENT DEVICE,
SHALL NOT EXCEED AMPACITY OF BUSBAR.

Maintenance label for electrical connection in panelboard.
Service Disconnect Directory

NEC Article 690.56(B)
Inverter Directory
NEC Articles 690.15(A)(4)/705.10
Planning, Size Up, and Tactical Considerations
Pre-plan development considerations:
• Buildings with installed solar PV systems
• Coordination with building department
• FMO Involvement in permit process?
• Maintain a record of buildings containing PV?
• Company training and walk through
• Dispatch center CAD entries
• After the initial size up, consider the following
  – Is there a PV system present on the structure/property?
  – A complete 360 is important to get a look at all sides and roof
• What type of system is it?
  – PV, Thermal, integrated
Meter and AC disconnect located on “D” side

Array installed right up to ridge line with no setbacks, will not allow roof ladder hooks to sit on roof
Roof has solar shingles with metal decking

PV inverters in basements

Meter and PV A/C disconnect “B/C” corner

“C” side of building across the street
• Is the system involved in a fire? If yes, what are the appropriate actions?

• Proper hose stream selection and safe distances for applying water to burning PV systems
• What do we have for roof access?
• Aerial or ground ladder operations (setbacks at ridge)
• Vertical ventilation might not be an option depending on PV system location

• Horizontal Ventilation might be the best and only choice
• Where are the disconnects located?
  – Interior (garage/basement) or exterior

• Do we have access to secure the disconnects?
• Lock out tag out

• Utilize LOTO procedures when disconnects or other power sources are secured
• This is **NOT** DIY work!

• Consider notification to Solar contractor for assistance
  – Look for labeling
  – Information will also be on electrical/building permit

• Labeling may or may not be present or legible
Residential Example: House containing PV on B and D sides.
Residential Example: PV inverter and AC disconnect located on B side.
Example of ground-mount array, large Inverter and disconnects located remotely.
Ground-mount array near highway.
Disconnecting Methods and Rapid Shutdown

Will this make the PV system safe for operations?
Options for Shutting Down

• Covering panels with tarps

• Shutting off all accessible disconnects
Utilizing Tarps

• May work on small residential systems
• Not practical for large PV systems
• UL test summary:

<table>
<thead>
<tr>
<th>Tarp #</th>
<th>Cost</th>
<th>Tarp</th>
<th>Color</th>
<th>Layers</th>
<th>Volts</th>
<th>Amps</th>
<th>Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$15</td>
<td>4.0 mil plastic film</td>
<td>Black</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>Safe</td>
</tr>
<tr>
<td>2</td>
<td>$16</td>
<td>5.1 mil all purpose plastic</td>
<td>Blue</td>
<td>1</td>
<td>126</td>
<td>2.1</td>
<td>Electrocution</td>
</tr>
<tr>
<td>3</td>
<td>$78</td>
<td>Fire Salvage Canvas</td>
<td>Green</td>
<td>1</td>
<td>3.2</td>
<td>0</td>
<td>Safe</td>
</tr>
<tr>
<td>4</td>
<td>$94</td>
<td>Fire Salvage Heavy Vinyl</td>
<td>Red</td>
<td>1</td>
<td>124</td>
<td>1.8</td>
<td>Electrocution</td>
</tr>
</tbody>
</table>

**Table 17: Results of experiments with tarps**

- Open Circuit
- Short Circuit

<table>
<thead>
<tr>
<th></th>
<th>0 - 2 mA</th>
<th>2.1 - 40 mA</th>
<th>40.1 - 240 mA</th>
<th>&gt; 240 MA</th>
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</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Safe</td>
<td>Perception</td>
<td>Lock On</td>
<td>Electrocution</td>
</tr>
</tbody>
</table>
Utilizing foam to cover modules

- UL performed a test with foam on a cloudy day
  - After 10 minutes the foam slid off the glass
  - UL concluded foam was not an effective method to block sun
Disconnects

- May be effective method to de-energize system
- Various system types
  - Some disconnects DO NOTHING
  - Can be in multiple locations
AC Microinverter System

• What will happen if I shut off the main disconnect?
  – Conductors will be energized only under modules
  – All AC electrical circuits/devices will be de-energized
AC Microinverter System

• What will happen if I shut off the main?

48 Vdc max

208-240 Vac

Courtesy of Enphase Energy
Central Inverter System
(Most Common)
Central Inverter System  
(Most Common)

• What will happen if I shut off the main?
  – All AC electrical circuits/devices de-energized
  – AC conductors up to inverter de-energized
  – DC conduit inside building still energized
  – Rooftop DC conduit still energized

*The following example assumes the PV system is connected to the main panelboard. Care should be taken, as this is not always the case and the PV system may have its own disconnect located remotely from the main breaker.*
Central Inverter System
(Most Common)

• What will happen if I shut off the main?
  – *AC circuits throughout building will be de-energized if PV breaker is in main panelboard*
Central Inverter System
(Most Common)

• What will happen if I shut off the main and DC disconnect?
  – *AC circuits throughout building will be de-energized if PV breaker is in main panelboard*
  – *DC will still be energized between inverter and array*
Central Inverter System
(Most Common)

• What will happen if I shut off the main and DC combiner disconnect?
  – AC circuits throughout building will be de-energized if PV breaker is in main panelboard
  – DC between inverter and combiner may be de-energized in 5 minutes
    • Inverters contain capacitors!
Central Inverter System
(Most Common)

• What will happen if I shut off the main, DC, and DC combiner disconnects?
  – *AC circuits throughout building will be de-energized if PV breaker is in main panelboard*
  – *All DC conductors between inverter and DC combiner will be de-energized*
    • *Array conductors still energized*
Example of commercial system. All array conductors remain energized even with DC disconnect off.
Combiner Box with DC Disconnect
Combiner Boxes with DCDisconnects
Combiner Boxes, No Disconnects

Prior to the 2011 National Electrical Code

Prior to the 2011 Code, combiner boxes were not required to have disconnects.
Combiner Boxes

• Opening fuseholders under load is dangerous
  – Arcing hazard

• Inverter or DC disconnect **MUST be shut down** before fuseholders are opened
  – Inverter will shut down automatically if main breaker is off
  – **If there is a fault** in the DC wiring (modules burning, etc.), current will still flow to ground and a **hazard may still exist** when opening fuseholders
Example of commercial system.
No rooftop DC disconnects, array conductors remain energized.
Example of commercial system. DC combiner contains disconnect, array will remain energized.
Ground-mount array with DC combiner/disconnect. Array conductors remain energized if disconnect is opened “off.”
Location of inverter/disconnect.
All other array conductors will remain energized when modules are exposed to light.
Rapid Shutdown of PV Systems on Buildings

• Applies to all buildings permitted to the 2014 edition of the NEC
• PV system circuits on or in buildings shall include a rapid shutdown function:
  – 690.12(1) through (5)
About Article 690.12

2014 National Electrical Code

- Intended to protect first responders
- Original 2014 proposal:
  - Disconnect power directly under array
    - Module-level shutdown
- Compromise:
  - Combiner-level shutdown
Rapid Shutdown of PV Systems on Buildings

2014 NEC Article 690.12

- 690.12(1)
  - More than 10’ from an array
  - More than 5’ inside a building
Rapid Shutdown of PV Systems on Buildings
2014 NEC Article 690.12

- **690.12(2)**
  - Within 10 seconds
    - Under 30 Volts
    - 240 Volt-Amps (Watts)
  - *A typical module:*
    - ~250 Watts
    - ~30 Volts

- **690.12(3)**
  - Measured between:
    - Any 2 conductors
    - Any conductor and ground
Rapid Shutdown of PV Systems on Buildings
2014 NEC Article 690.12

• 690.12(4)
  – Labeled per 690.56(C)

PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN

• Minimum 3/8” CAPS
  • White on Red
• Reflective
Rapid Shutdown of PV Systems on Buildings
2014 NEC Article 690.12

• 690.12(5)
  – "Equipment that performs the rapid shutdown shall be listed and identified."
About Article 690.12

• Open-ended gray areas:
  – Location of “rapid shutdown initiation method”
  – Maximum number of switches
About Article 690.12

• Considerations:
  – Disconnect power within 10 seconds
  – Inverters can store a charge for up to 5 minutes (UL 1741)
About Article 690.12

• What complies:
  – Microinverters
  – AC modules
  – DC-to-DC Optimizers/Converters
    • May or may not depending on the model
About Article 690.12

• What complies:
  – Exterior string inverters if either:
    • Located within 10 feet of array
    • Inside building within 5 feet
  – “Contactor” or “Shunt Trip” Combiner Boxes/Disconnects
    • Must be listed for “Rapid Shutdown” as a system
  – Many considerations & variations for full system compliance
    • Plans should be discussed with AHJ prior to installation
Extinguishing a PV Fire and Hose Stream

Is water a good idea??
Firefighter Safety and Photovoltaic Installations Research Project

During the UL research project many variables were considered.

- Voltage of PV system
- Nozzle diameter
- Pattern of water spray
- Distance between nozzle and live components
- Conductivity of water
UL conducted two experiments

Smooth Bore
Up to 1.25”

Adjustable Solid Stream to Wide fog
Hose Stream

Test with pond water and **smooth bore** nozzle

<table>
<thead>
<tr>
<th>Distance Feet</th>
<th>Smooth bore nozzle size</th>
<th>Pressure PSI</th>
<th>Voltage DC Volts</th>
<th>Leakage current Milliamps</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1 inch</td>
<td>21</td>
<td>1000</td>
<td>5.7</td>
</tr>
<tr>
<td>10</td>
<td>1 inch</td>
<td>21</td>
<td>600</td>
<td>3.2</td>
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<td>21</td>
<td>300</td>
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<td>10</td>
<td>1 inch</td>
<td>21</td>
<td>50</td>
<td>0.3</td>
</tr>
<tr>
<td>20</td>
<td>1 inch</td>
<td>23</td>
<td>1000</td>
<td>1.5</td>
</tr>
</tbody>
</table>

- **0 - 2 mA**  Safe
- **2.1 - 40 mA**  Perception
- **40.1 - 240 mA**  Lock On
- **> 240 MA**  Electrocution

Source: UL.com
Hose Stream

Test with pond water and narrow fog pattern at 5’
Zero leakage current at 1000 Volts

Source: UL.com
Hose Stream

• In conclusion UL recommends:
  – At least 20’ away for smooth bore
  – At least 10° angle for adjustable
• UL 401 Standard, 30° min cone angle
  – “Portable Spray Hose Nozzles for Fire-Protection Service”
Personal Protective Equipment (PPE)

Are we safe from all hazards?
Personal Protective Equipment (PPE)

• UL tested firefighter gloves and boots to determine electrical insulating properties.
• Various tests performed on items:
  – New
  – Soiled
  – Wet
  – Worn
Personal Protective Equipment (PPE)

- Typical electrician rubber gloves evaluated to ASTM D 120, and must be worn with leather protectors

- Firefighter boots and gloves typically tested to NFPA 1971
  - Boots require similar test to electrician boots
  - No electrical requirements for gloves
# Personal Protective Equipment (PPE)

<table>
<thead>
<tr>
<th>Glove Sample</th>
<th>Soiled</th>
<th>Wetted Outside</th>
<th>Wetted Inside</th>
<th>Measured milliAmps, DC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50 Vdc 300 Vdc 600 Vdc 1000 Vdc</td>
</tr>
<tr>
<td>1</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>0 0 0</td>
</tr>
<tr>
<td>2</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>91 &gt;250</td>
</tr>
<tr>
<td>3</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>38 89 &gt;250</td>
</tr>
<tr>
<td>1</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>43 &gt;250 0.5 0</td>
</tr>
<tr>
<td>2</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>93 &gt;250</td>
</tr>
<tr>
<td>3</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>64 &gt;250</td>
</tr>
<tr>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>78 &gt;250</td>
</tr>
<tr>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>

**Legend:**
- **Safe**
- **Perception**
- **Lock On**
- **Electrocution**
Personal Protective Equipment (PPE)

<table>
<thead>
<tr>
<th>Sample</th>
<th>New</th>
<th>50% Toe</th>
<th>100% Toe</th>
<th>Hole in Bottom</th>
<th>Measured milliAmps, DC^4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Aged^1</td>
<td>Aged^2</td>
<td></td>
<td>50 Vdc</td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td></td>
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<td>30</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>

*Safe, Perception, Lock On, Electrocution*
Alternative Light Sources

No sun, no hazard??
Alternative Light Sources

- Artificial light sources
- Light from fire
- Moonlight
Alternative Light Sources

• UL tested a variety of trucks and light levels at night to determine if there was a presence of dangerous voltage
Alternative Light Sources

In most cases, artificial light produced enough power to energize PV to a dangerous level.

Table 18 – Results of experiments with fire truck illumination
1000 Volt Array with Night-Time Illumination from Fire Truck(s) Lighting

<table>
<thead>
<tr>
<th>Test</th>
<th>Truck #1</th>
<th>Truck #2</th>
<th>Total Lighting</th>
<th>Distance from Array (Feet)</th>
<th>Open Circuit Volts</th>
<th>Short Circuit MilliAmps</th>
<th>Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>None</td>
<td>48</td>
<td>812</td>
<td>132</td>
<td>Safe</td>
</tr>
<tr>
<td>2</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>10.5 kW</td>
<td>25</td>
<td>780</td>
<td>88</td>
<td>Lock On</td>
</tr>
<tr>
<td>3</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>4.5 kW</td>
<td>38</td>
<td>738</td>
<td>50</td>
<td>Lock On</td>
</tr>
<tr>
<td>4</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>28.5 kW</td>
<td>25 &amp; 38</td>
<td>836</td>
<td>212</td>
<td>Lock On</td>
</tr>
<tr>
<td>5</td>
<td>Partial Bed</td>
<td>Bed 6 kW</td>
<td>3 kW</td>
<td>25</td>
<td>657</td>
<td>22</td>
<td>Perception</td>
</tr>
<tr>
<td>6</td>
<td>Partial Bed</td>
<td>Bed 6 kW</td>
<td>1.5 kW</td>
<td>25</td>
<td>575</td>
<td>11</td>
<td>Perception</td>
</tr>
<tr>
<td>7</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>18 kW</td>
<td>50</td>
<td>735</td>
<td>37</td>
<td>Perception</td>
</tr>
<tr>
<td>8</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>10.5 kW</td>
<td>75</td>
<td>700</td>
<td>22</td>
<td>Perception</td>
</tr>
<tr>
<td>9</td>
<td>Bed 12 kW</td>
<td>Bed 6 kW</td>
<td>28.5 kW</td>
<td>50 &amp; 75</td>
<td>773</td>
<td>49</td>
<td>Lock On</td>
</tr>
<tr>
<td>10</td>
<td>Partial Bed</td>
<td>Bed 6 kW</td>
<td>1.5 kW</td>
<td>50</td>
<td>340</td>
<td>1.5</td>
<td>Safe</td>
</tr>
</tbody>
</table>
Light from nearby fire

- 12 burning wood skids
- Mobile array with 2 modules
- Took voltage readings at various distances, starting from 75’ away, to 15’ away

Figure 73  Test fixture with modules approaching fire

Source: UL.com
UL concluded dangerous voltages were present at each distance
  - No test was performed over 75’
Moonlight

- UL concluded dangerous voltages were **not** present in moonlight conditions **with no other ambient light present**
  - From 20 minutes after sunset to 20 minutes before sunrise
  - Caution should still be used as equipment can vary
Electrical Hazards
The National Electrical Code

• Allows the use of exposed single-conductor cables on the rooftop, where protected from physical damage
• Requires outdoor PV wiring methods to follow rest of code
• As of 2011, requires PV conductors under roof to be at least 10” down, to allow for roof venting
• Requires indoor DC conduit to be metal or have a disconnect at point of entry
• As of 2011, requires indoor DC PV conduit to be labeled every 10’
Cutting Live Conductors

- UL tested effects of cutting conductors and conduit with live hazardous DC voltages
  - Uninsulated cable cutter
  - Fiberglass handle axe
  - Rotary saw
  - Chain saw
Cutting Live Conductors

- All metal surfaces of tools were grounded
  - Represented accidental contact to metal building surfaces
- Conductors energized to represent typical commercial PV system application
Cutting Live Conductors

- UL concluded that with hand tools and a single energized conductor:
  - Almost always a shock hazard
  - The faster the cut, the shorter the hazard duration

Figure 51 Cutting wire with cable cutter

Figure 52 Carbon deposit from arcing on axe blade after severing conductor
Cutting Live Conductors

• Rotary saw and chain saw test
  – Metal conduit (EMT)
  – Nonmetallic conduit
  – Flexible metal conduit
Rotary Saw
Nonmetallic Conduit

Figure 54  Cutting through nonmetallic conduit

Figure 55  Open flame from arcing

Source: UL.com
Rotary Saw
Flexible Metal Conduit

Figure 56  Cutting through flexible metal conduit

Figure 57  Open flame from arcing

Source: UL.com
Chain Saw
Flexible Metal Conduit

Figure 58  Cutting through flexible metal conduit

Figure 59  Open flame from arcing
Power Tools and Multiple Conductors

- UL concluded:
  - Tool shorted out conductors, often resulted in arcing and additional fire
  - Left energized conductors exposed, additional shock hazard
  - Chainsaw sometimes pulled energized conductors out of conduit

Source: UL.com

Figure 60 Exposed conductor from action of chain cutting
Damaged Modules and Equipment
UL tested two types of damage:
- Physical with axe or other tool
- Damage from fire
Damaged Modules/Equipment

- Physical damage test with glass frame modules:
  - Axe or other tool was grounded, similar to wire cut test
  - Arcing and flames occurred
Physical damage test with laminate modules:
- 883 Volts measured between metal “roof” and earth
- Shock hazard for anyone in contact with roof
Damaged Modules/Equipment

- UL tested many modules after exposure to fire:
Damaged Modules/Equipment

- After fire:
  - Array reconstructed
Damaged Modules/Equipment

- Every module tested

Figure 117 - Module D1 – badly burnt on backside, but functional and producing full voltage
60% of modules still produced full power
Only 25% completely destroyed → no power
Shock Hazards

*During and Post-Fire...*
Shock Hazards

- UL identified many shock hazards present
  - Bare conductors
  - Energized racking
  - Energized metal roof
Shock Hazards

Figure 183  Bare energized conductors contacting broken rails and metal frames

Source: UL.com
Shock Hazards

Figure 157  Voltage between exposed wires

Source: UL.com
Night time fires involving PV systems

- Use caution during overhaul as PV wiring can be hidden in attics and walls
- Modules can produce dangerous voltage from scene lighting
- PV modules will become energized during daylight hours
Other Hazards

*Beyond the wires...*
Inhalation hazards
(This is nasty smoke)

• You MUST use SCBA when dealing with fire involving PV arrays
  – Treat it like the Hazmat call it is
• PV cells can produce three main chemicals when burning:
• Cadmium Telluride (usually on commercial or utility scale installations)
  – Carcinogenic
• Gallium Arsenide
  – Highly toxic and carcinogenic
• Phosphorous
  – The worst of the three
  – Lethal dose is 50 mg
In addition to electrical hazards

- Broken glass
- Falling modules
- Tripping and slipping hazards can be amplified on pitched roofs
- Insects and rodents
Trip/Slip Hazards

Be aware of conduit and conductors on flat rooftops.

Poor wire management leads to additional hazards.
Trip/Slip Hazards

Array covered entirely in snow.

Rooftop conduits buried in snow.
Case Studies

- Trenton, NJ
- Webster Groves, MO
- Glastonbury, CT
- East Brunswick, NJ
Terracycle
Trenton, New Jersey

• Date of fire: 3/27/12
• Contractors finishing 100 panel PV system installation
• Rooftop inverter arced, shocked several workers and started a fire in several junction boxes
• Contractors disconnected sections to allow FF’s to extinguish fires. Dry chemical extinguishers were used each time a box was taken offline. almost 2 hours until all power was cut.
Webster Groves High School
Webster Groves, Missouri

• Date of fire: 5/18/13
• Arc in junction box cited as likely cause
• 2 alarms, under control in 15 minutes
• Fire sparks more debate on fire operations around solar panels
Dogwood Lane 2/23/15
Glastonbury, Connecticut

• Date of fire: 2/23/15
• Single family occupied residential dwelling
• Fire reported at approximately 19:30 hours
• Heavy fire conditions on arrival to rear of residence
• Heavy snow fall accumulation on ground from previous days storm (2-3 feet)
• FD was not aware of PV system presence at time of fire
• 2-3 PV modules had fallen from roof prior to FD arrival, embedded in snow and located during daylight hours
Dogwood Lane 2/23/15
Glastonbury, Connecticut
Dogwood Lane 2/23/15
Glastonbury, Connecticut

PV disconnects and meter were located here.
Dogwood Lane 2/23/15
Glastonbury, Connecticut

Panels producing power during daylight

PV array and roof collapse

PV panels found buried in snow on other side of bushes
Dogwood Lane 2/23/15
Glastonbury, Connecticut
Old Bridge Volunteer Fire Department
East Brunswick, NJ

• Date of fire: February 11, 2016
• Macy’s Department store, East Brunswick Square mall
• Fire reported at approximately 10:00 am
• Incident Commander reports fire in Solar panels on roof
• 2nd Alarm transmitted
• Access to roof made and disconnects utilized
• Aerial ladder used with fog pattern to extinguish fire
• Fire contained to Solar panels, overhaul withheld until contractor arrived on scene (1 hour from notification)
• Approximately 30 modules involved
• Department had no formal training in Safety around solar panels
Old Bridge Volunteer Fire Department
East Brunswick, NJ
In Conclusion...

• Work with building department to determine locations of all PV systems on buildings in your district

• Familiarize yourself with the systems on large public buildings, installers/inspector will often welcome a tour to learn the hazards

• Always treat all conductors as live until proven otherwise by a qualified person
Currently there have been no United States fire service related deaths resulting from incidents involving Photovoltaic systems.

Through education, training, preplanning and a solid partnership with the PV industry our goal is to keep this number at ZERO.
PV Fire Safety Trainers

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