Solar Photovoltaic (PV) Fire Safety Training

Matt Piantedosi
Senior Assoc. Engineer & Master Electrician
The Cadmus Group Inc.
Matt.Piantedosi@cadmusgroup.com

Tony Granato
Lieutenant and CT Certified Fire Instructor
Connecticut E2 Journeyman Electrician
Tonyg68@cox.net

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Nate Hausman, Project Manager
Clean Energy States Alliance
(802)223-2554
Nate@cleanegroup.org

New England Solar Cost-Reduction Partnership

- 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

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SunShot Initiative Rooftop Solar Challenge

- 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.
- The New England Solar Cost-Reduction Partnership is the only Rooftop Solar Challenge II award for New England.

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Solar Photovoltaic (PV) Safety for Firefighters

Clean Energy States Alliance

Matt Piantedosi

Tony Granato

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About this presentation…

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 Piantedosi

- 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



- 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”

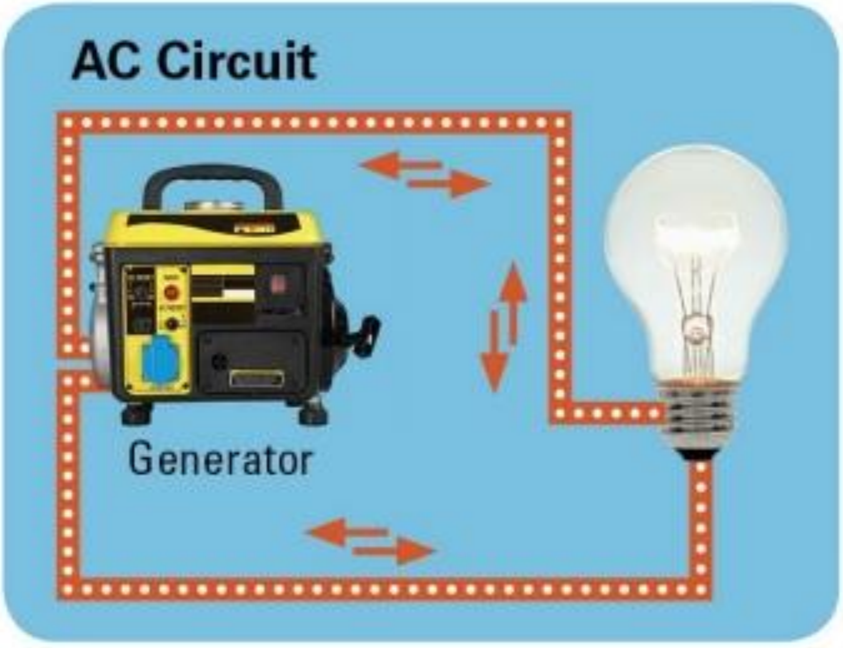
- The ”photovoltaic effect” is the creation of voltage or electric current in a material upon exposure to light.

- 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**)

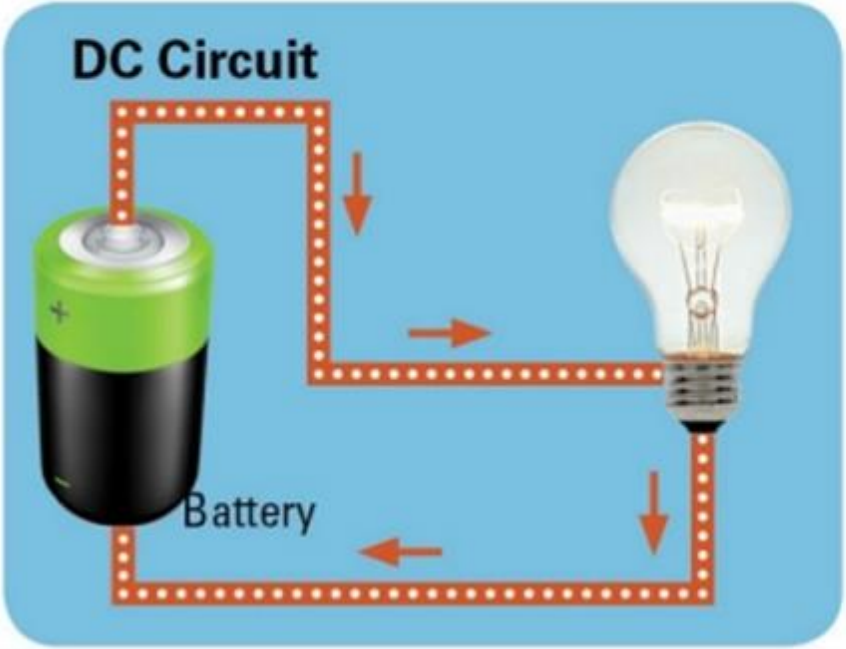
- The direction of current flowing in a circuit is constantly being reversed back and forth.
- The frequency of repetition of this current is 60 Hertz (North America). The direction of the current changes sixty times every second.
- Power from grid is AC



What is the difference between **AC** and **DC**

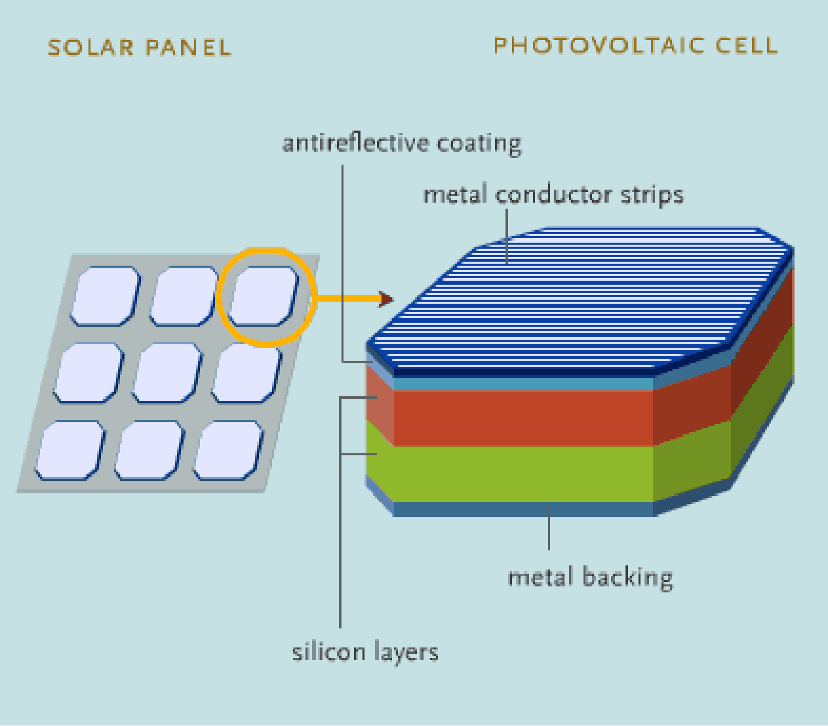
Direct Current (**DC**)

- 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

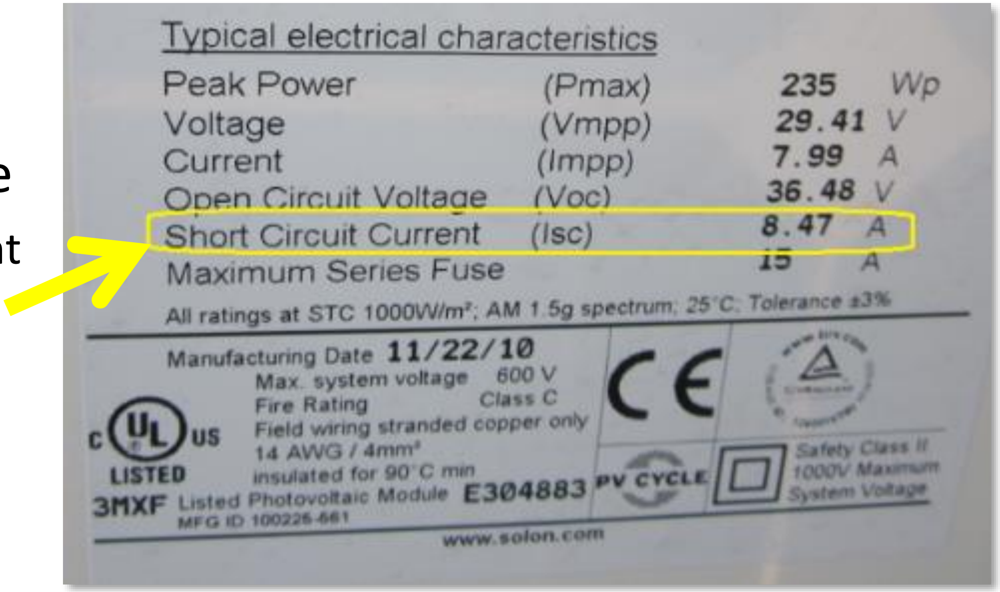


How solar cells become a solar array

- Multiple PV cells are connected and become a Module.

How do they work?

- Specifications unique to make/model
- Current-limiting power source
  - Will <u>never</u> produce more current than their short-circuit current (Isc) rating
- Strung together in series to produce greater voltages
  - Similar to a DC battery



Nameplate rating on a typical PV module.

- Power depends on ***sun exposure*** and ***temperature***
- <u>Lower</u> temperature, <u>higher</u> 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

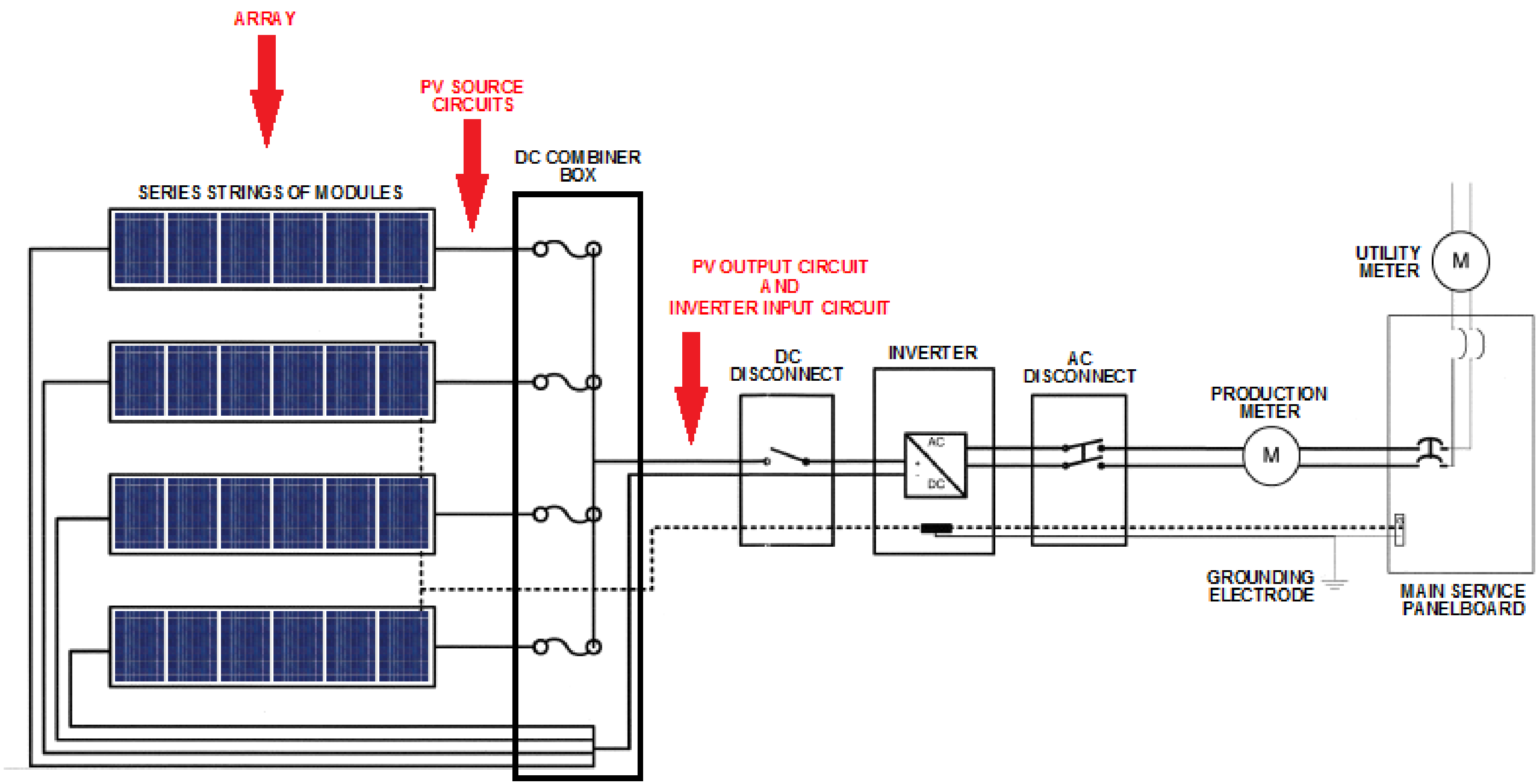
How solar cells become a solar array

- Modules are connected in series and to increase voltage and become ***Strings***.

How solar cells become a solar array

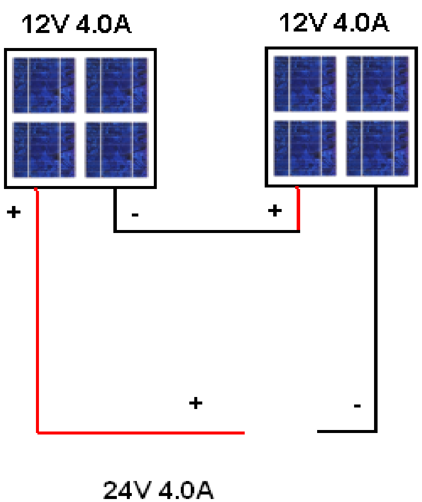
- Strings are tied into each other in parallel to increase amperage and become an ***Array***.

Utility-Interactive Central Inverter System



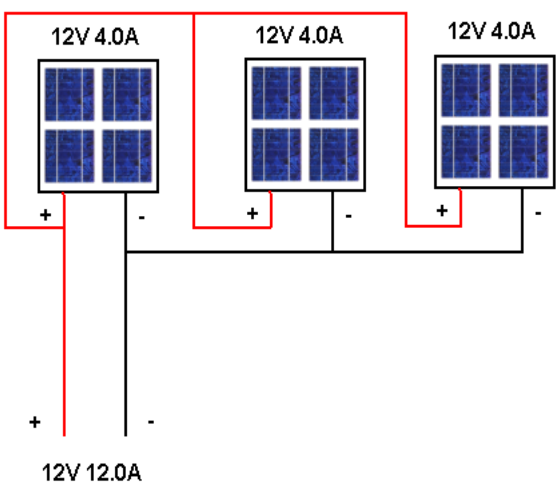
Series - parallel - series/parallel

Series Connected Solar Panels



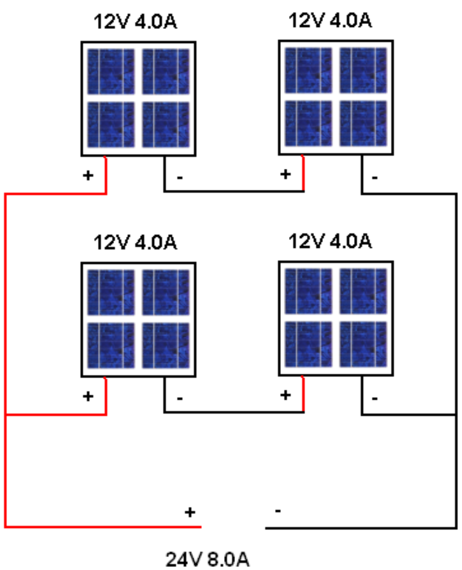
By series connecting gives higher voltage
Current remains same.

Parallel Connected Solar Panels



Parallel connected solar panels give more current (ampere)

Series and Parallel connecting solar panels

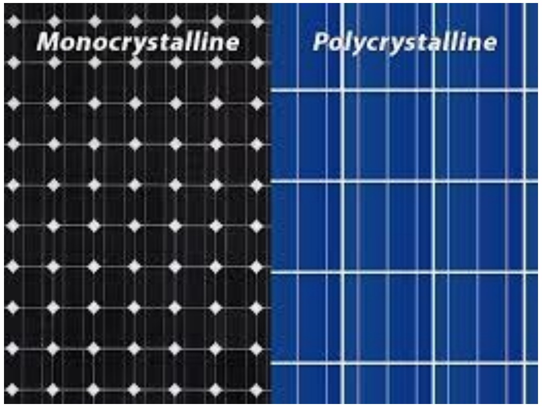


Series and Parallel connected Solar Panels gives higher voltage and higher current.

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

Roof-mounted commercial

Building integrated shingles

Building integrated walls

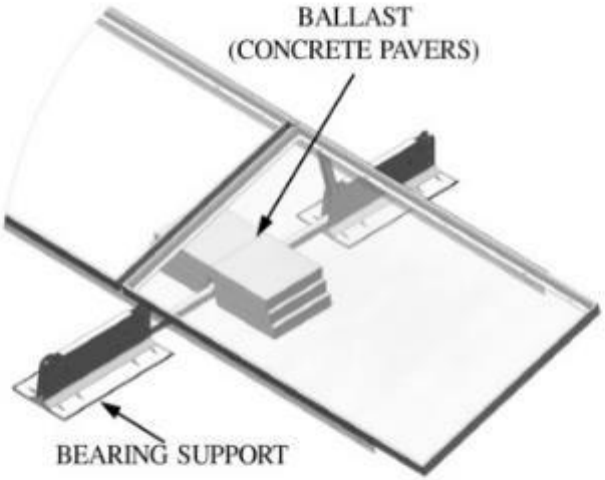
Typical pitched-roof mounting

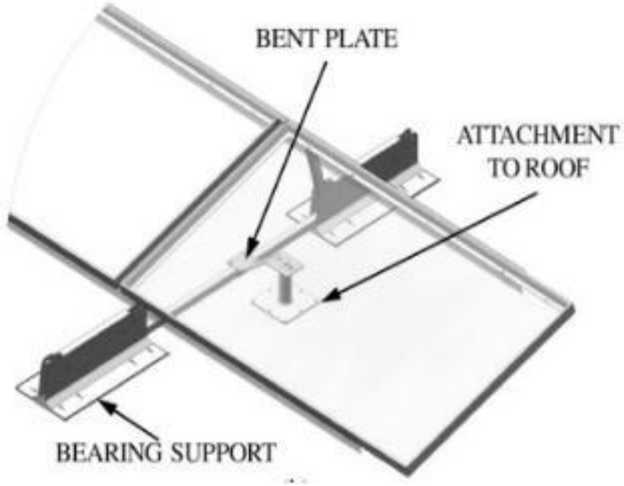
- Panels are secured using an aluminum racking system

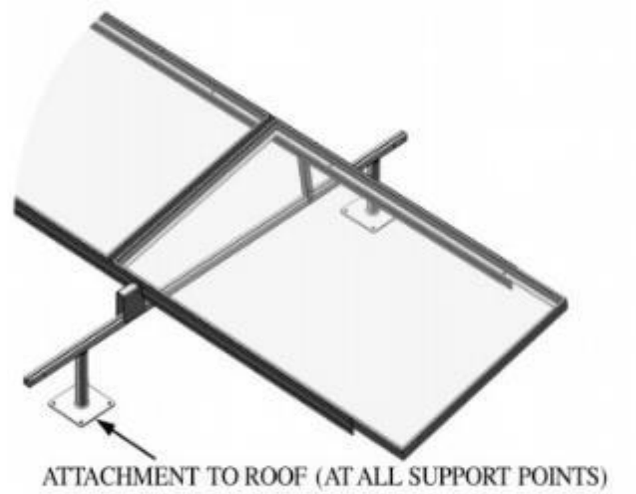
- Racking is secured to roof with lag screws drilled int structural rafters

- 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*
- <u>All types stop converting power when utility power shuts down</u>

Central Inverter System

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


SOLECTRIA
RENEWABLES
SOLECTRIA
RENEWABLES

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

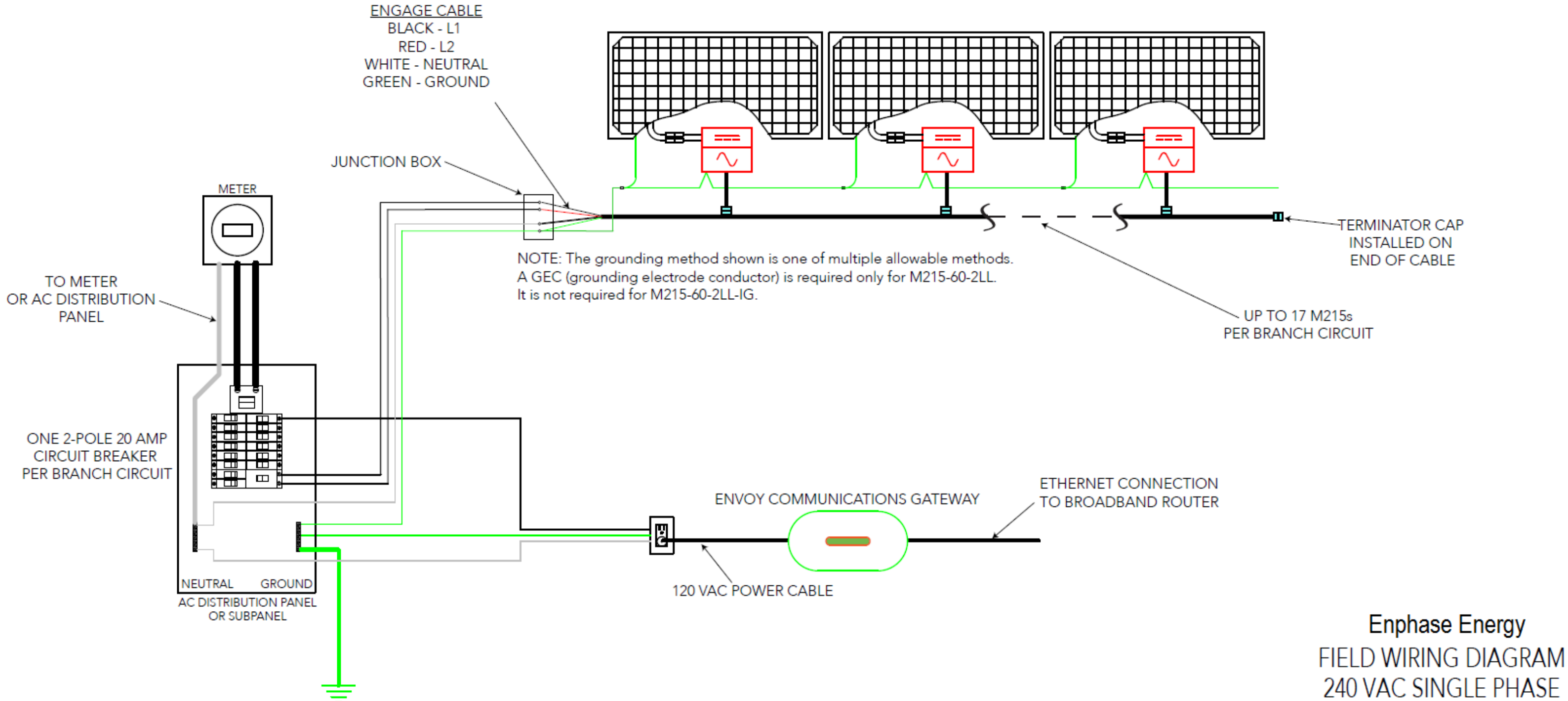

CELLAR
WARNING
ELECTRICAL SHOCK HAZARD
solaredge
PHOTOVOLTAIC SYSTEM
DISCONNECT
APA
532
WARNING
ELECTRICAL SHOCK HAZARD
PHOTOVOLTAIC SYSTEM
kWh METER


WARNING: PHOTOVOLTAIC POWER SOURCE
solaredge
ON
OFF
PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN
DC PHOTOVOLTAIC DISCONNECT
EATON
AC PHOTOVOLTAIC DISCONNECT
NSTAR UTILITY DISCONNECT
WARNING

Microinverter System

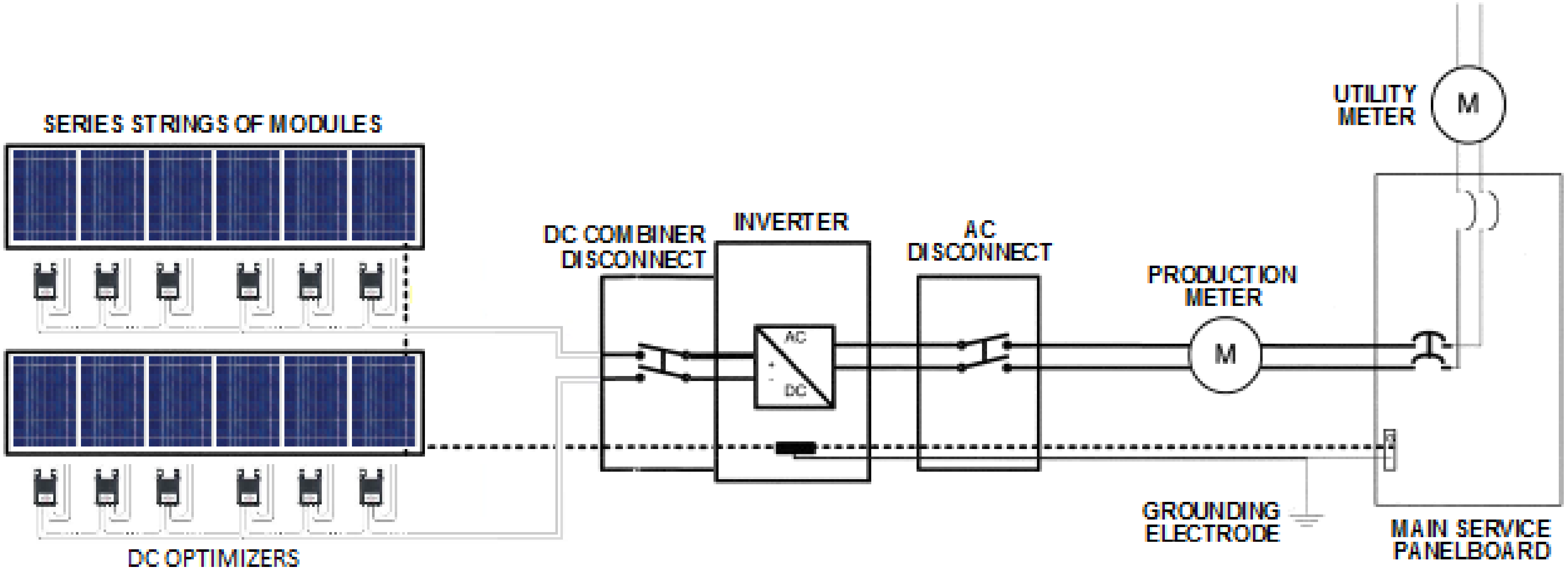
- Mini inverter under each module
- Most-common type for residential rooftop systems
- Typically not found on large commercial systems
- Minimum DC exposure

Utility-Interactive AC (Microinverter) System




Courtesy of Newport Solar

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

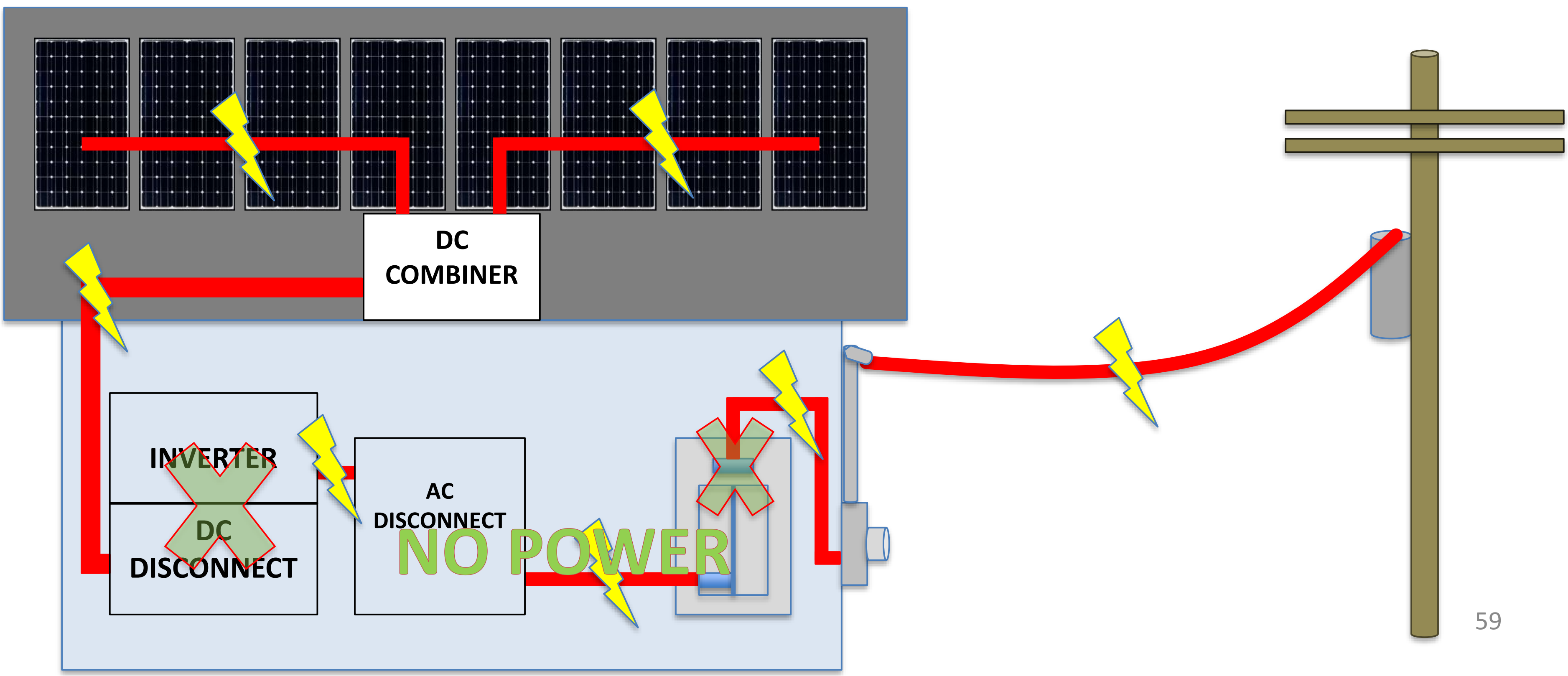
PV systems may contain a production meter in addition to the existing utility meter

Data Acquisition Systems (DAS)

Larger PV systems may contain a DAS, that will remotely monitor power production.

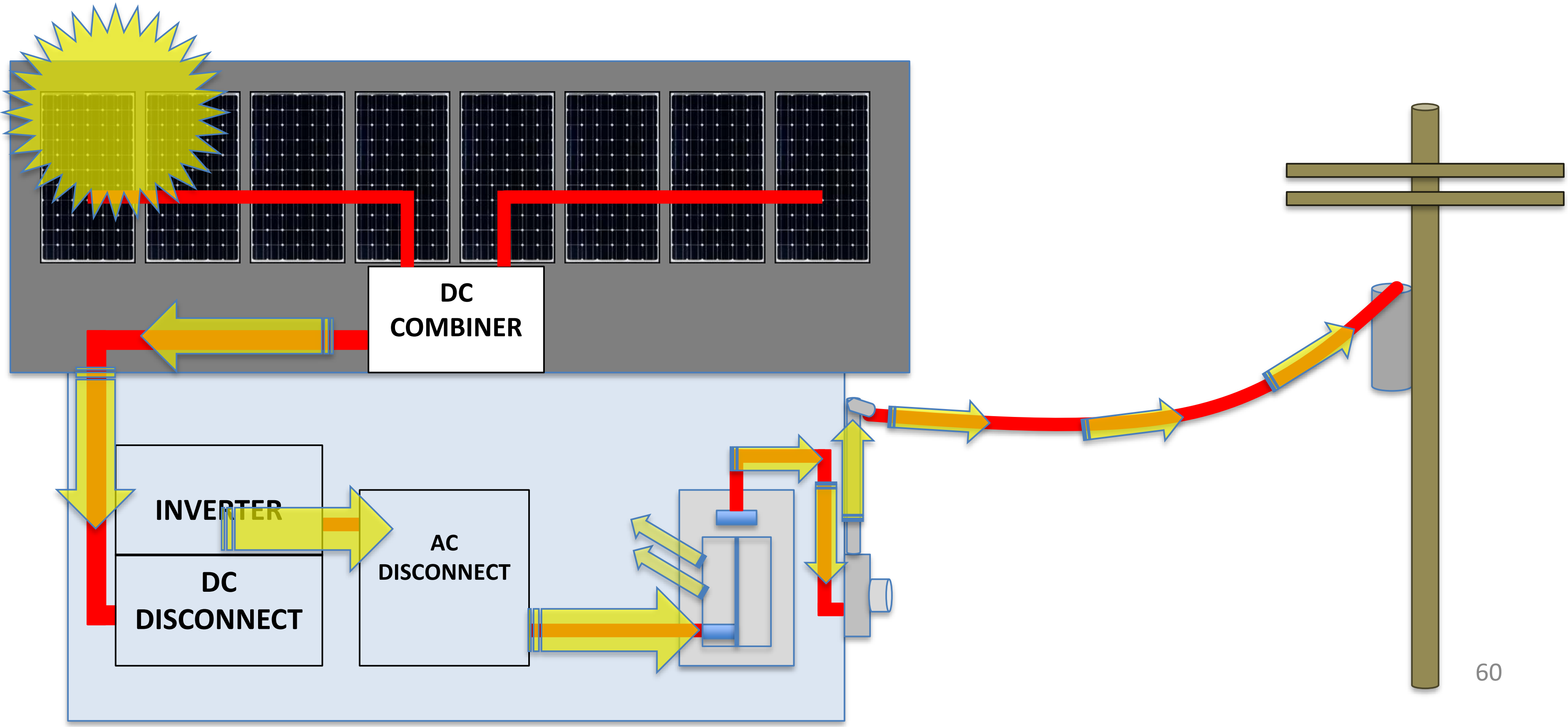
PV System Operation

- 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 <u>today</u> **do not contain batteries or energy storage**



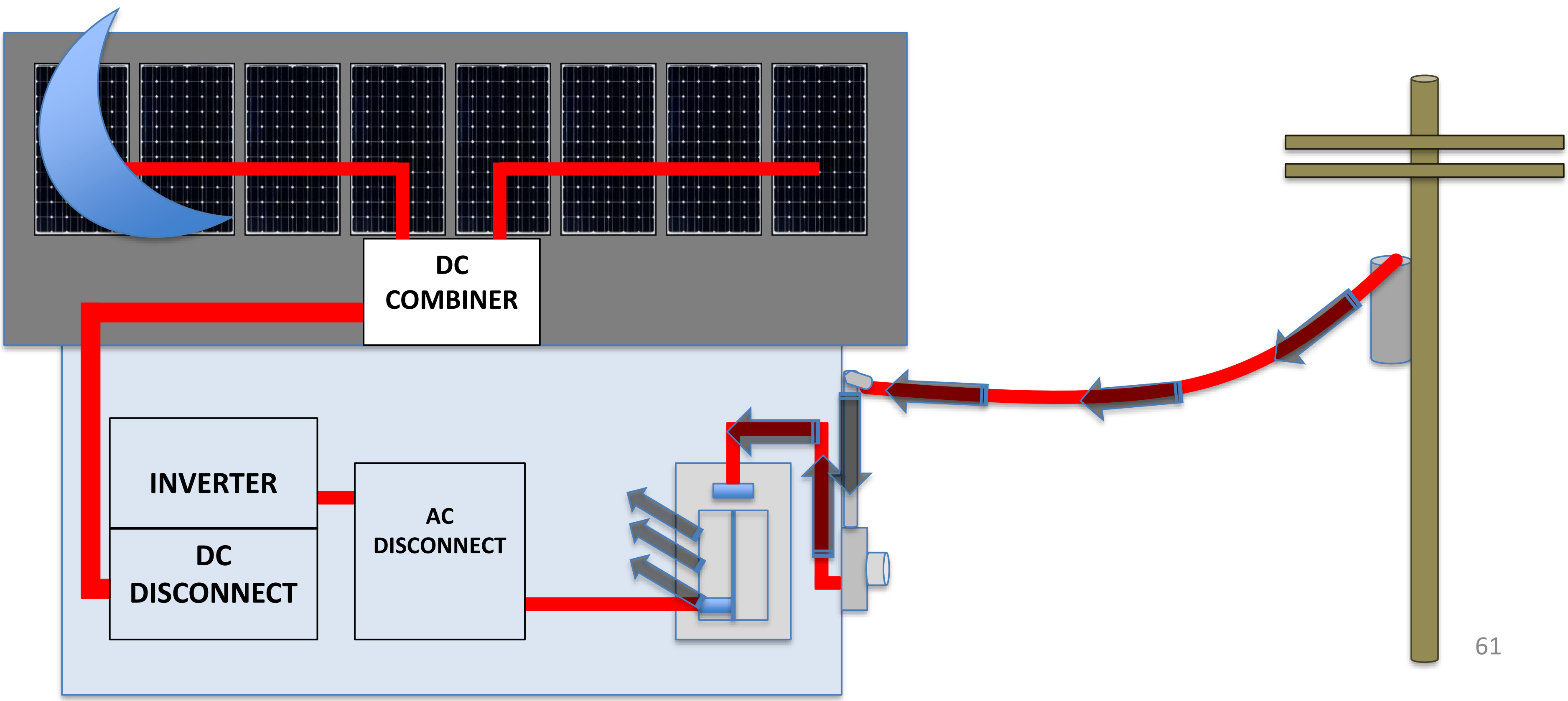
PV System Operation

- 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

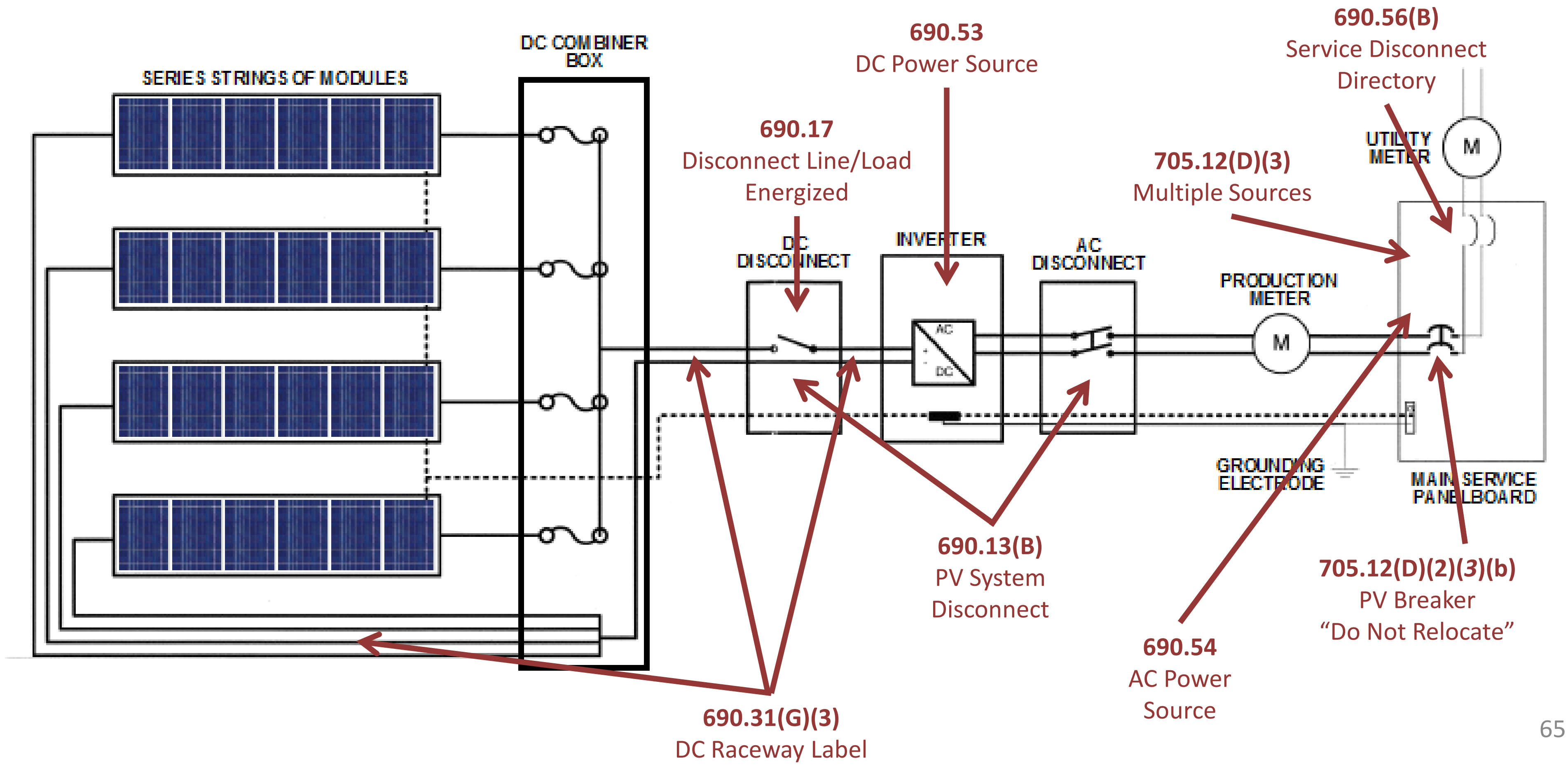
PV system battery hazards

- 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

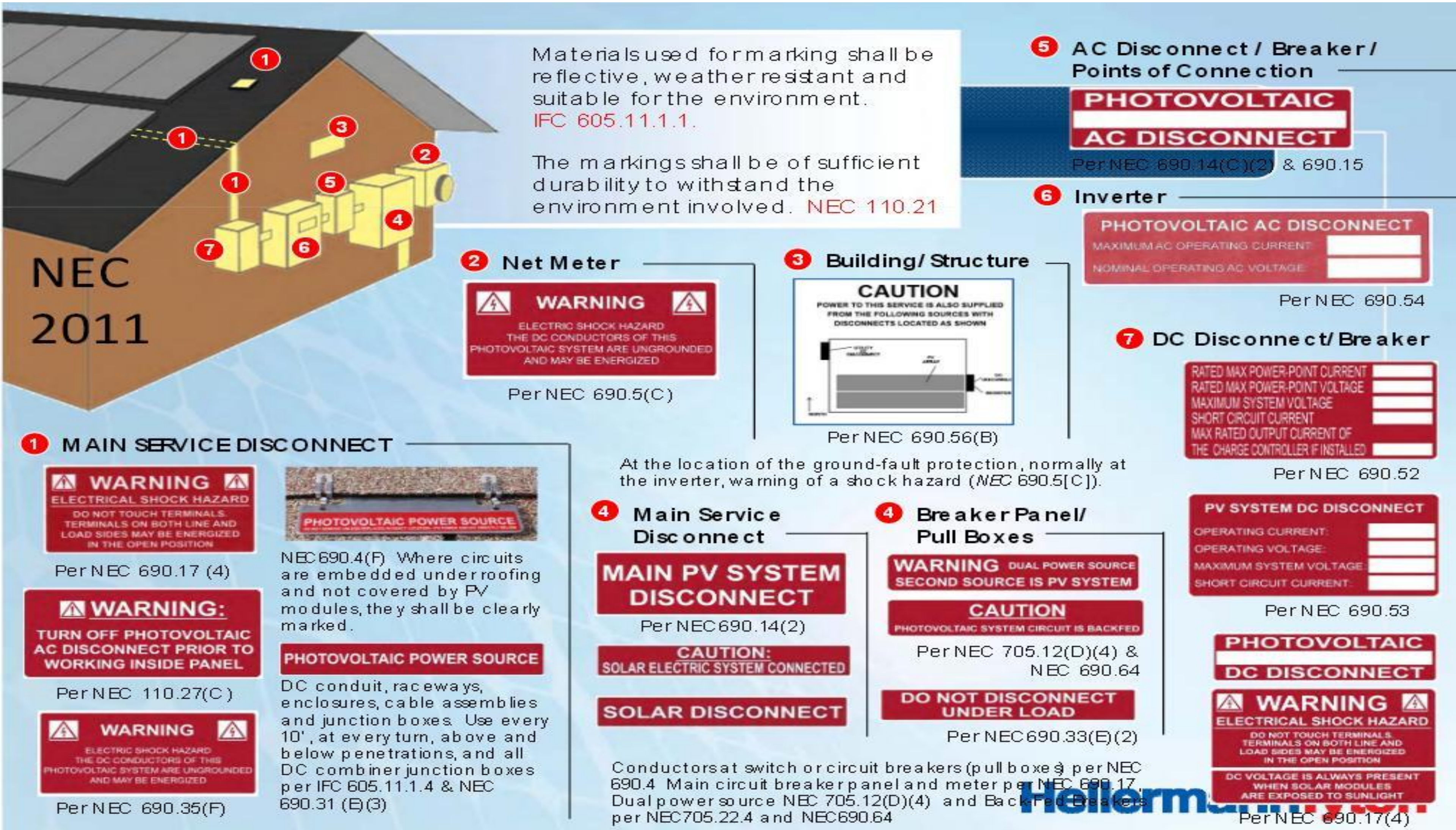
PV System Common Labels



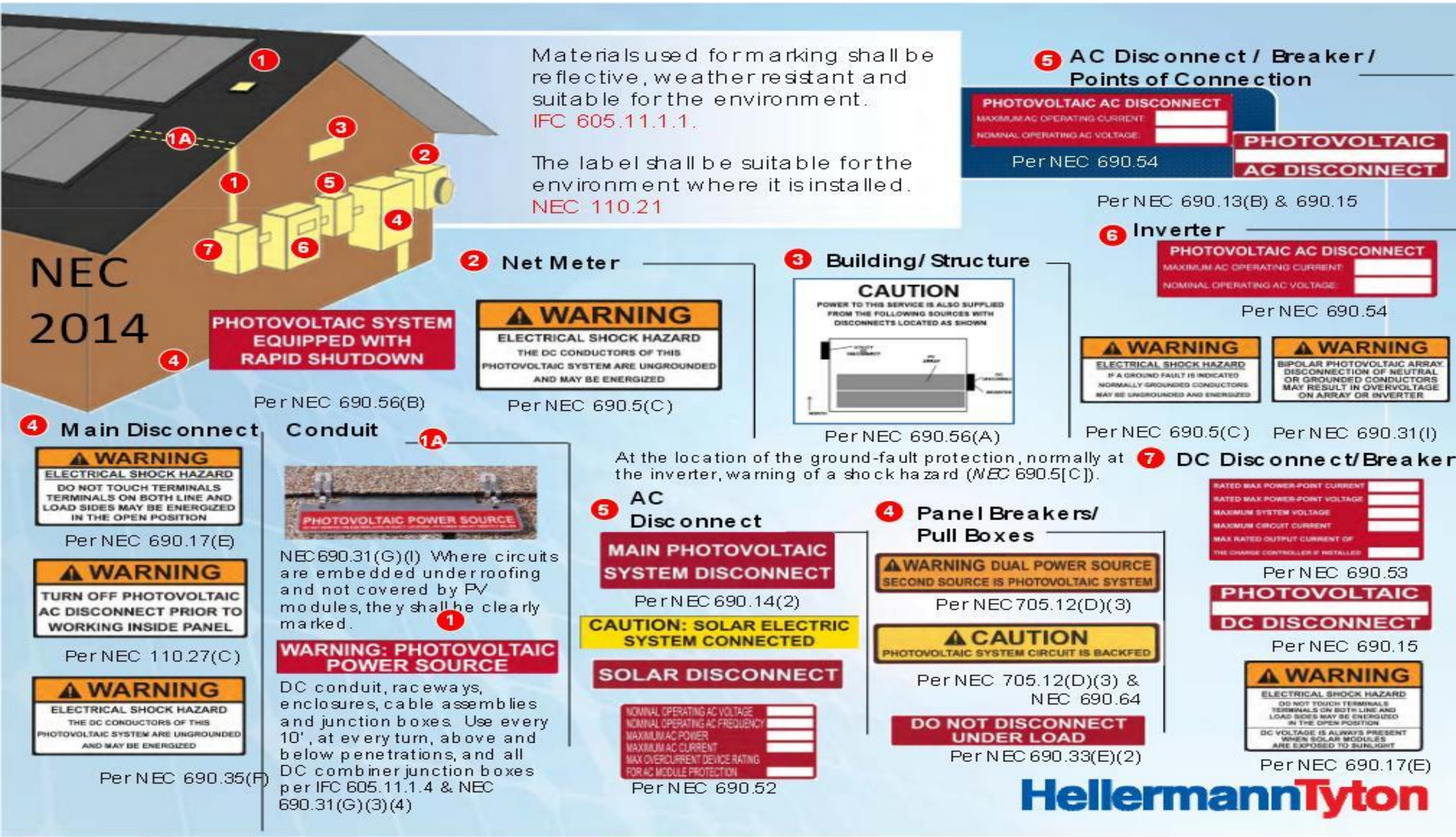
PV System Labeling



PV System Labeling



PV System Labeling



DC Raceway Label

NEC Article 690.31(G)(3)

- On or inside a building

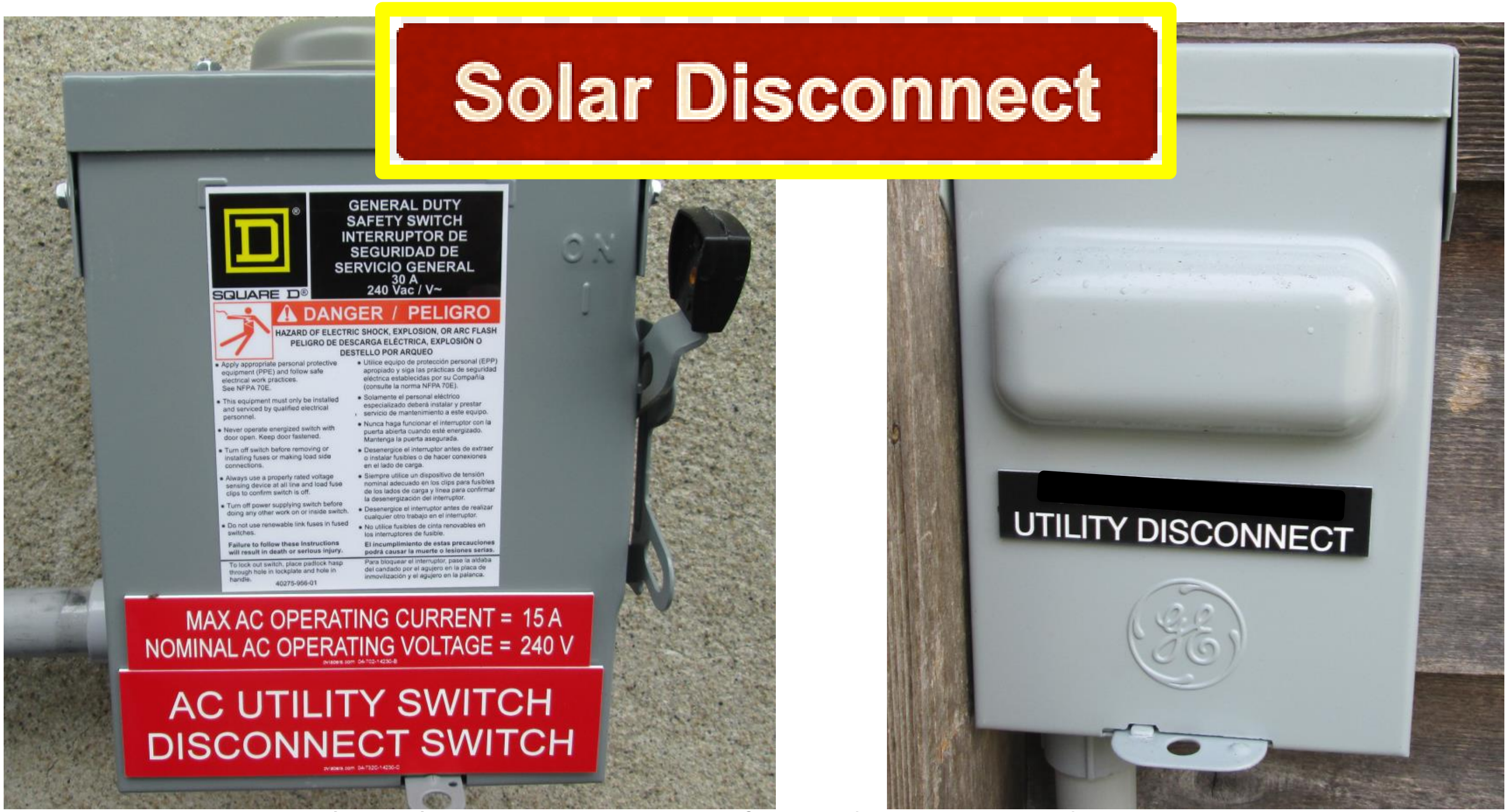
WARNING:
PHOTOVOLTAIC POWER SOURCE

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

Required on all DC raceways, every 10 feet.

PV System Disconnect

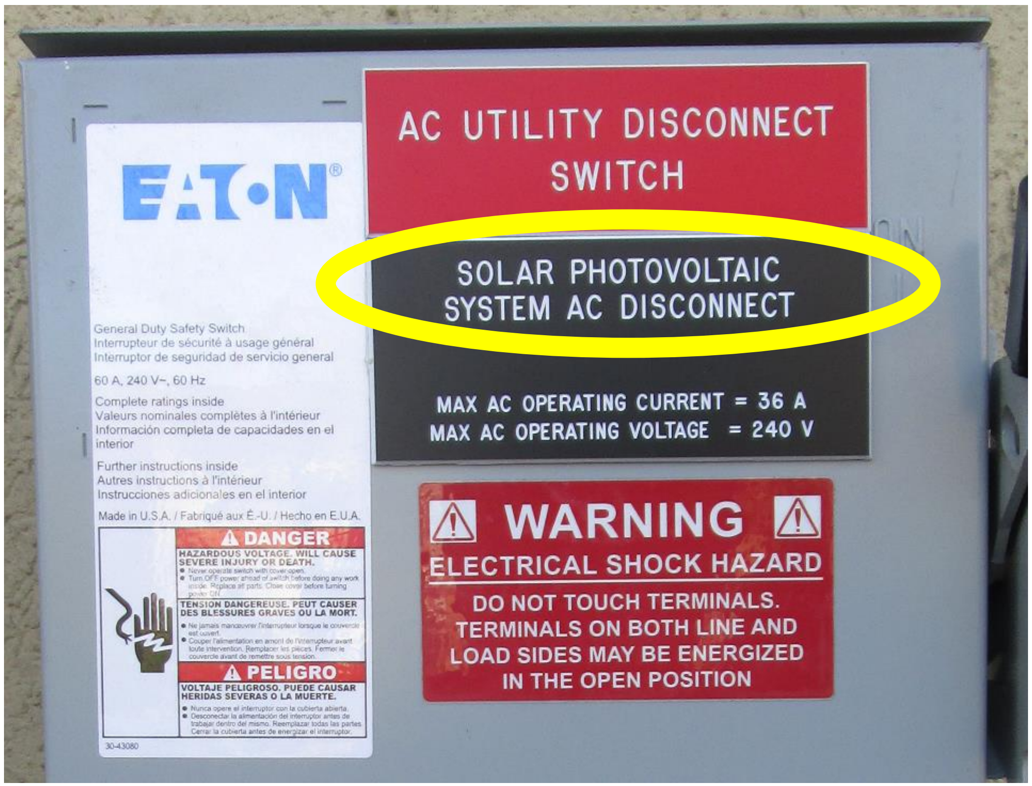
NEC Article 690.13(B)



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 <u>Service Disconnect</u>.

PV System Disconnect

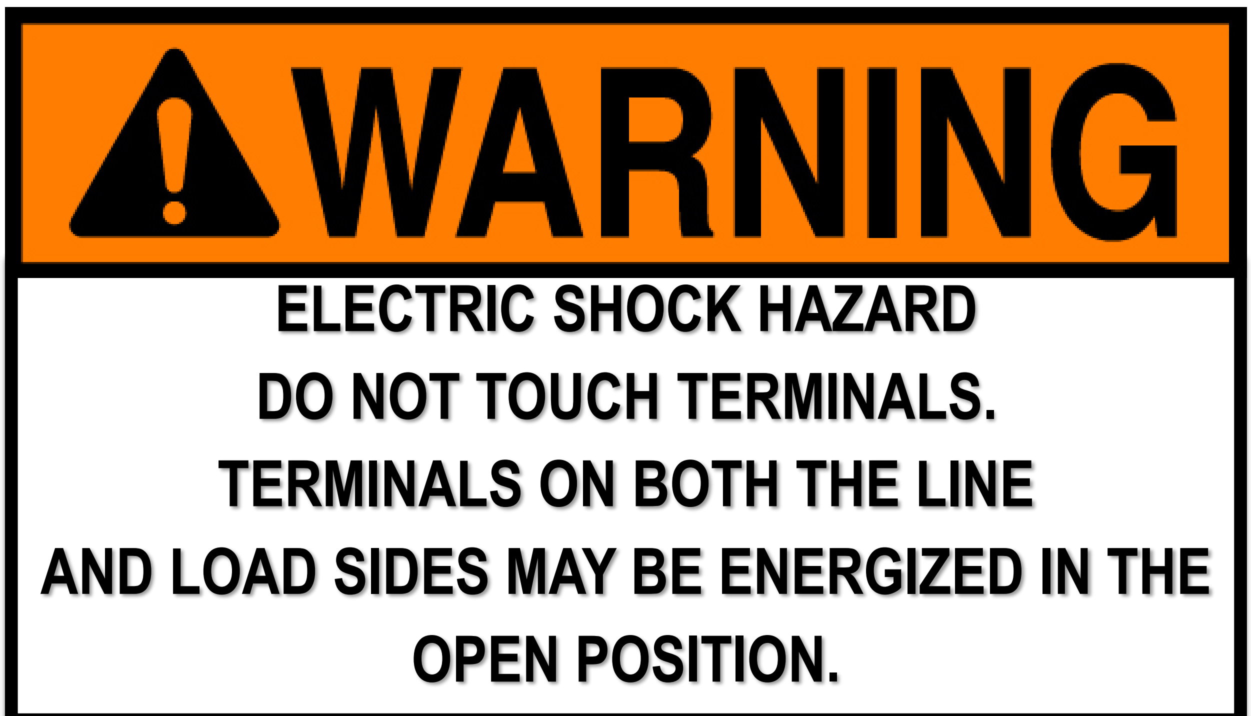
NEC Article 690.13(B)



The correct way: Label identifying disconnect as Solar PV disconnect.

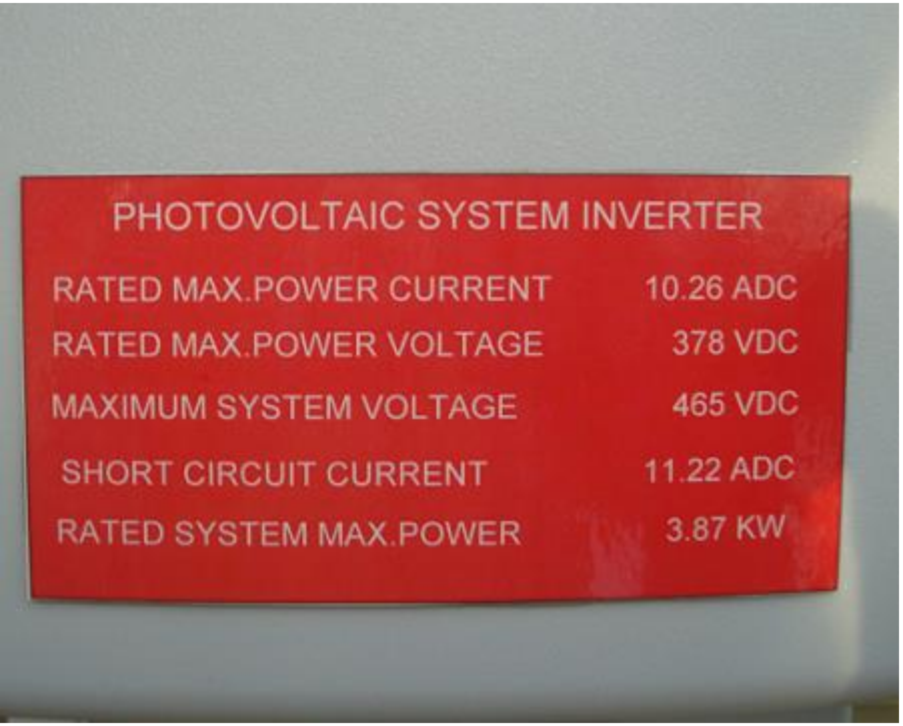
Disconnect Line/Load Energized

NEC Article 690.17(E)



DC Power Source

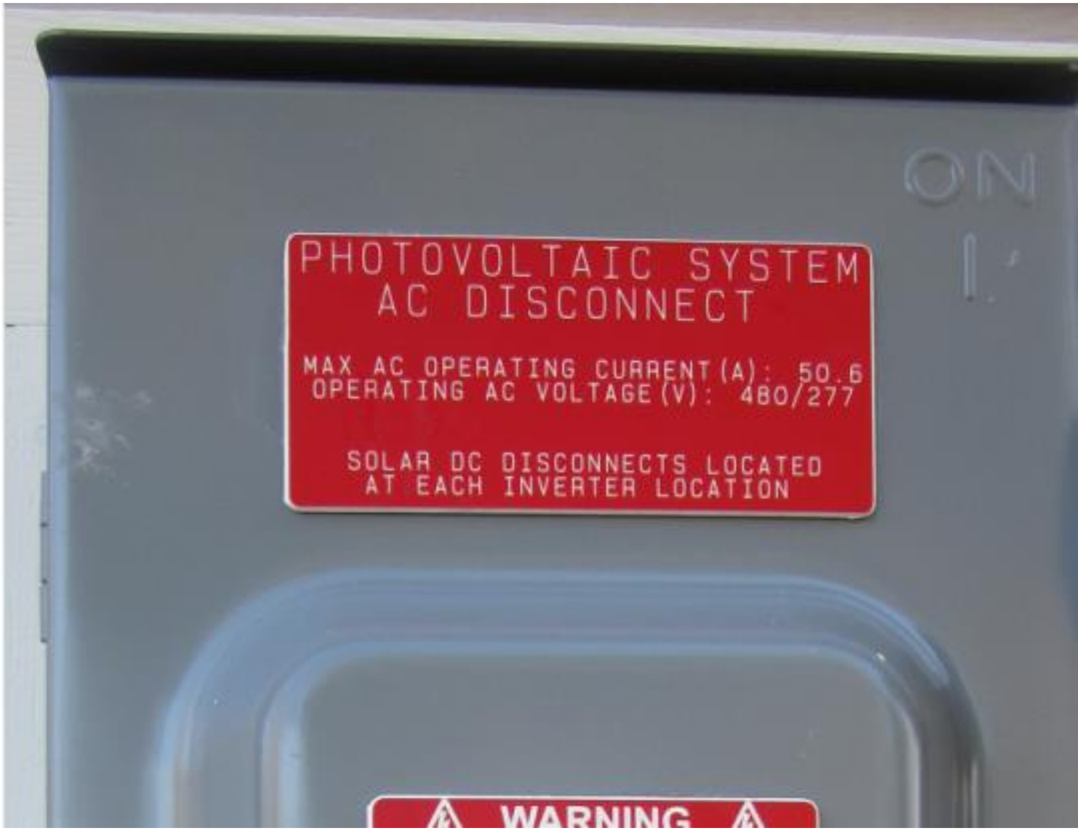
NEC Article 690.53



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.

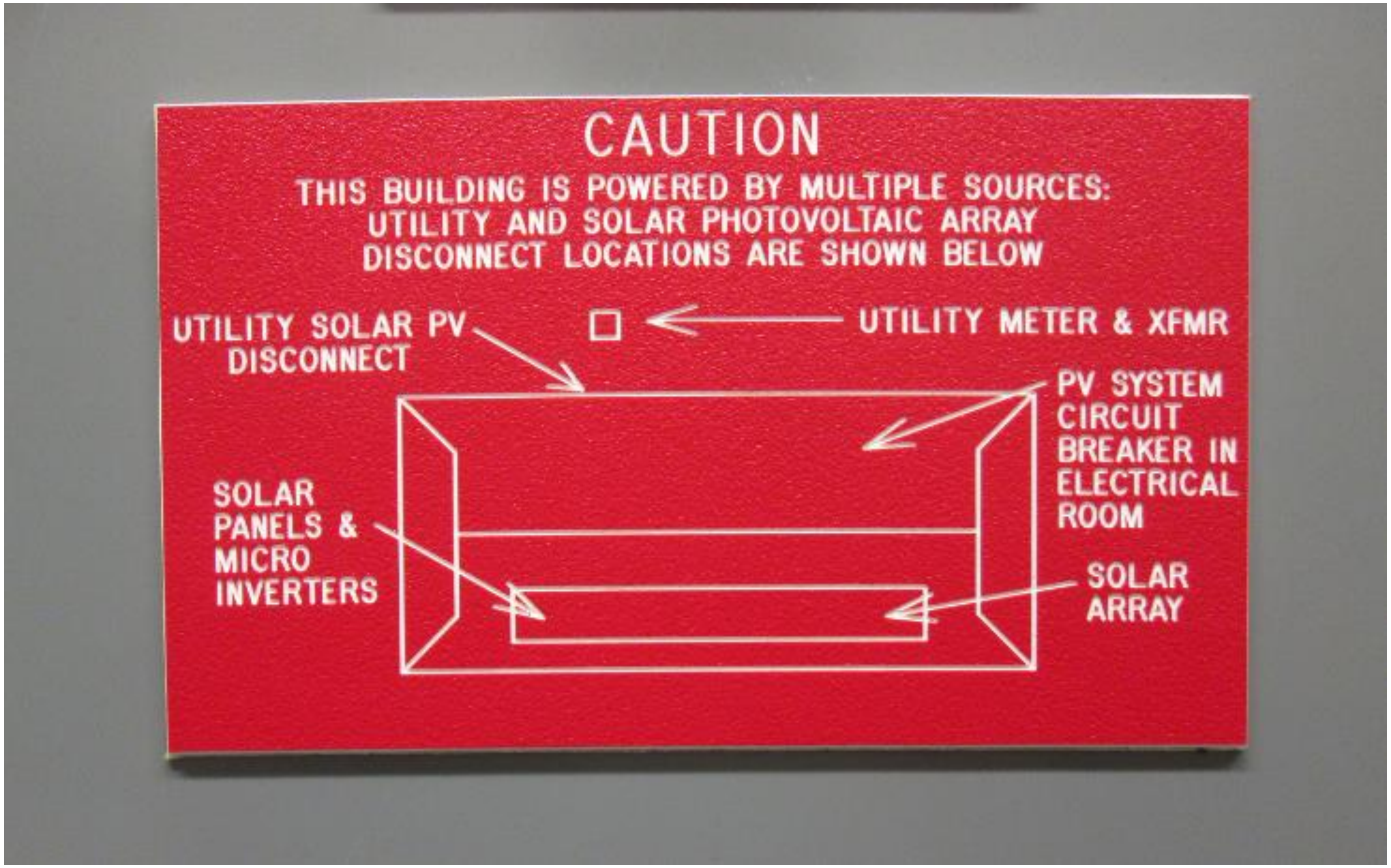
AC Combiner Panel

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

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

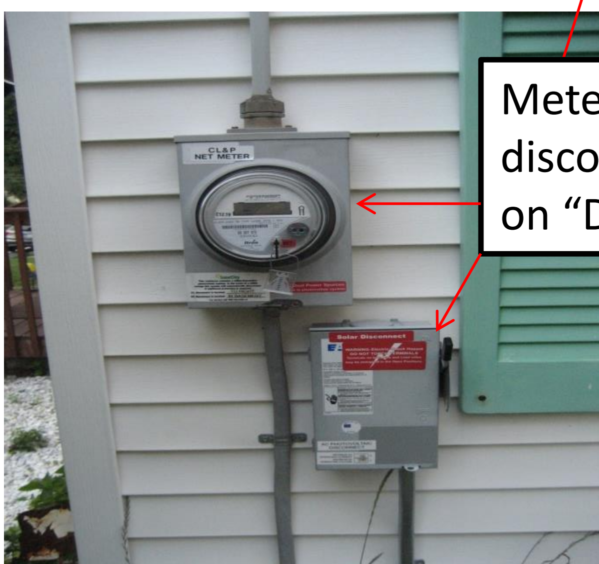
Planning, Size Up, and Tactical Considerations

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

Array installed right up to ridge line with no setbacks, will not allow roof ladder hooks to sit on roof



Meter and AC disconnect located on “D” side

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

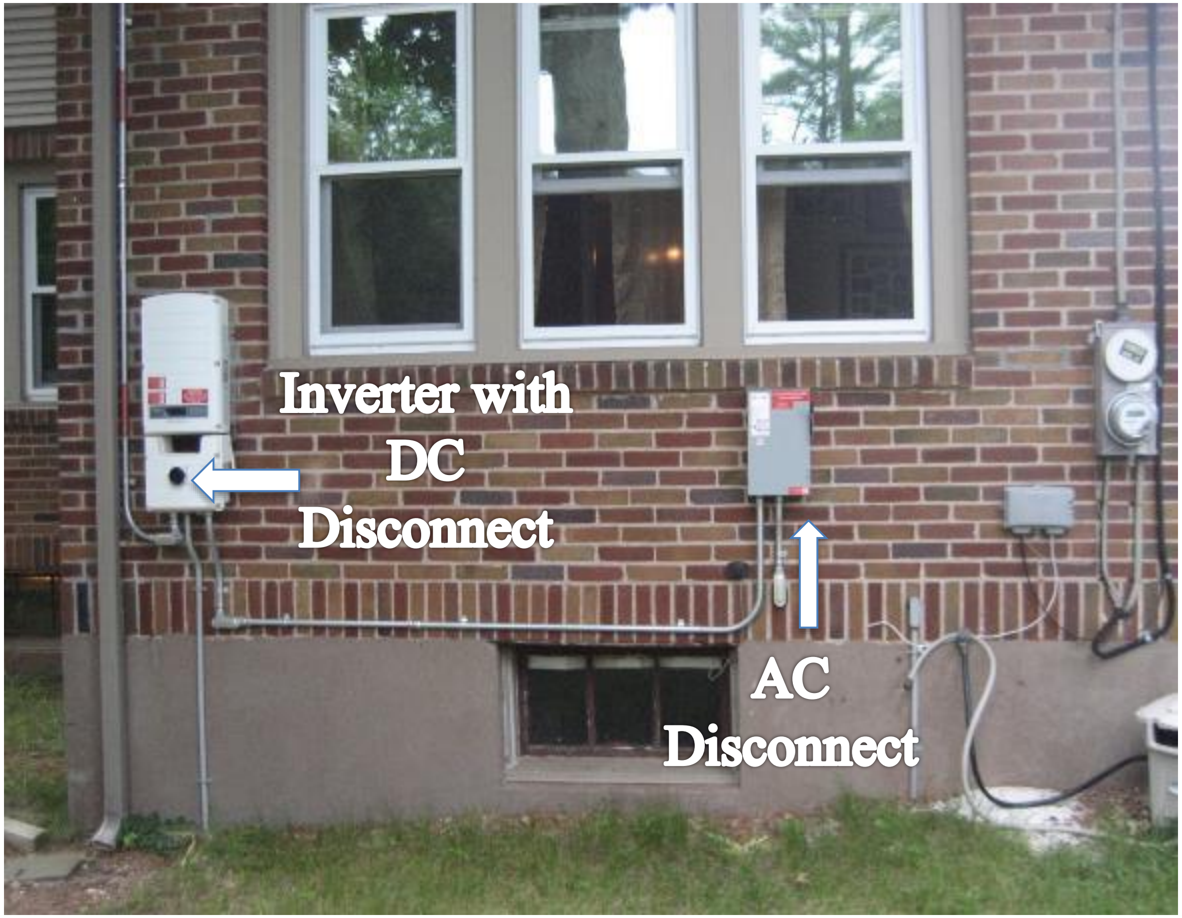
- Utilize LOTO procedures when disconnects or other power sources are secured

- This is <u>NOT</u> DIY work!

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

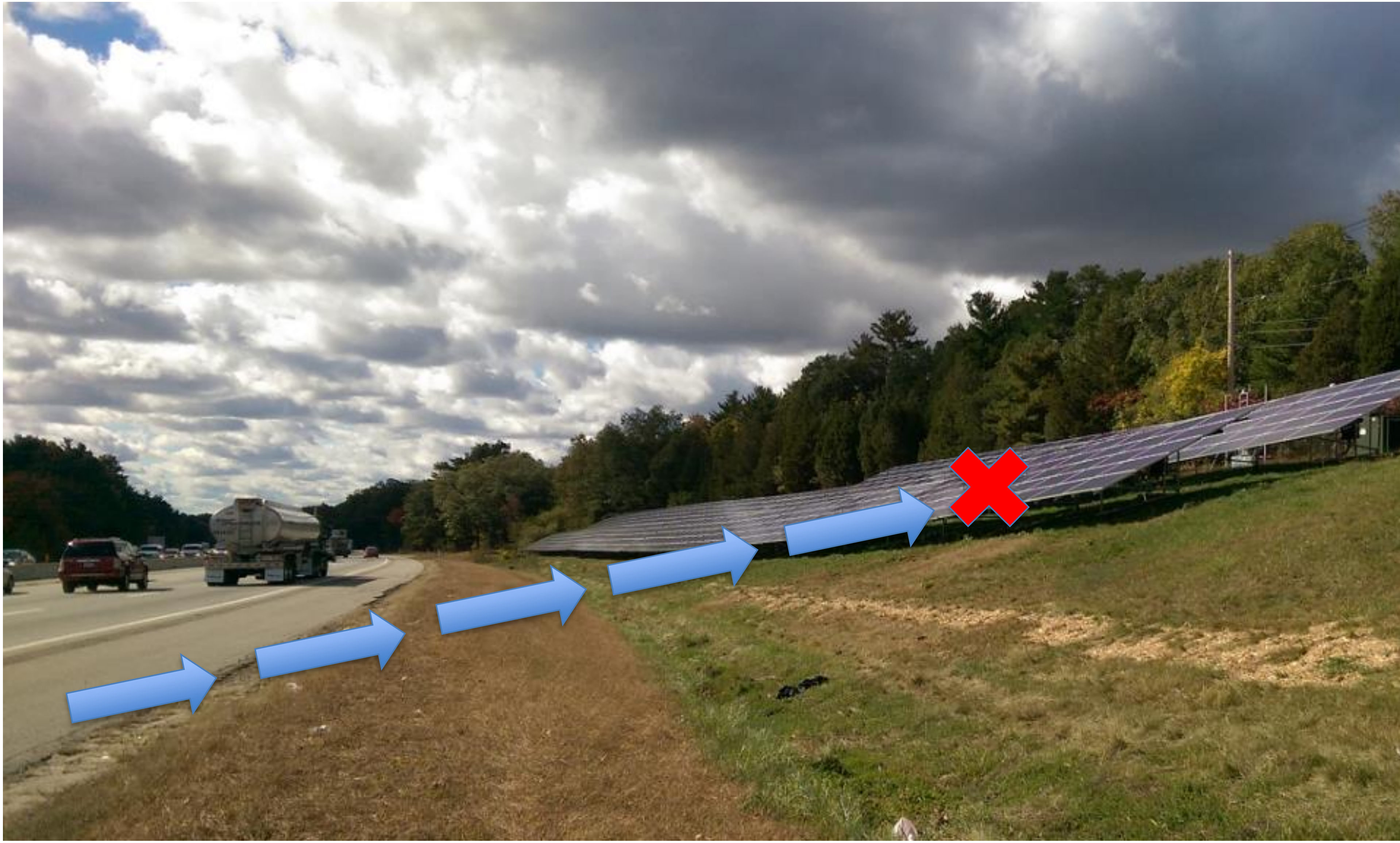
- Labeling may or may not be present or legible

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

Firefighter Safety and Photovoltaic Systems

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

Table 17 Results of experiments with tarps

Tarp #	Cost	Tarp	Color	Layers	Open Circuit Volts	Short Circuit Amps	Hazard
1	$15	4.0 mil plastic film	Black	1	33	0	Safe
2	$16	5.1 mil all purpose plastic	Blue	1	126	2.1	Electrocution
3	$78	Fire Salvage Canvas	Green	1	3.2	0	Safe
4	$94	Fire Salvage Heavy Vinyl	Red	1	124	1.8	Electrocution
		Full Sun			148	8.1	

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

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

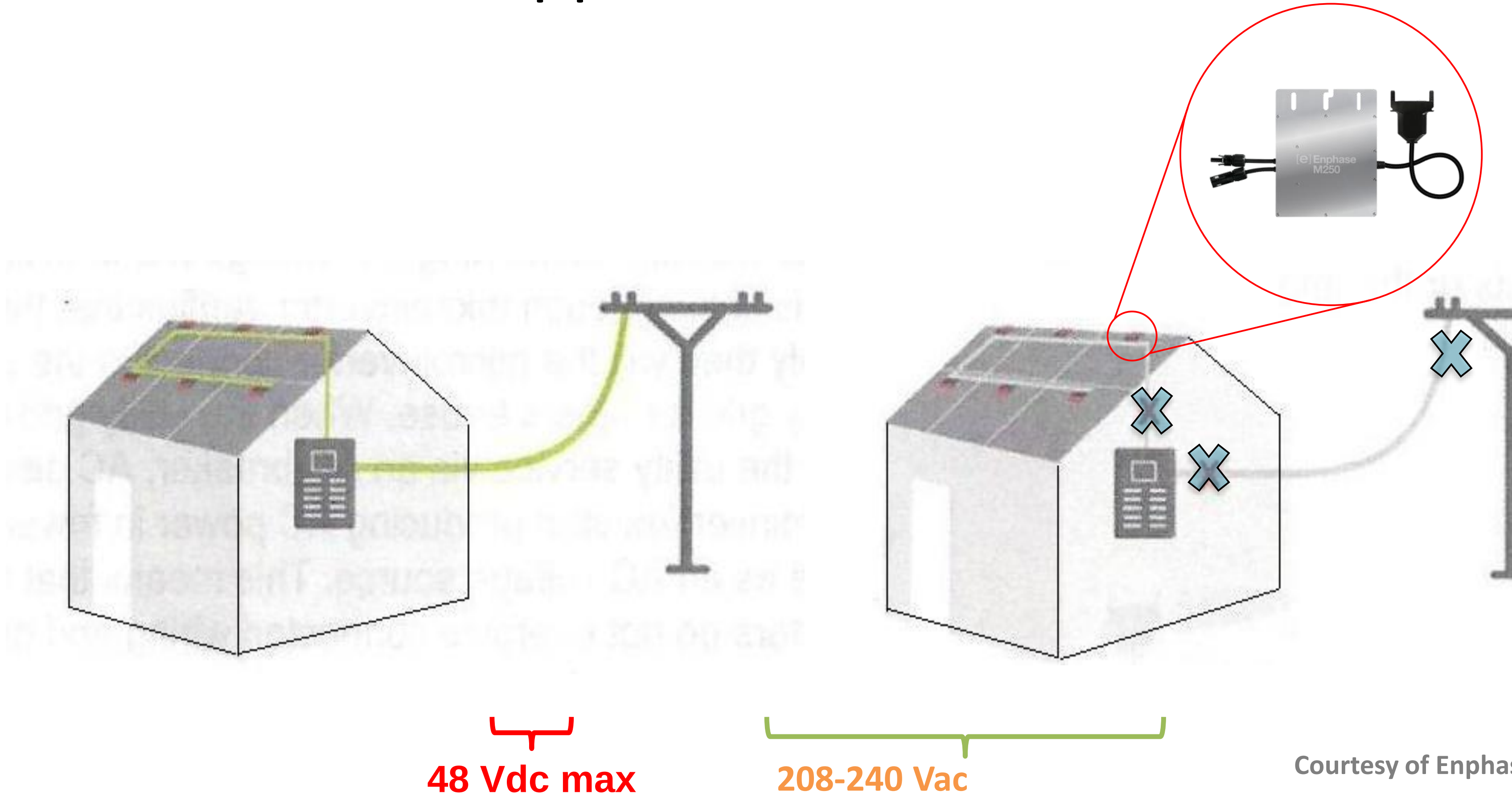
- <u>May</u> be effective method to de-energize system
- Various system types
  - Some disconnects DO NOTHING
  - Can be in multiple locations

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

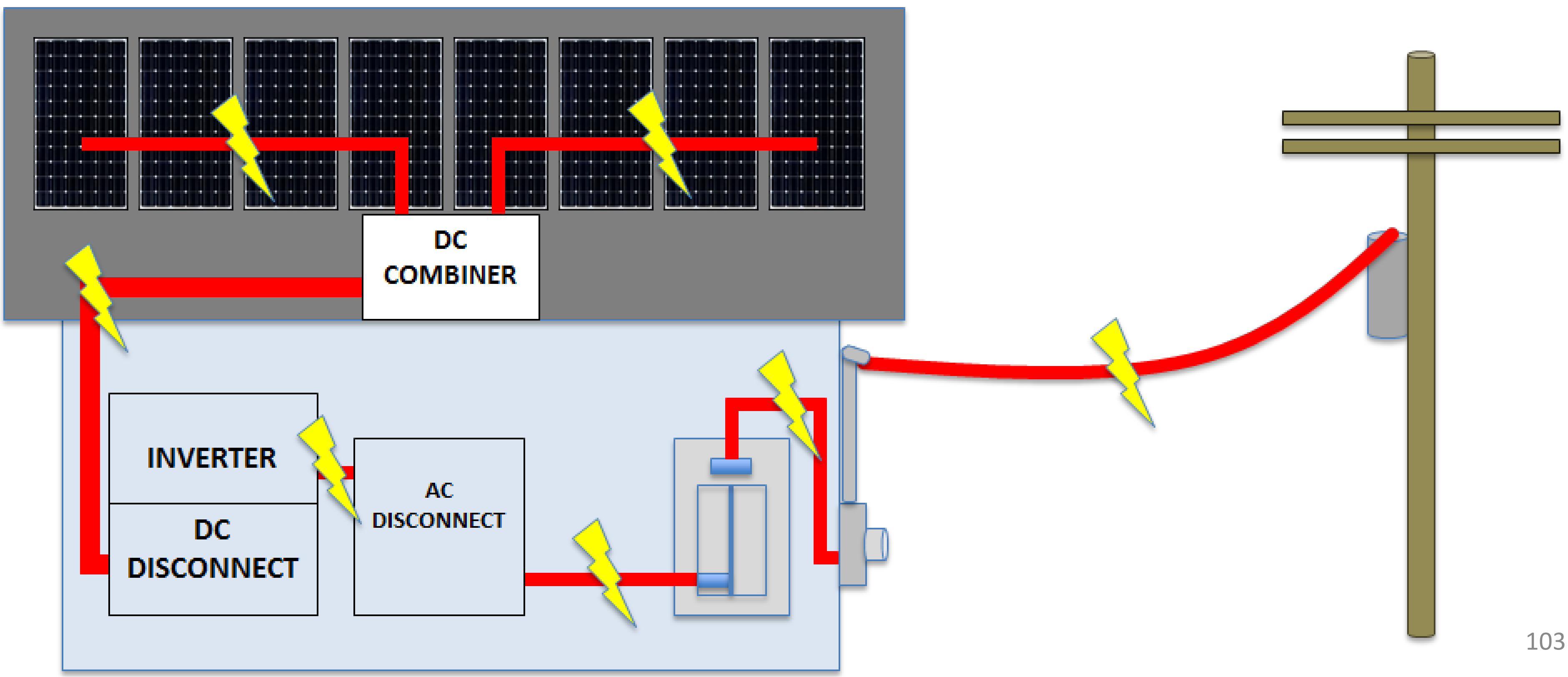
AC Microinverter System

- What will happen if I shut off the main?



Courtesy of Enphase Energy

Central Inverter System
(Most Common)



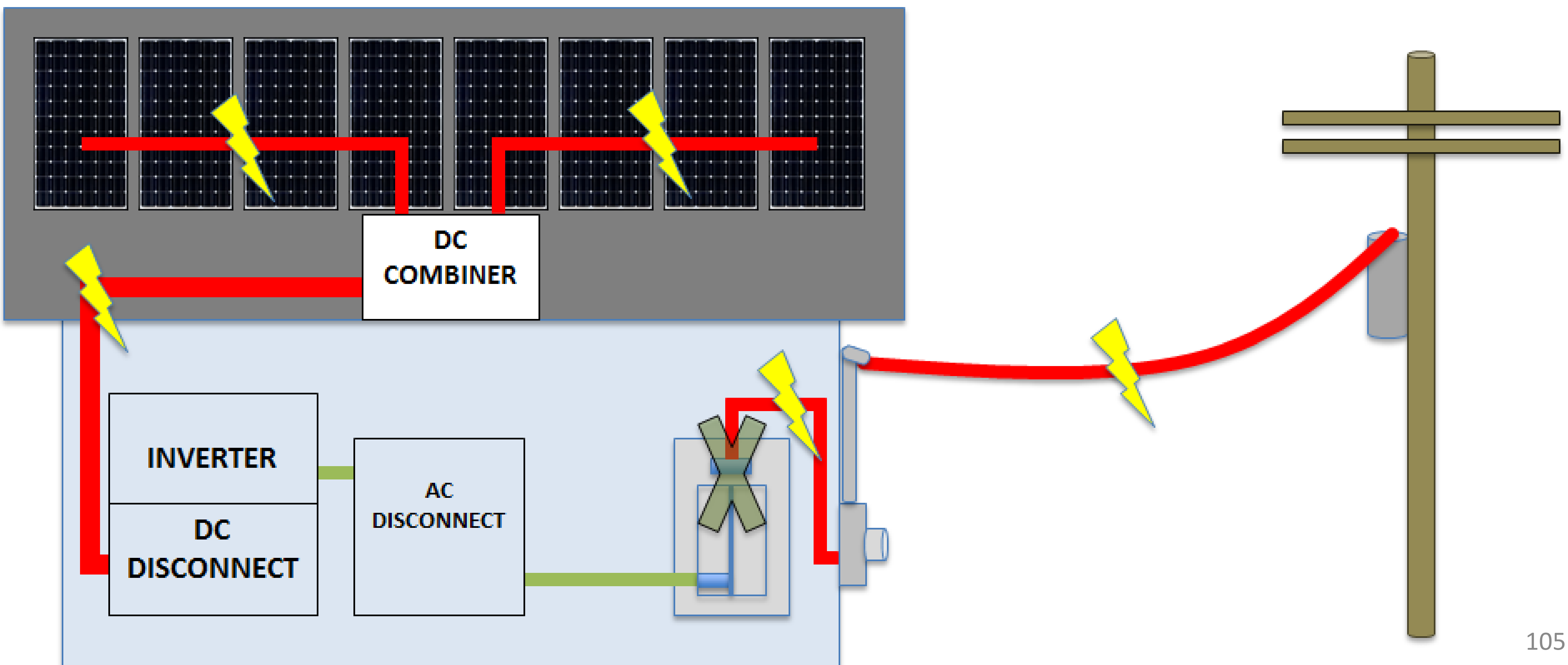
Central Inverter System
(Most Common)

- 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.

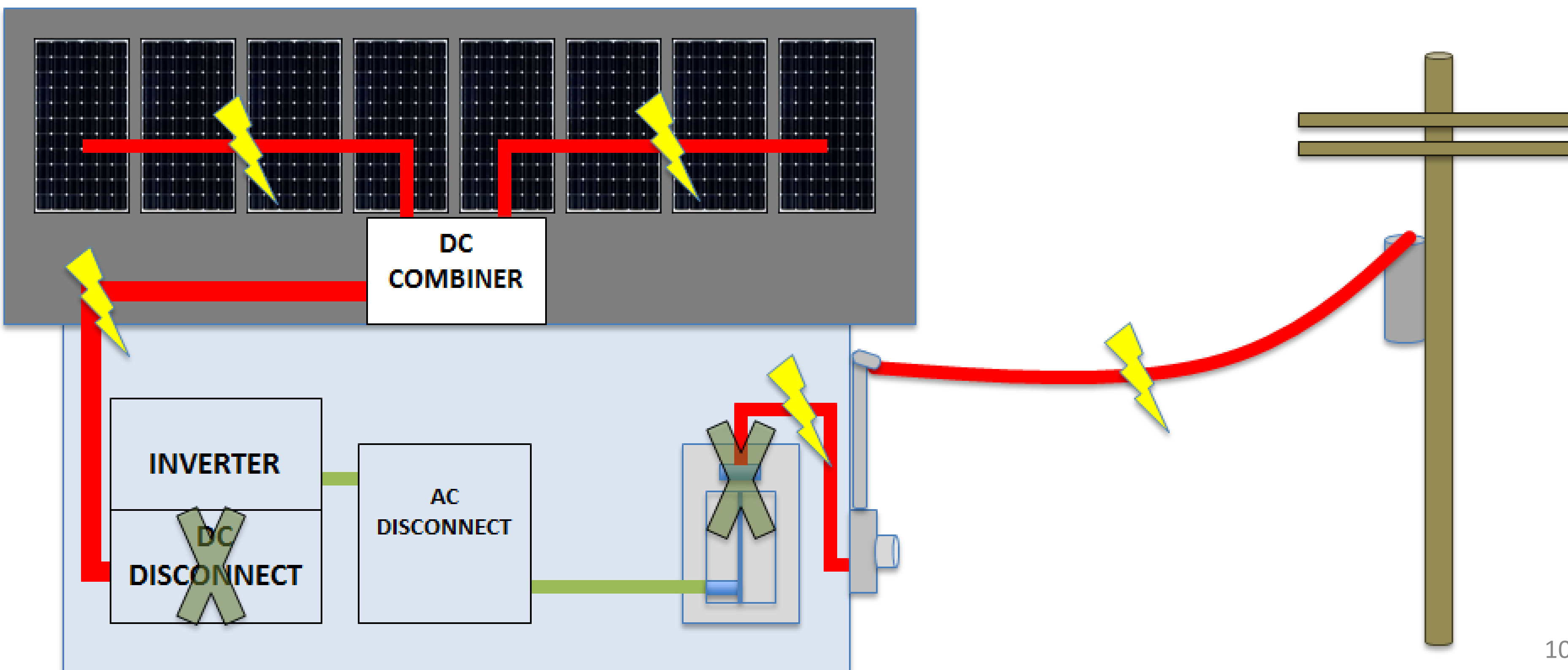
Central Inverter System
(Most Common)

- What will happen if I shut off the main?
  - *AC circuits throughout building will be de-energized if PV breaker is in main panelboard*



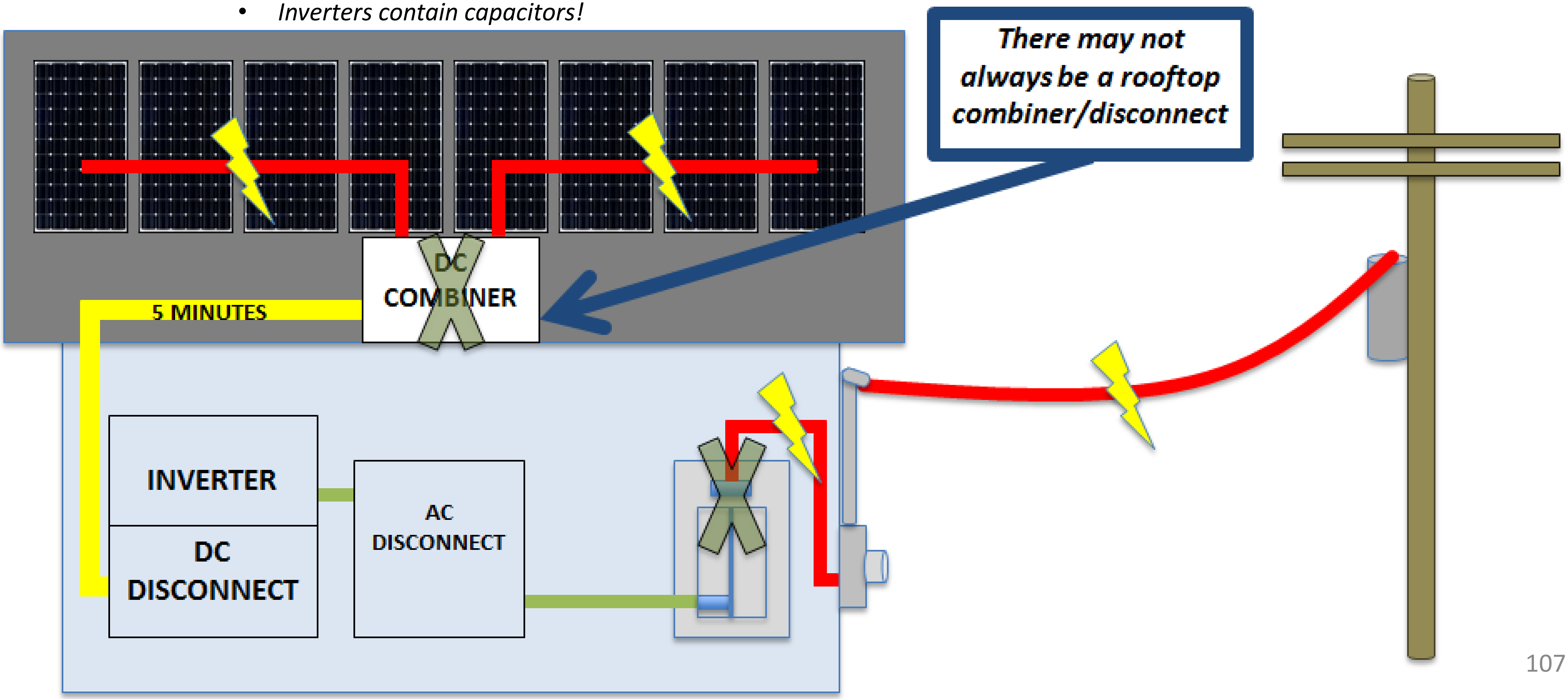
Central Inverter System
(Most Common)

- 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*



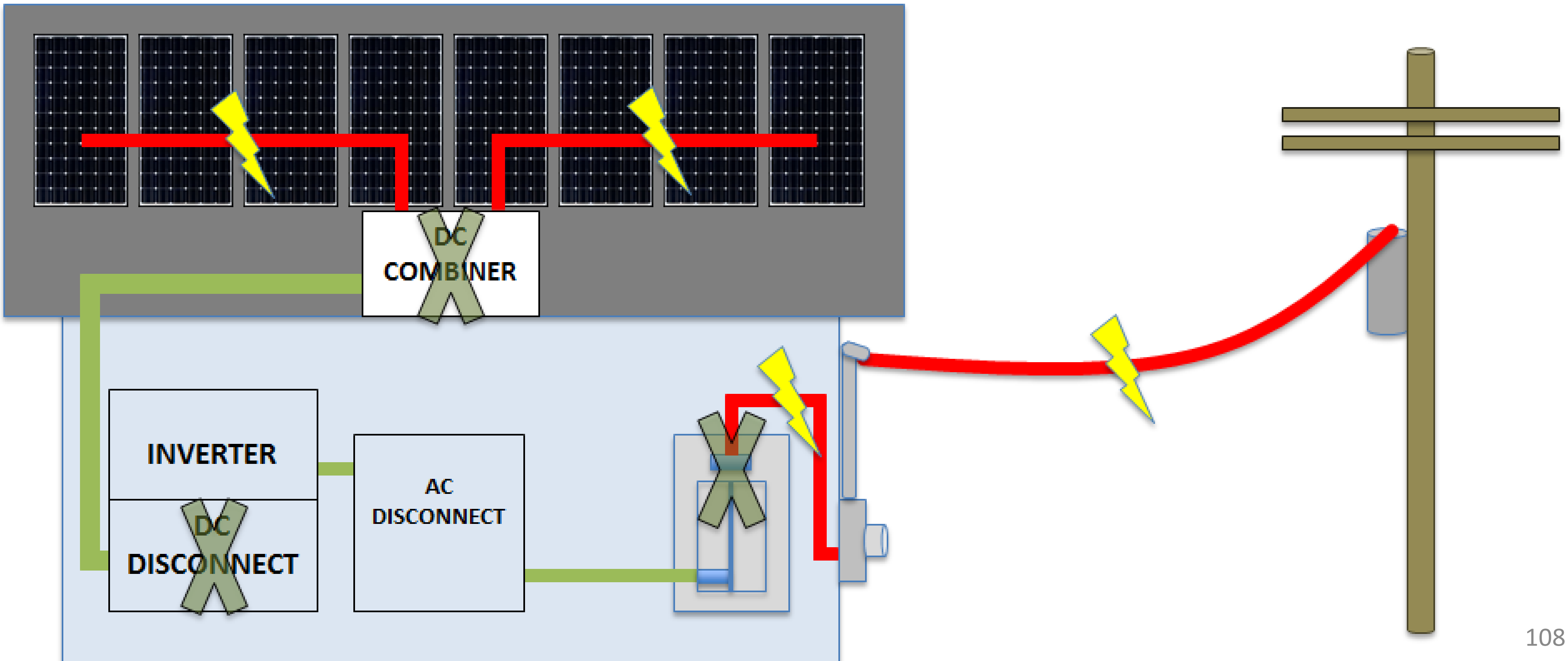
Central Inverter System
(Most Common)

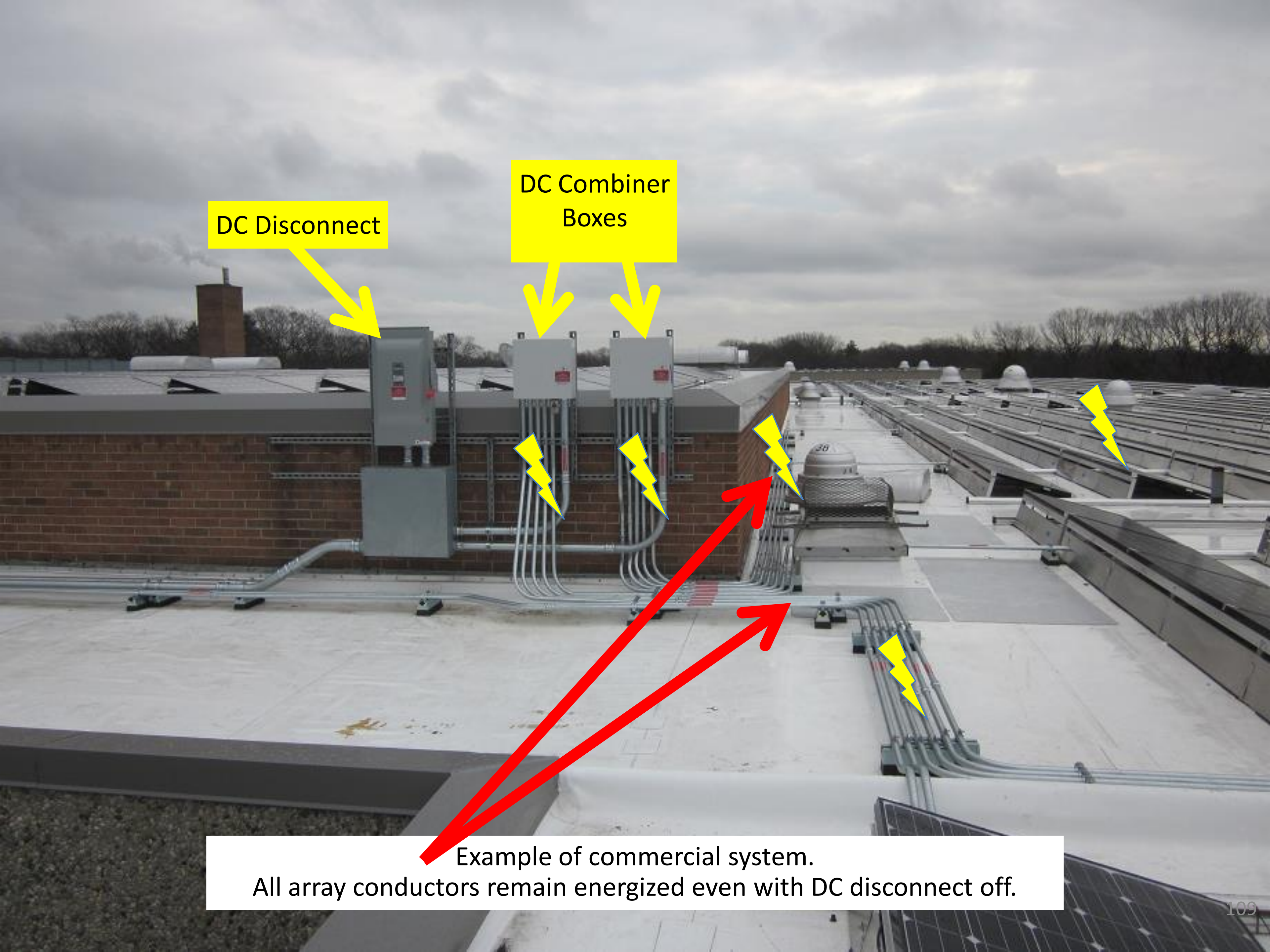
- What will happen if I shut off the main and DC combiner disconnect?
  - *AC circuits throughout building will be de-energized if PV breaker is in main panelboard*
  - *DC between inverter and combiner may be de-energized in 5 minutes*
    - *Inverters contain capacitors!*



Central Inverter System
(Most Common)

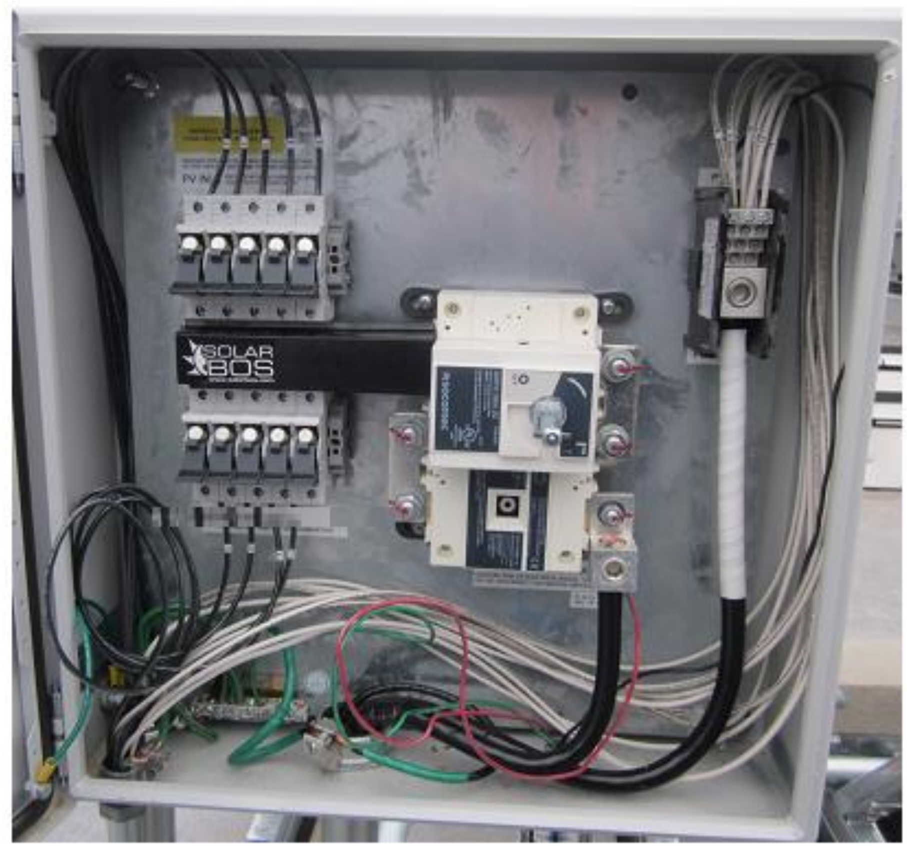
- What will happen if I shut off the main, DC, and DC combiner disconnects?
  - *AC circuits throughout building will be de-energized if PV breaker is in main panelboard*
  - *All DC conductors between inverter and DC combiner will be de-energized*
    - *Array conductors still energized*





DC Disconnect
DC Combiner Boxes
Example of commercial system.
All array conductors remain energized even with DC disconnect off.

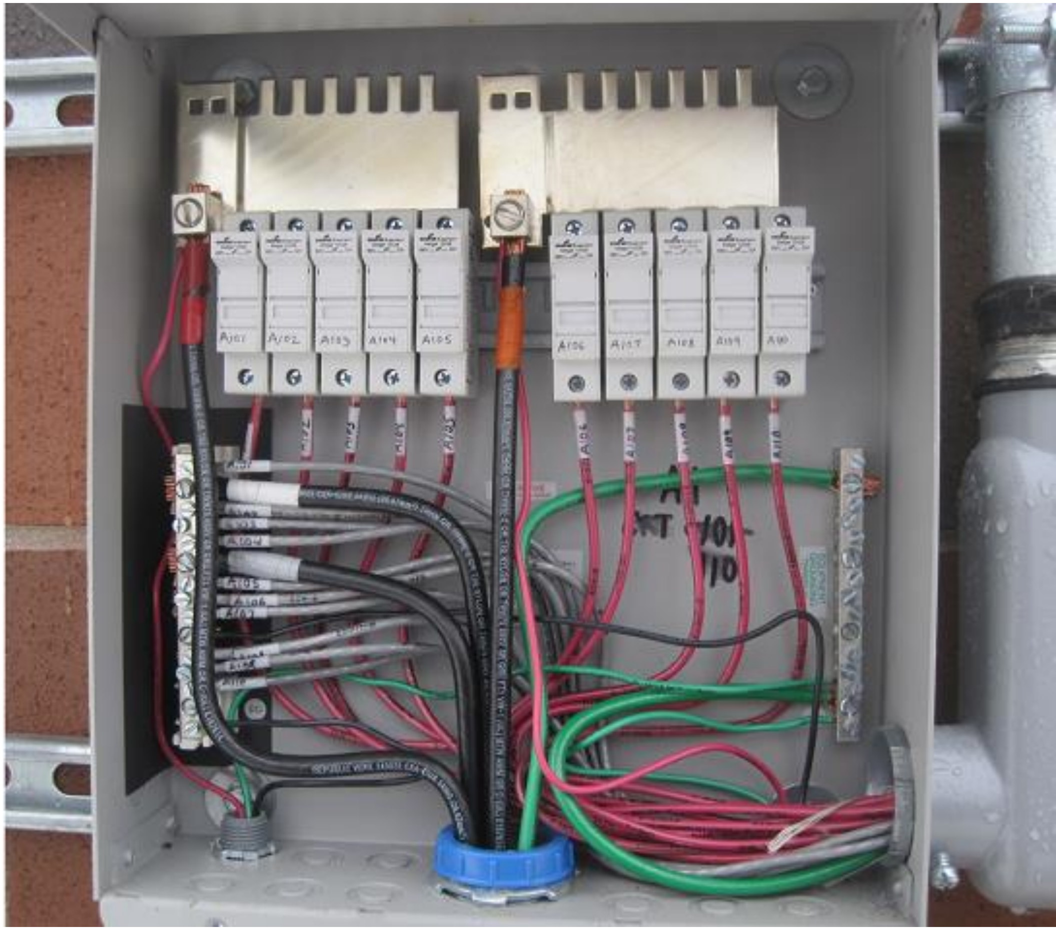
Combiner Box with DC Disconnect



Combiner Boxes with DC Disconnects

Combiner Boxes, No Disconnects

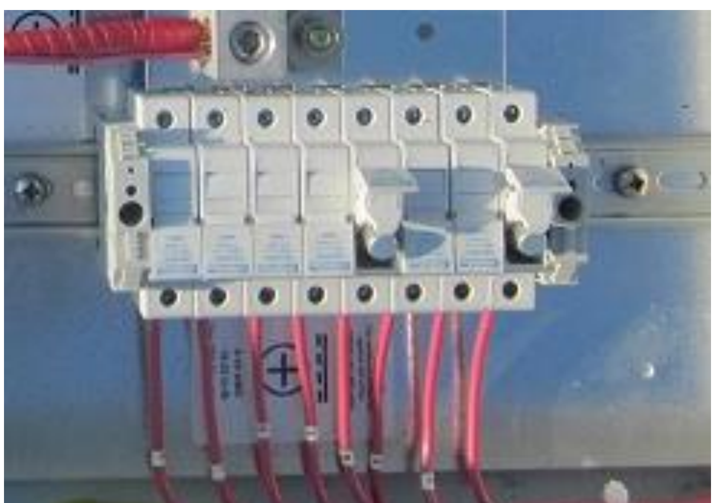
Prior to the 2011 National Electrical Code

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

Combiner Boxes

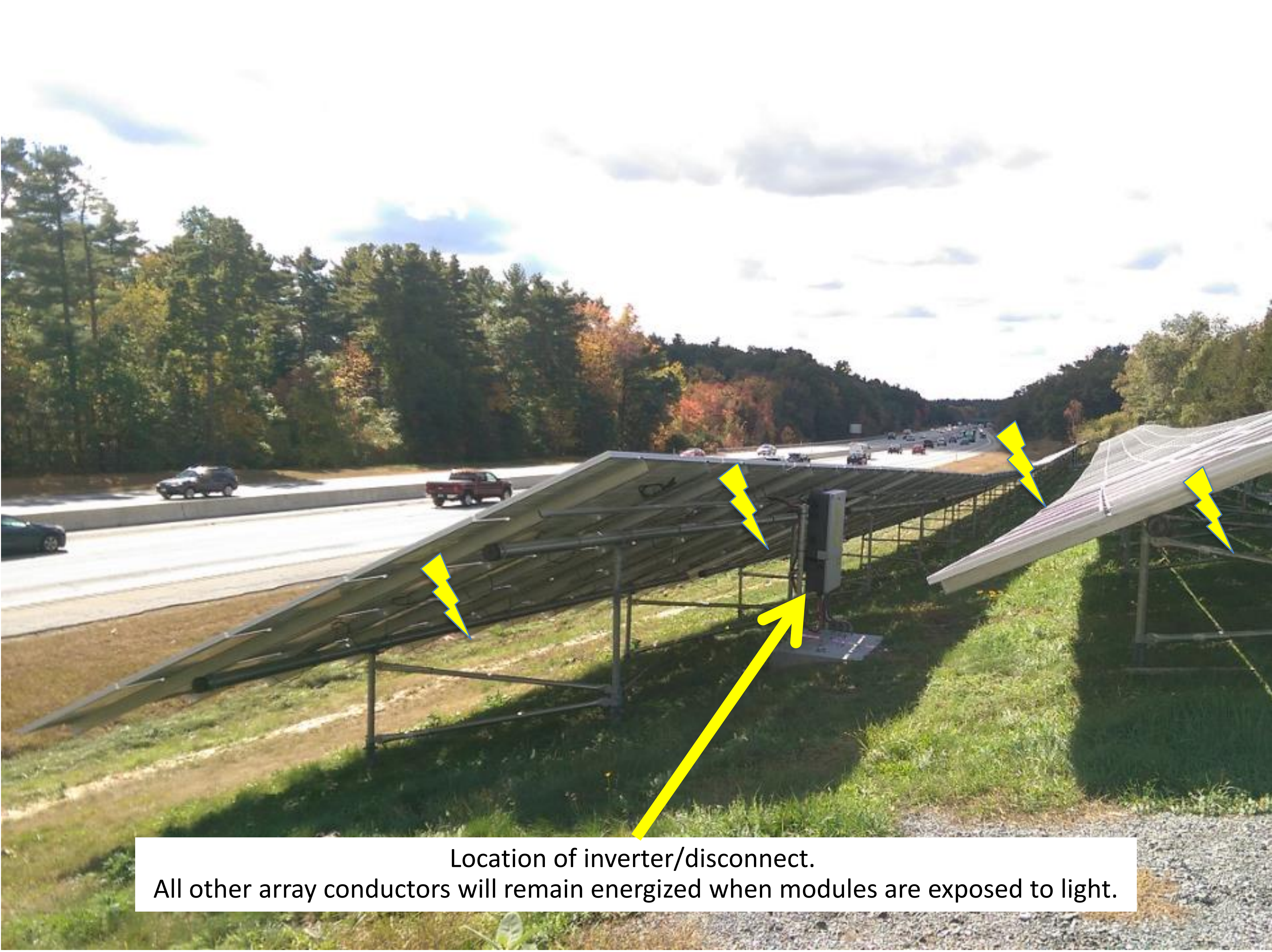
- Opening fuseholders under load is dangerous
  - Arcing hazard
- Inverter or DC disconnect MUST be shut down before fuseholders are opened
  - Inverter will shut down automatically if main breaker is off
  - If there is a fault in the DC wiring (modules burning, etc.), current will still flow to ground 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 of 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

New requirement in 2014 National Electrical Code (NEC): Article 690.12

- 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

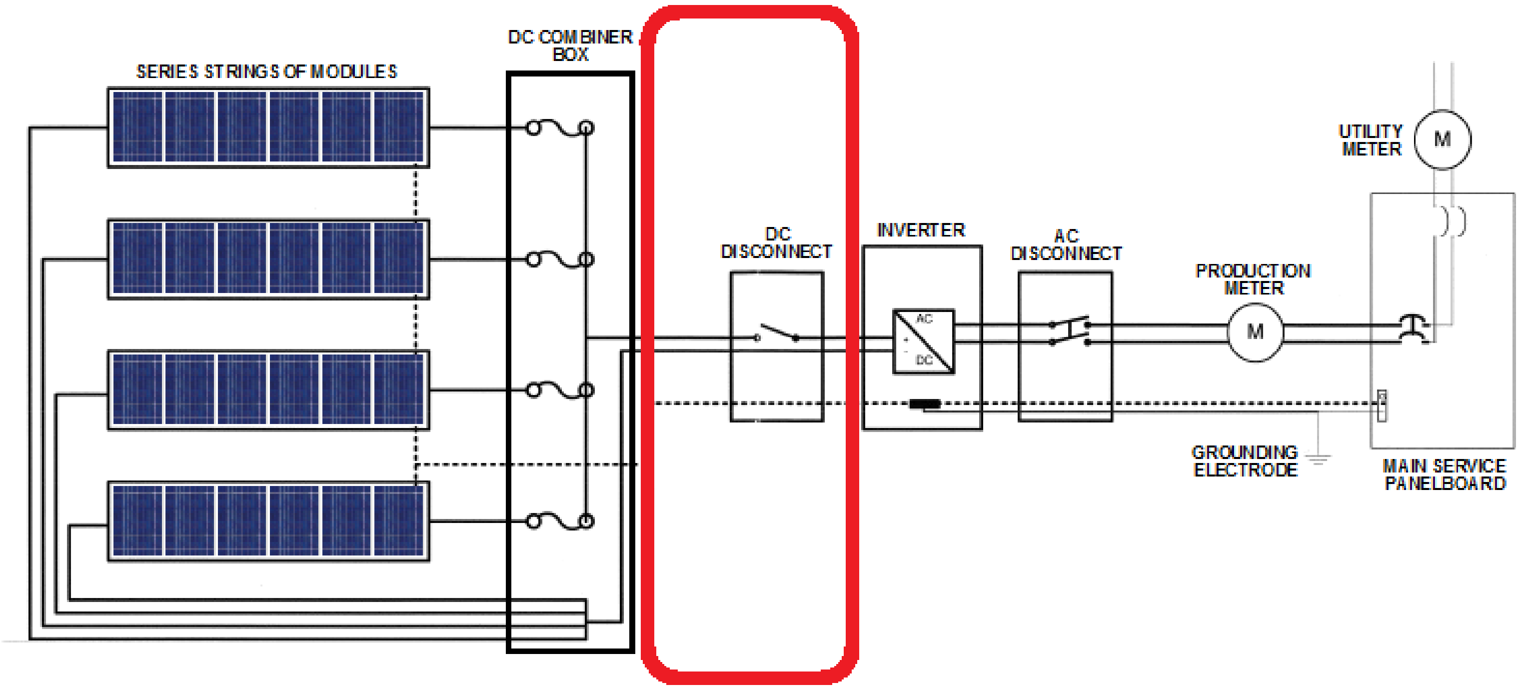
- 690.12(5)
  - *“Equipment that performs the rapid shutdown shall be listed and identified.”*

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

Firefighter Safety and Photovoltaic Systems

- http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_SafetyFinalReport.pdf

During the UL research project many variables were considered.

Firefighter Safety and Photovoltaic Systems

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

UL conducted two experiments

Firefighter Safety and Photovoltaic Systems

Smooth Bore

Up to 1.25”

Adjustable Solid Stream to Wide fog

Hose Stream

Firefighter Safety and Photovoltaic Systems

Test with pond water and smooth bore nozzle

Distance Feet	Smooth bore nozzle size	Pressure PSI	Voltage DC Volts	Leakage current Milliamps
10	1 inch	21	1000	5.7
10	1 inch	21	600	3.2
10	1 inch	21	300	1.6
10	1 inch	21	50	0.3
20	1 inch	23	1000	1.5

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

Hose Stream

Firefighter Safety and Photovoltaic Systems

Test with pond water and narrow fog pattern at 5’

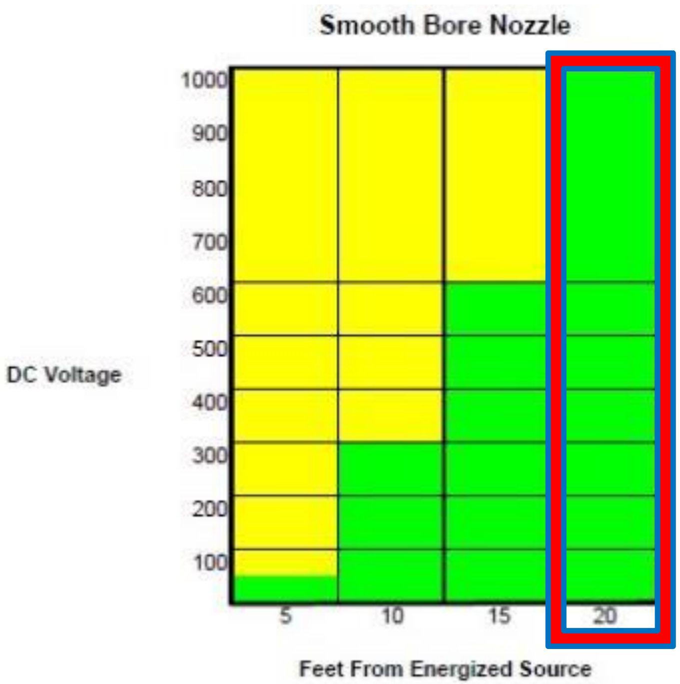
Zero leakage current at 1000 Volts

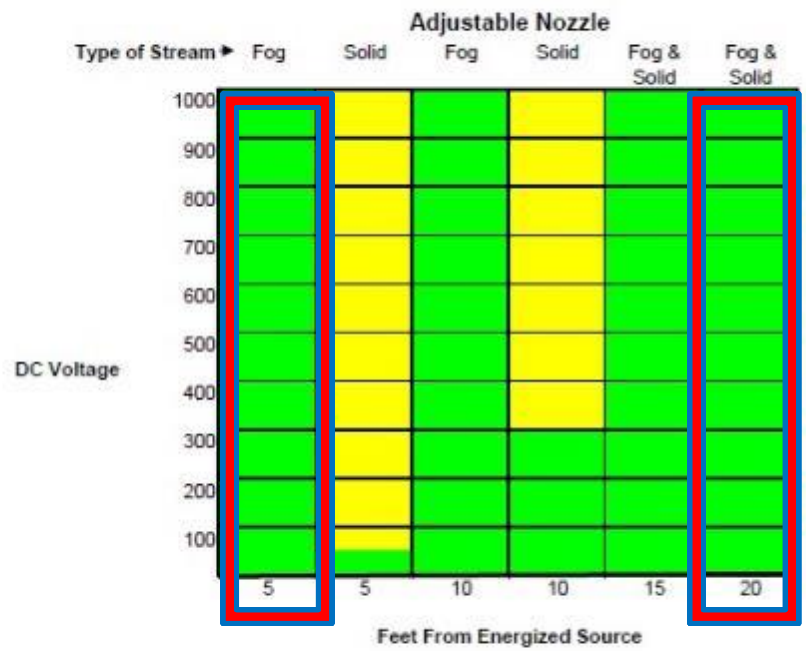

Source: UL.com

Hose Stream

Firefighter Safety and Photovoltaic Systems

- 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)

Firefighter Safety and Photovoltaic Systems

- UL tested firefighter gloves and boots to determine electrical insulating properties.
- Various tests performed on items:
  - New
  - Soiled
  - Wet
  - Worn


Figure 29 Testing a glove in metal shot

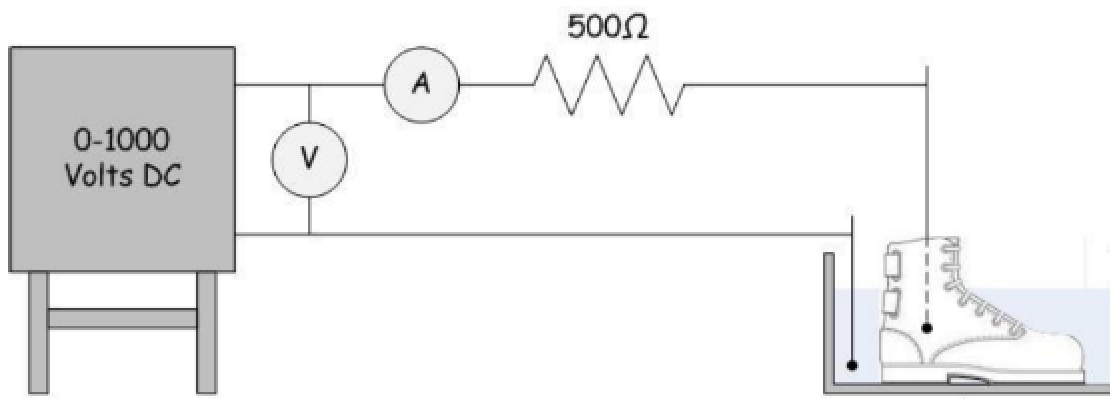


Figure 34 Diagram of boot test set-up

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)

Firefighter Safety and Photovoltaic Systems

1

2

3

Glove Sample	Soiled	Wetted Outside	Wetted Inside	Measured milliAmps, DC 50 Vdc	300 Vdc	600 Vdc	1000 Vdc
1	no	no	no				0
2	no	no	no				0
3	no	no	no				0
1	no	yes	no	91	>250		
2	no	yes	no	0.5	2	100	>250
2	no	yes	yes	38	89	>250	>250
3	no	yes	no	3	17	24	54
3	no	yes	yes	43	>250		
1	yes	no	no				0.5
2	yes	no	no				0
3	yes	no	no				0
1	yes	yes	no	91	>250		
1	yes	yes	yes	93	>250		
2	yes	yes	no	0	2	3	4
2	yes	yes	yes	64	>250		
3	yes	yes	no	0	0	0	0
3	yes	yes	yes	78	>250		

Safe | Perception | Lock On | Electrocution

Personal Protective Equipment (PPE)

Firefighter Safety and Photovoltaic Systems

1

2

3

Boot Sample	New	50% Toe Aged[1]	100% Toe Aged[2]	Hole in Bottom[3]	Measured milliAmps, DC[4] 50 Vdc	300 Vdc	600 Vdc	1000 Vdc
1	X							0
2	X							0
3	X				6	45	94	160
1		X			1	7	18	35
2		X			13	108	>250	
3		X			13	99	>250	
1			X		4	78	135	240
2			X		30	184	>250	
3			X		26	>250		
1				X	27	178	>250	
2				X	31	212	>250	
3				X	30	204	>250	

Safe	Perception	Lock On	Electrocution

Alternative Light Sources

No sun, no hazard??

Alternative Light Sources

Firefighter Safety and Photovoltaic Systems

- Artificial light sources
- Light from fire
- Moonlight

Source: UL.com

Source: UL.com

Alternative Light Sources

Firefighter Safety and Photovoltaic Systems

- UL tested a variety of trucks and light levels at night to determine if there was a presence of dangerous voltage

Source: UL.com

Source: UL.com

Alternative Light Sources

Firefighter Safety and Photovoltaic Systems

- 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

Test	Truck #1 Bed 12 kW Boom 6 kW	Truck #2 Bed 6 kW Boom 4.5 kW	Total Lighting kW	Distance from Array (Feet)	Open Circuit Volts	Short Circuit MilliAmps	Hazard
			None		48	0	Safe
1	Bed + Boom		18	25	812	132	Lock On
2		Bed + Boom	10.5	38	780	88	Lock On
3		Boom	4.5	38	738	50	Lock On
4	Bed + Boom	Bed + Boom	28.5	25 & 38	836	212	Lock On
5	Partial Bed		3	25	657	22	Perception
6	Partial Bed		1.5	25	575	11	Perception
7	Bed + Boom		18	50	735	37	Perception
8		Bed + Boom	10.5	75	700	22	Perception
9	Bed + Boom	Bed + Boom	28.5	50 & 75	773	49	Lock On
10	Partial Bed		1.5	50	340	1.5	Safe

Light from nearby fire

Firefighter Safety and Photovoltaic Systems

- 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

Light from nearby fire

Firefighter Safety and Photovoltaic Systems

- UL concluded dangerous voltages were present at each distance
  - No test was performed over 75’

Table 19 Results of experiments with light from a fire

Light from a Fire (Single Module)

Distance from Fire (Feet)	Open Circuit Volts	Short Circuit MilliAmps	Hazard
75	30	52	Lock On
50	31	57	Lock On
40	32	59	Lock On
15	33	62	Lock On
Full Sun	37	7500	

Moonlight

Firefighter Safety and Photovoltaic Systems

- 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


Source: www.travelization.net

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

Firefighter Safety and Photovoltaic Systems

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

Source: UL.com

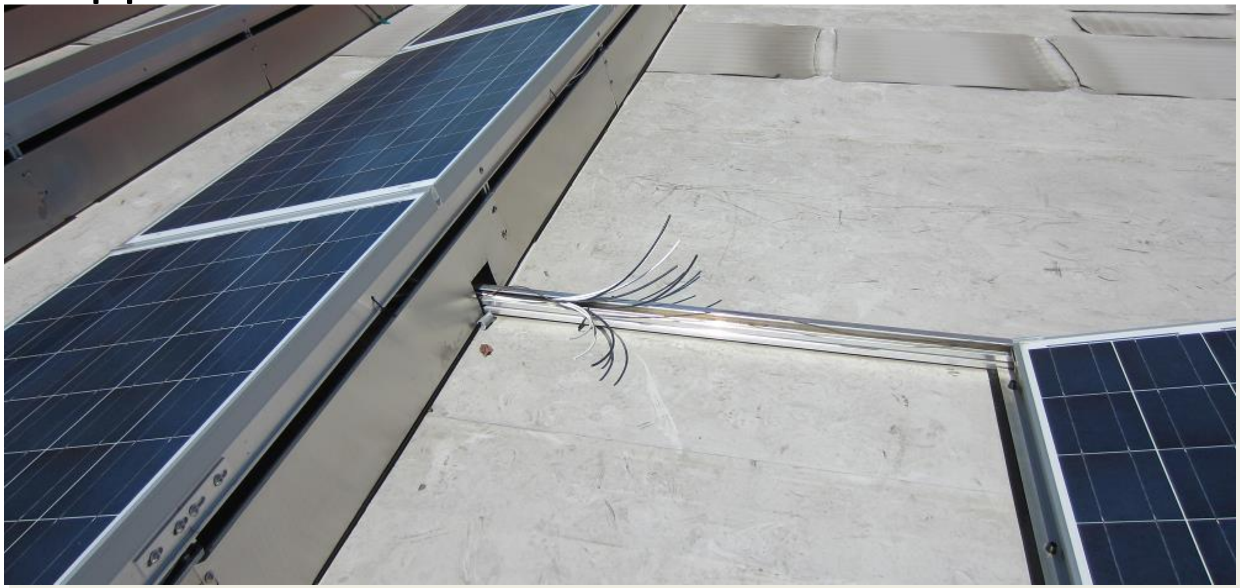
Source: UL.com

Source: UL.com

Source: UL.com

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

Firefighter Safety and Photovoltaic Systems

- 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

Firefighter Safety and Photovoltaic Systems

- Rotary saw and chain saw test
  - Metal conduit (EMT)
  - Nonmetallic conduit
  - Flexible metal conduit

Figure 53 Rotary saw cutting through EMT

Rotary Saw

Nonmetallic Conduit

Firefighter Safety and Photovoltaic Systems

Figure 54 Cutting through nonmetallic conduit

Figure 55 Open flame from arcing

Source: UL.com

Rotary Saw

Flexible Metal Conduit

Firefighter Safety and Photovoltaic Systems

Figure 56 Cutting through flexible metal conduit

Figure 57 Open flame from arcing

Source: UL.com

Chain Saw

Flexible Metal Conduit

Firefighter Safety and Photovoltaic Systems

Figure 58 Cutting through flexible metal conduit

Figure 59 Open flame from arcing

Power Tools
and Multiple Conductors

Firefighter Safety and Photovoltaic Systems

- 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

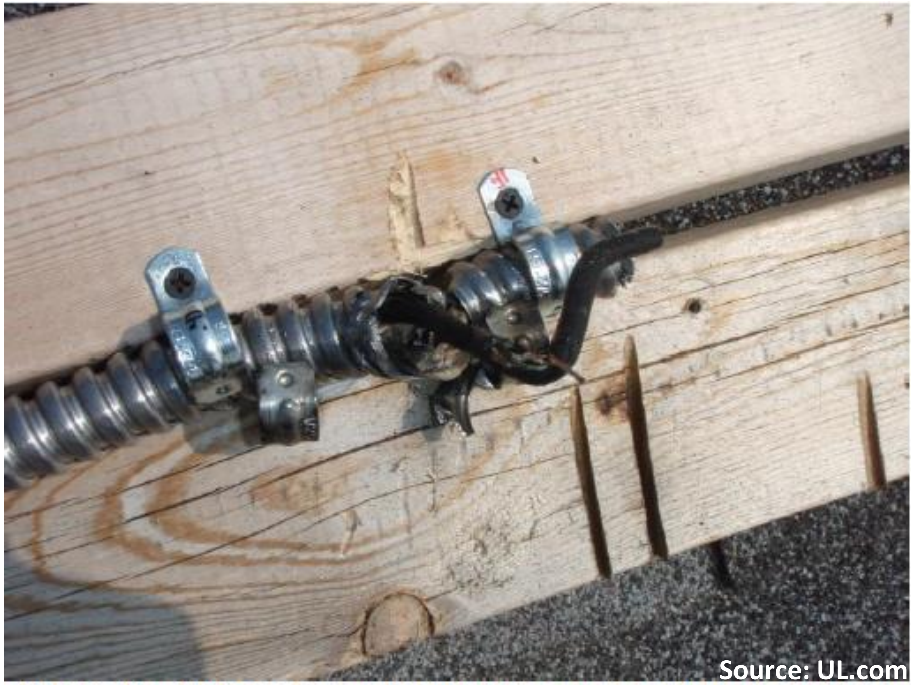


Figure 60 Exposed conductor from action of chain cutting

https://www.youtube.com/watch?v=b7SUvb5QmbY

Damaged Modules and Equipment

Damaged Modules/Equipment

- UL tested two types of damage:
  - Physical with axe or other tool
  - Damage from fire

Source: UL.com

Source: UL.com

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

Source: UL.com

Damaged Modules/Equipment

Firefighter Safety and Photovoltaic Systems

- Physical damage test with laminate modules:
  - 883 Volts measured between metal “roof” and earth
  - Shock hazard for anyone in contact with roof

Figure 65 Axe penetrates laminate

Source: UL.com

Figure 66 Halligan tool imbedded in ground

Damaged Modules/Equipment

Firefighter Safety and Photovoltaic Systems

- UL tested many modules after exposure to fire:

Figure 101 Open flames on roof

Figure 102 Modules sagging

Figure 103 Roof and modules collapsing

Figure 104 Roof collapsed -fire extinguished

Damaged Modules/Equipment

Firefighter Safety and Photovoltaic Systems

- After fire:
  - Array reconstructed

Figure 113 Post fire, front surface

Figure 114 Post fire, back surface

Source: UL.com

Damaged Modules/Equipment

Firefighter Safety and Photovoltaic Systems

- Every module tested

Source: UL.com

Figure 117 - Module D1 – badly burnt on backside, but functional and producing full voltage

Damaged Modules/Equipment

Firefighter Safety and Photovoltaic Systems

- 60% of modules still produced full power
- Only 25% completely destroyed → no power

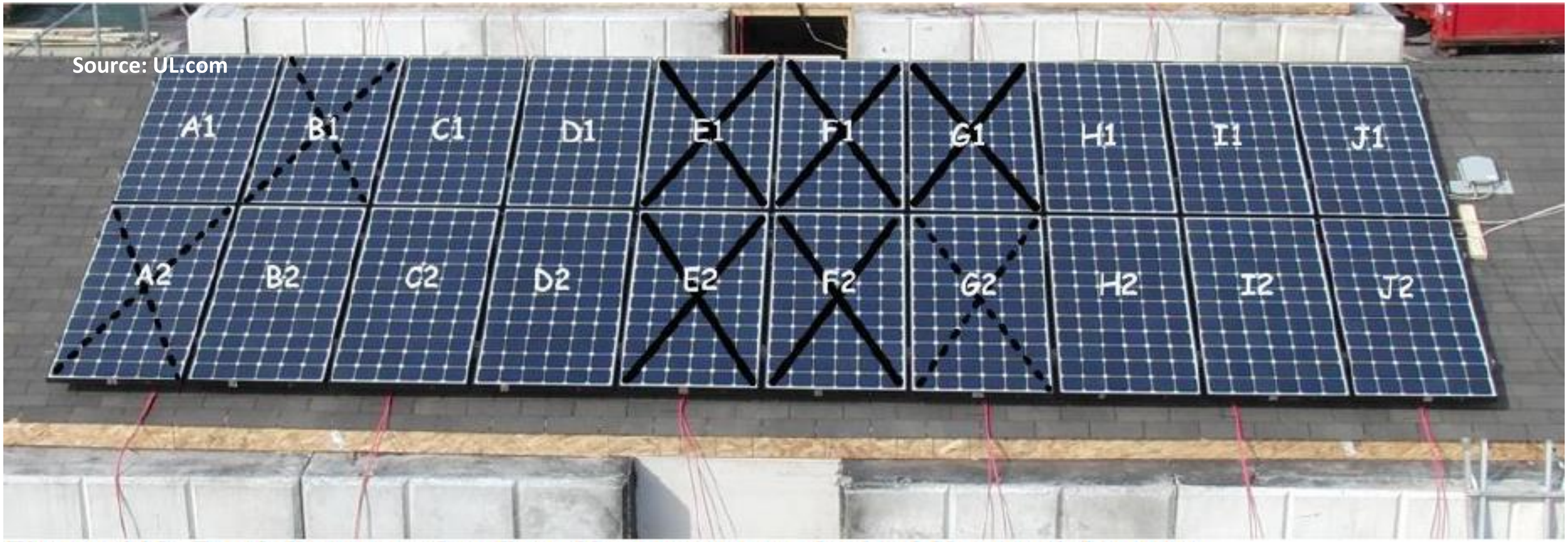


Figure 112 Roof diagram after fire: X = no power, dashed-X = partial power

Shock Hazards

During and Post-Fire…

Shock Hazards

Firefighter Safety and Photovoltaic Systems

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

Source: UL.com

Figure 184 Looking under module for dangers

Figure 185 cutting leads

Shock Hazards

Figure 183 Bare energized conductors contacting broken rails and metal frames

Shock Hazards

Firefighter Safety and Photovoltaic Systems

Source: UL.com

Figure 157 Voltage between exposed wires

Night time fires involving PV systems

Firefighter Safety and Photovoltaic 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)

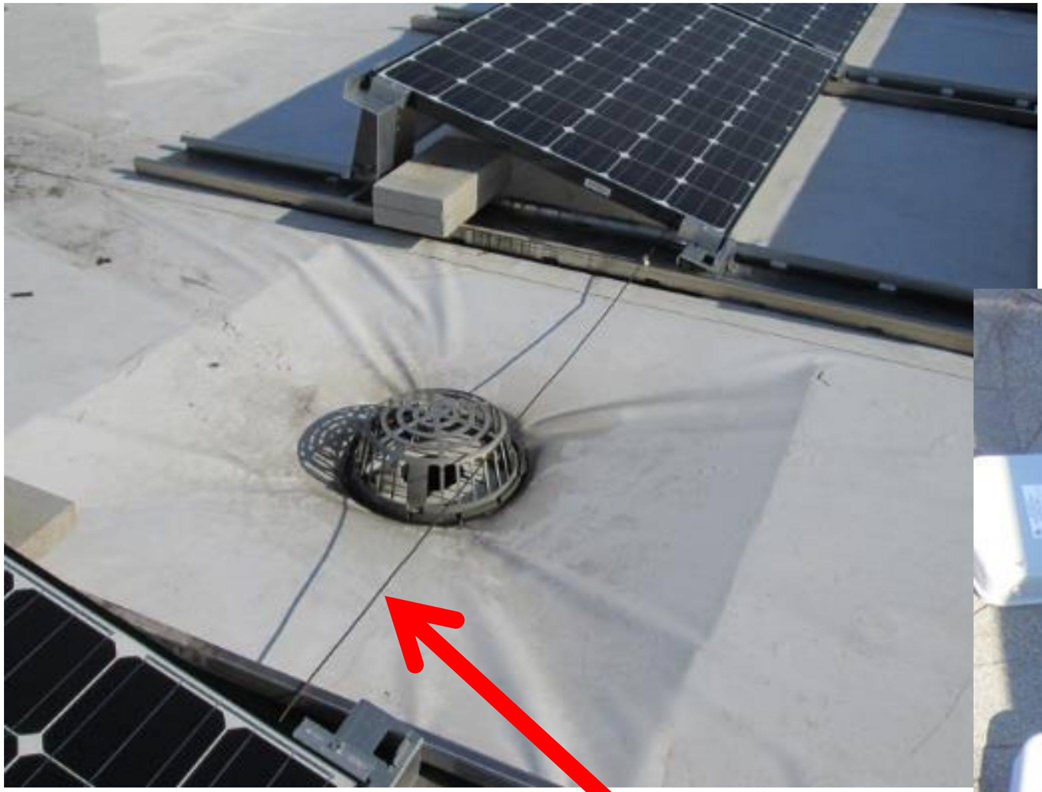
- You MUST use SCBA when dealing with fire involving PV arrays
  - Treat it like the Hazmat call it is
- PV cells can produce three main chemicals when burning:
- Cadmium Telluride (usually on commercial or utility scale installations)
  - Carcinogenic
- Gallium Arsenide
  - Highly toxic and carcinogenic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

In addition to electrical hazards

Firefighter Safety and Photovoltaic Systems

- 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 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

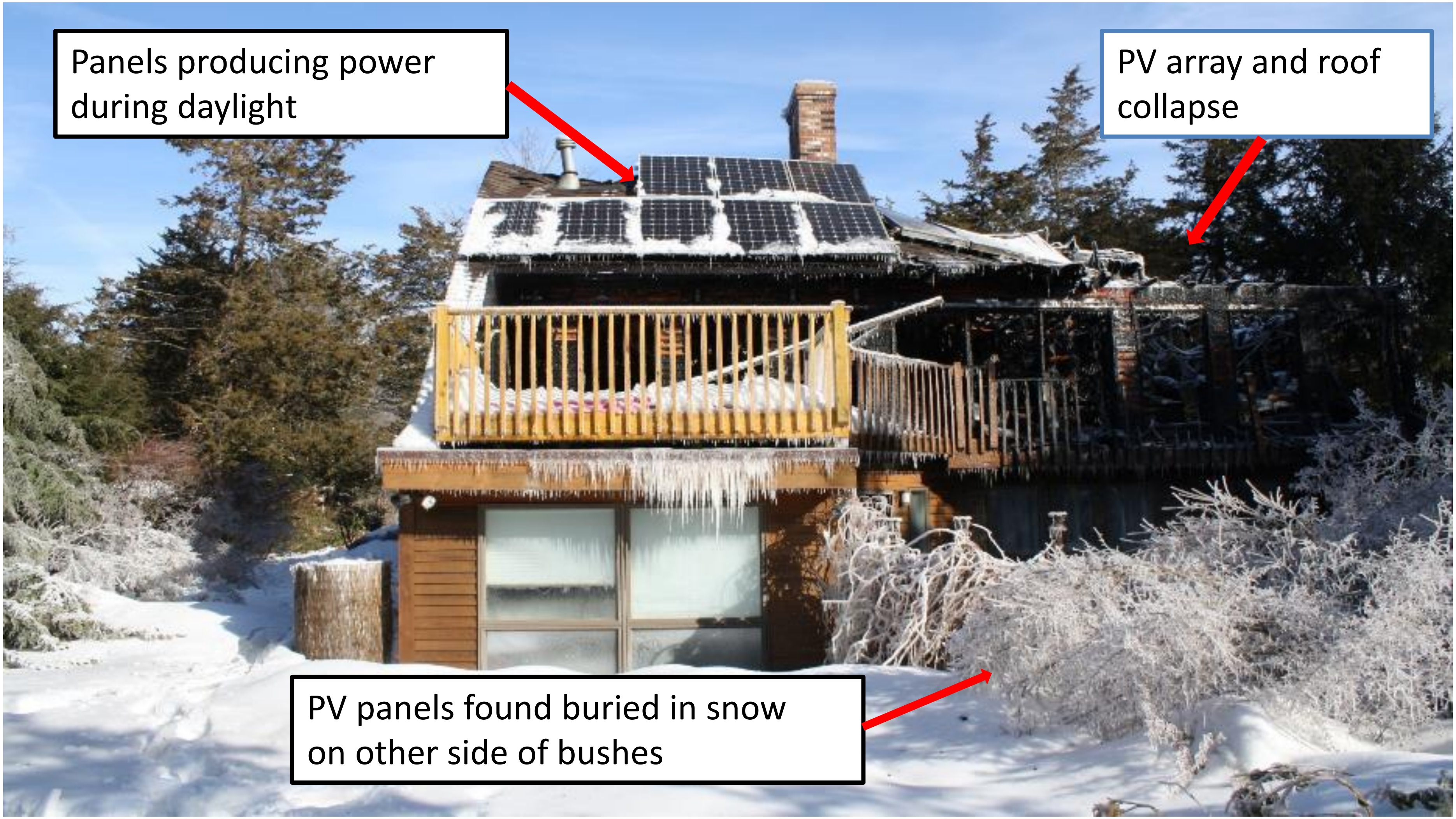
Glastonbury, Connecticut

Dogwood Lane 2/23/15

Glastonbury, Connecticut

Dogwood Lane 2/23/15

Glastonbury, Connecticut



Dogwood Lane 2/23/15

Glastonbury, Connecticut

Dogwood Lane 2/23/15

Glastonbury, Connecticut

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
- 2^{nd} 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
- <u>Department had no formal training in Safety around solar panels</u>


901

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

Matt Piantedosi
Senior Associate Engineer and Master Electrician
The Cadmus Group Inc.
Email: Matt.Piantedosi@cadmusgroup.com

Tony Granato
Lieutenant and CT Certified Fire Instructor
Connecticut E2 Journeyman Electrician
Email: tonyg68@cox.net

Nate Hausman, Project Manager
Clean Energy States Alliance
(802)223-2554
Nate@cleanegroup.org