Electrical Integration of PV Systems

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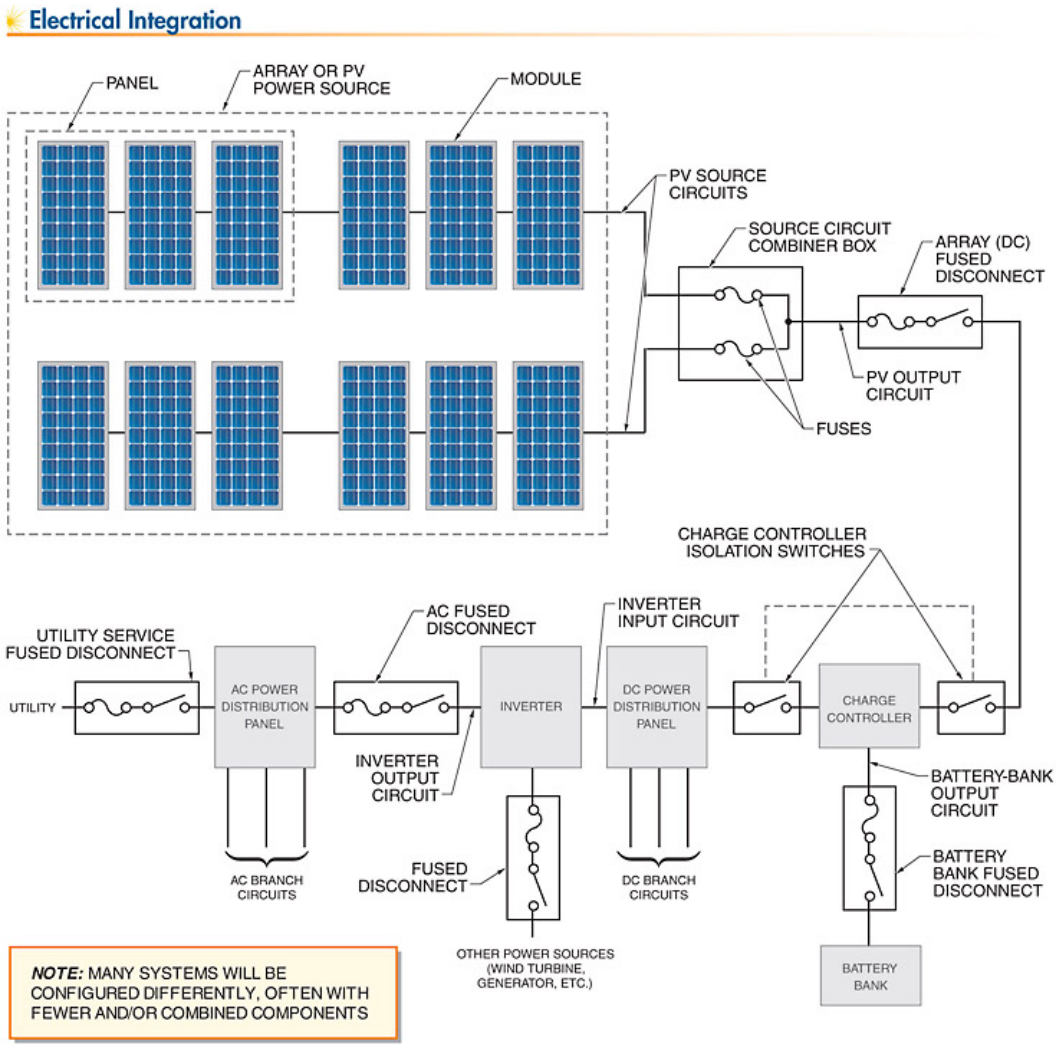
- Many articles in the NEC® are applicable to the electrical integration of a PV system, particularly Article 690.

Selected Applicable NEC® Articles

110*	Requirements for Electrical Installations
200	Use and Identification of Grounded Conductors
210*	Branch Circuits
220	Branch-Circuit, Feeder, and Service Calculations
230*	Services
240*	Overcurrent Protection
250*	Grounding and Bonding
280	Surge Arrestors
285	Transient Voltage Surge Suppressors: TVSSs
300	Wiring Methods
310*	Conductors for General Wiring
334	Nonmetallic-Sheathed Cable: Types NM, NMC, and NMS
338	Service-Entrance Cable: Types SE and USE
340*	Underground Feeder and Branch Circuit Cable: Type UF
400*	Flexible Cords and Cables
422	Appliances
445	Generators
450*	Transformers and Transformer Vaults
480*	Storage Batteries
490*	Equipment, Over 600 Volts, Nominal
690	Solar Photovoltaic Systems
702	Optional Standby Systems
705*	Interconnected Electric Power Production Sources
720	Circuits and Equipment Operating at Less Than 50 Volts

* Articles directly referenced in Article 690

- The NEC® defines the various circuits and components in PV systems and specifies their requirements.



- Array open-circuit voltage is corrected for low temperatures to yield the maximum possible array voltage.

Voltage Correction Factors for Low Temperatures

AMBIENT TEMPERATURE*	VOLTAGE CORRECTION FACTOR
25 to 10	1.06
9 to 0	1.10
–1 to –10	1.13
–11 to –20	1.17
–21 to –40	1.25

* in °C

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- Larger conductors have lower resistance for a given length.

Conductor Resistances*

AWG	SOLID COPPER	STRANDED COPPER
18	7.77	7.95
16	4.89	4.99
14	3.07	3.14
12	1.93	1.98
10	1.21	1.24
8	0.764	0.778
6	—	0.491
4	—	0.308
3	—	0.245
2	—	0.194
1	—	0.154
0 (1/0)	—	0.122
00 (2/0)	—	0.0967

* in Ω/kft at 75°C (167°F)

- **Conductor sizes typically used in PV systems range from 20 AWG to 2/0 AWG. Conductors may be solid or stranded.**

Conductor Sizes

AWG	DIAMETER*	AREA	AWG	DIAMETER*	AREA
20	0.0320		6	0.1620	
18	0.0403		4	0.2043	
16	0.0508		3	0.2294	
14	0.0641		2	0.2576	
12	0.0808		1	0.2893	
10	0.1019		0 (1/0)	0.3249	
8	0.1285		00 (2/0)	0.3648	

* in.

- Ampacity is the current-carrying capacity of a conductor and depends on conductor type and size.

Ampacities of Insulated Copper Conductors*

	TYPE OF INSULATION	TW, UF	RHW, THHW, THW, THWN, XHHW, USE, ZW	TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW-2, ZW-2
	AWG	60°C Rated	75°C Rated	90°C Rated
CONDUCTORS IN A RACEWAY, CABLE, CONDUIT, OR EARTH (DIRECTLY BURIED)	18	—	—	14
	16	—	—	18
	14	20	20	25
	12	25	25	30
	10	30	35	40
	8	40	50	55
	6	55	65	75
	4	70	85	95
	3	85	100	110
	2	95	115	130
	1	110	130	150
	0 (1/0)	125	150	170
	0 (2/0)	145	175	195
CONDUCTOR IN FREE AIR	18	—	—	18
	16	—	—	24
	14	25	30	35
	12	30	35	40
	10	40	50	55
	8	60	70	80
	6	80	95	105
	4	105	125	140
	3	120	145	165
	2	140	170	190
	1	165	195	220
	0 (1/0)	195	230	260
	0 (2/0)	225	265	300

* Based on ambient temperature of 30°C (86°F) and not more than three current-carrying conductors when in a raceway, cable, or earth (directly buried).

- **Conductor ampacity must be derated for high temperatures.**

Ampacity Correction Factors for High Temperatures

AMBIENT TEMPERATURE*	CONDUCTOR TEMPERATURE RATING		
	60°C Rated	75°C Rated	90°C Rated
21 to 25	1.08	1.05	1.04
26 to 30	1.00	1.00	1.00
31 to 35	0.91	0.94	0.96
36 to 40	0.82	0.88	0.91
41 to 45	0.71	0.82	0.87
46 to 50	0.58	0.75	0.82
51 to 55	0.41	0.67	0.76
56 to 60	—	0.58	0.71
61 to 70	—	0.33	0.58
71 to 80	—	—	0.41

* in °C

- Conductor ampacity must be derated for more than three current-carrying conductors together in a conduit or cable.

Ampacity Correction Factors for Number of Conductors

NUMBER OF CURRENT-CARRYING CONDUCTORS	CORRECTION FACTOR
4 to 6	0.80
7 to 9	0.70
10 to 20	0.50
21 to 30	0.45
31 to 40	0.40
Over 40	0.35

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- Size, insulation type, resistances, and other information are printed on the outer jacket of conductors.

Conductor Insulation Markings

- **Conductors in different parts of a PV system have different requirements.**

Recommended Insulation Types for PV Systems

APPLICATION	REQUIRED RESISTANCES				NUMBER OF CABLE CONDUCTORS		INSTALLATION		RECOMMENDED INSULATION TYPE
	Moisture	Sunlight	≥ 90°C	Fire	One	Multiple	Exposed	Conduit	
Source-circuit wiring	✓	✓	✓		✓		✓	✓*	USE, USE-2, UF, SE
Output-circuit wiring	✓		✓		✓			✓	USE-2, XHHW-2, RHW-2, THWN-2
	✓	✓	✓			✓	✓		UF, TC
Interior wiring				✓	✓			✓	THHN, THW, RHW, XHHW, RH
				✓		✓	✓†		NM, NMB, UF
Battery wiring	✓				✓		✓		USE, RHW, THW

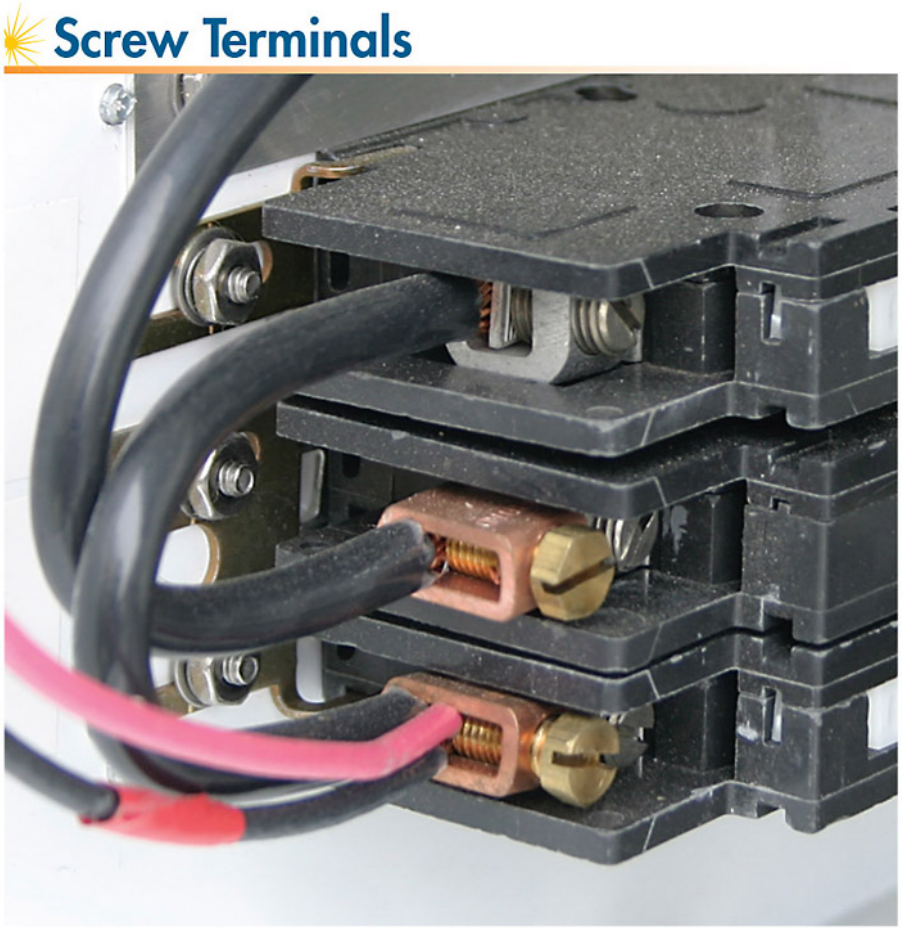
* only flexible conduit
† may not be permitted in local jurisdiction

- Source circuits are usually wired with exposed conductors.

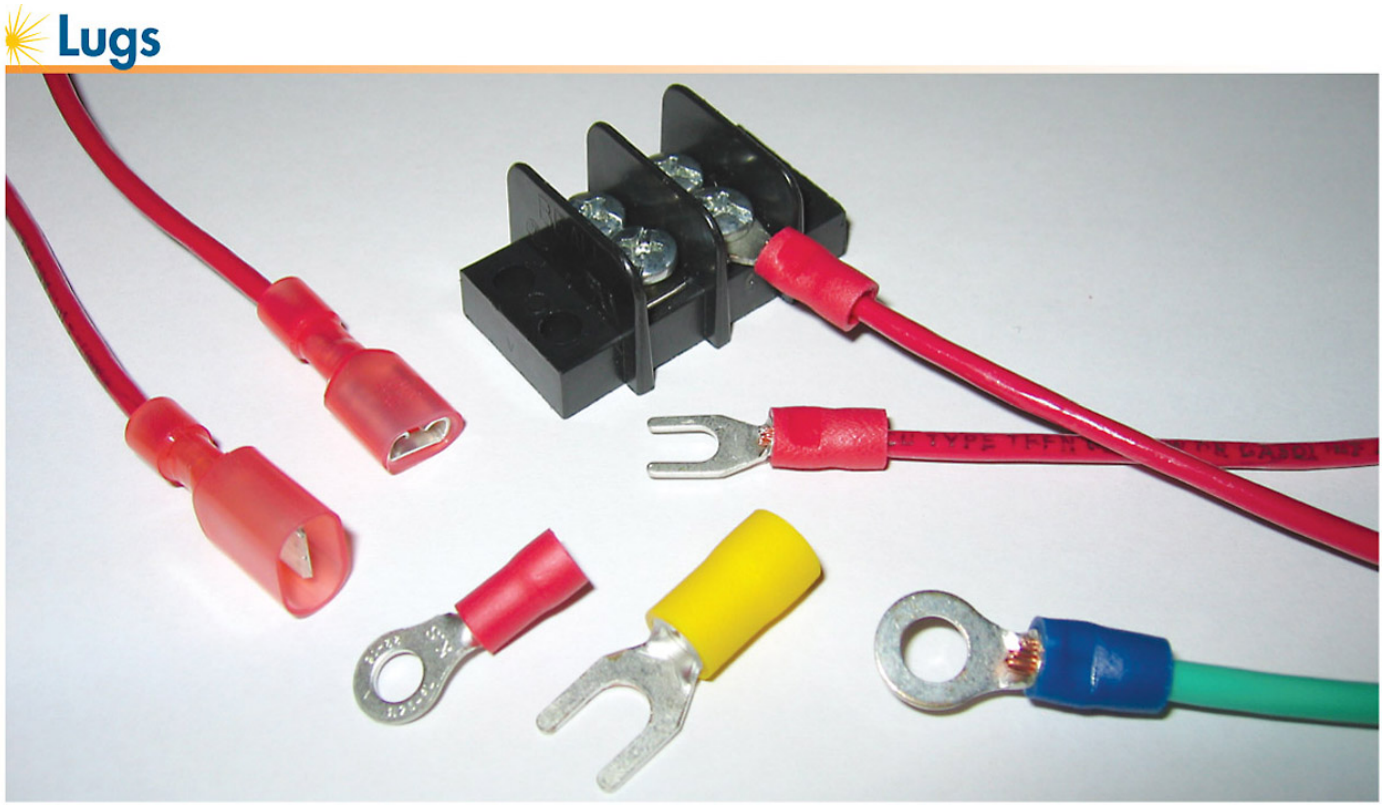
- Modules are typically connected together with external, exposed connectors.

Module Connectors

- When tightened properly, screw terminals produce secure and low-resistance connections.

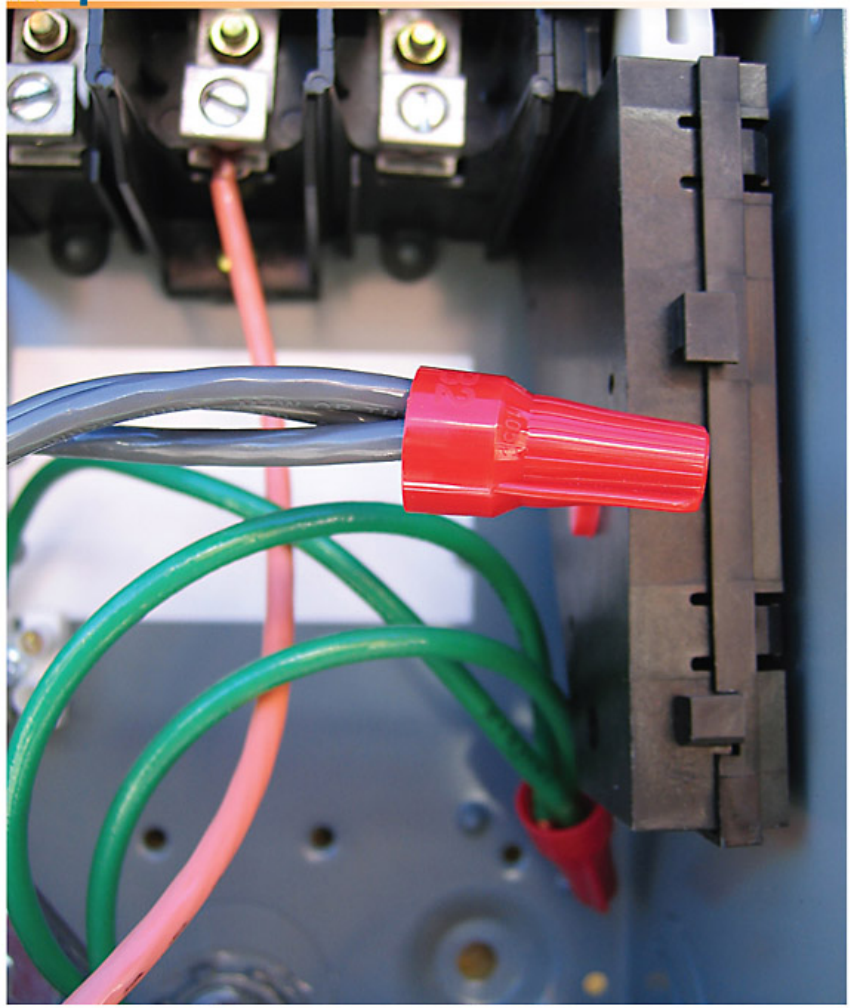


- Lugs are crimped conductor terminations in ring, fork, spade, or pin shapes.

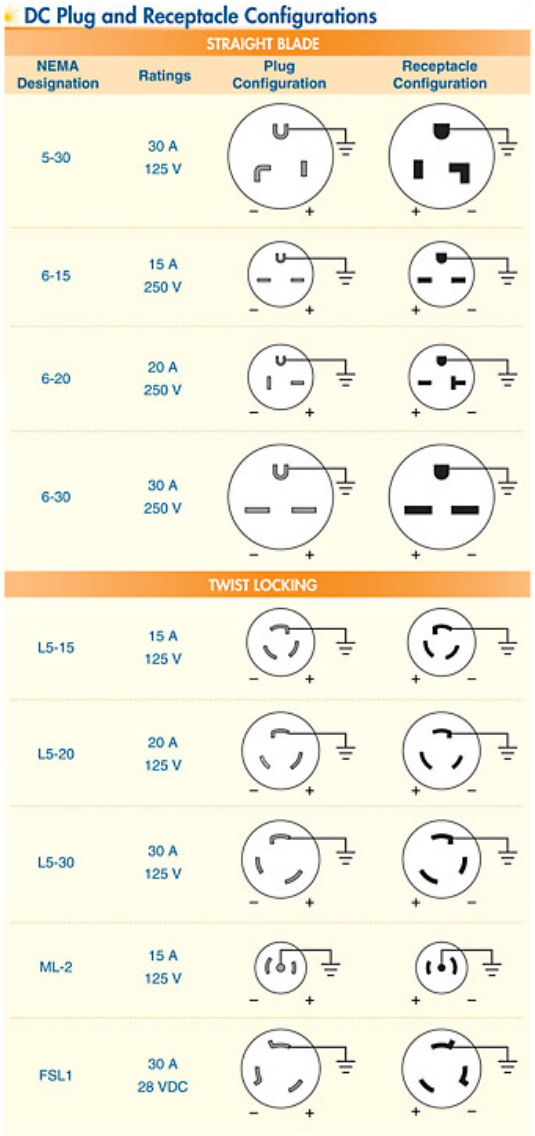


Splices

- Splices are used in PV systems to connect or extend conductors, parallel array source circuits, or tap service-entrance conductors for supply-side interconnections.



- Several NEMA plug-and-receptacle configurations are acceptable for use with DC branch circuits.



DC Plug and Receptacle Configurations

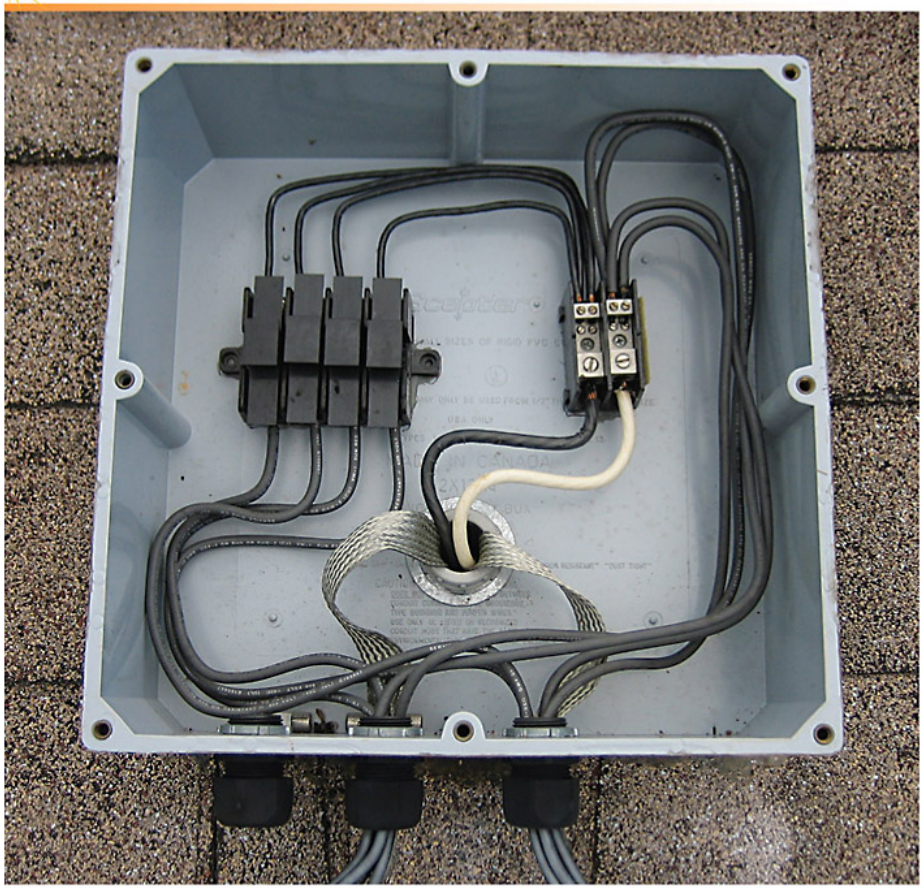
NEMA Designation	Ratings	Plug Configuration	Receptacle Configuration
STRAIGHT BLADE			
5-30	30 A 125 V		
6-15	15 A 250 V		
6-20	20 A 250 V		
6-30	30 A 250 V		
TWIST LOCKING			
L5-15	15 A 125 V		
L5-20	20 A 125 V		
L5-30	30 A 125 V		
ML-2	15 A 125 V		
FSL1	30 A 28 VDC		

- Module junction boxes contain and protect the module terminal connections and diodes in the source circuit.

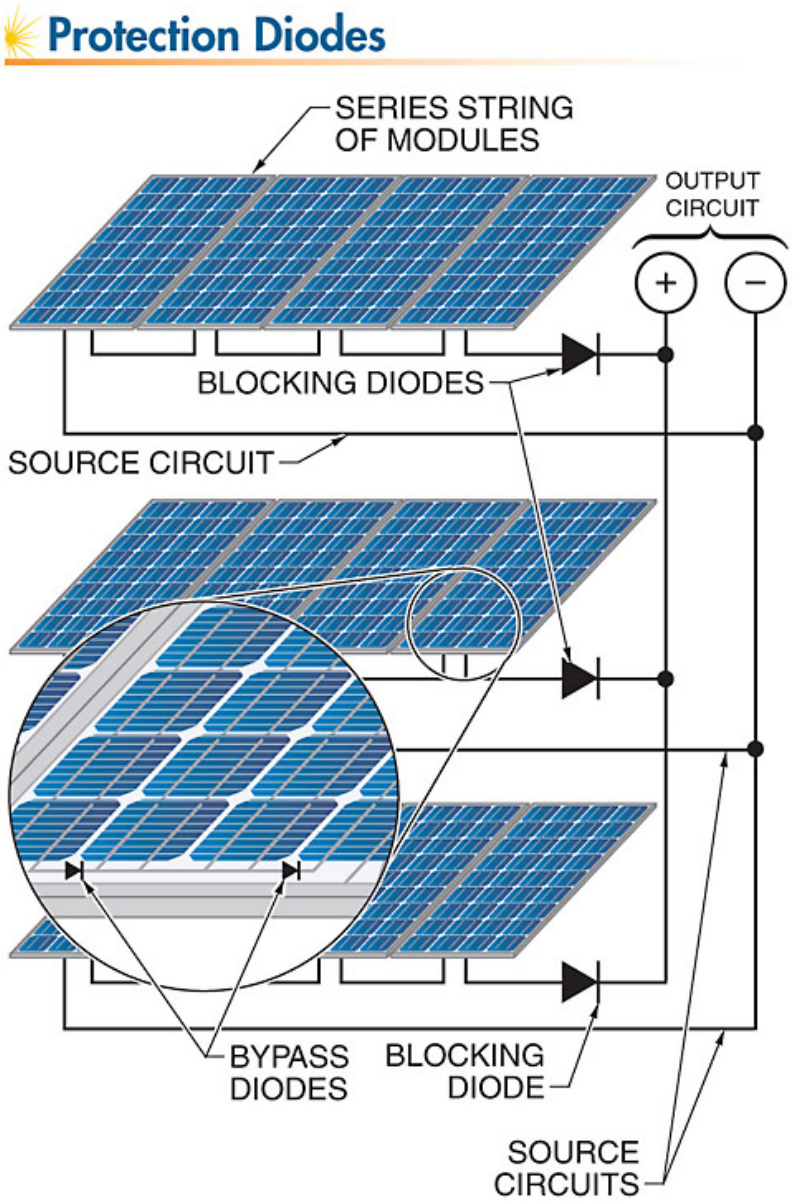
Module Junction Boxes

- Multiple PV source circuits are combined into the PV output circuit within the combiner box.

Source-Circuit Combiner Boxes

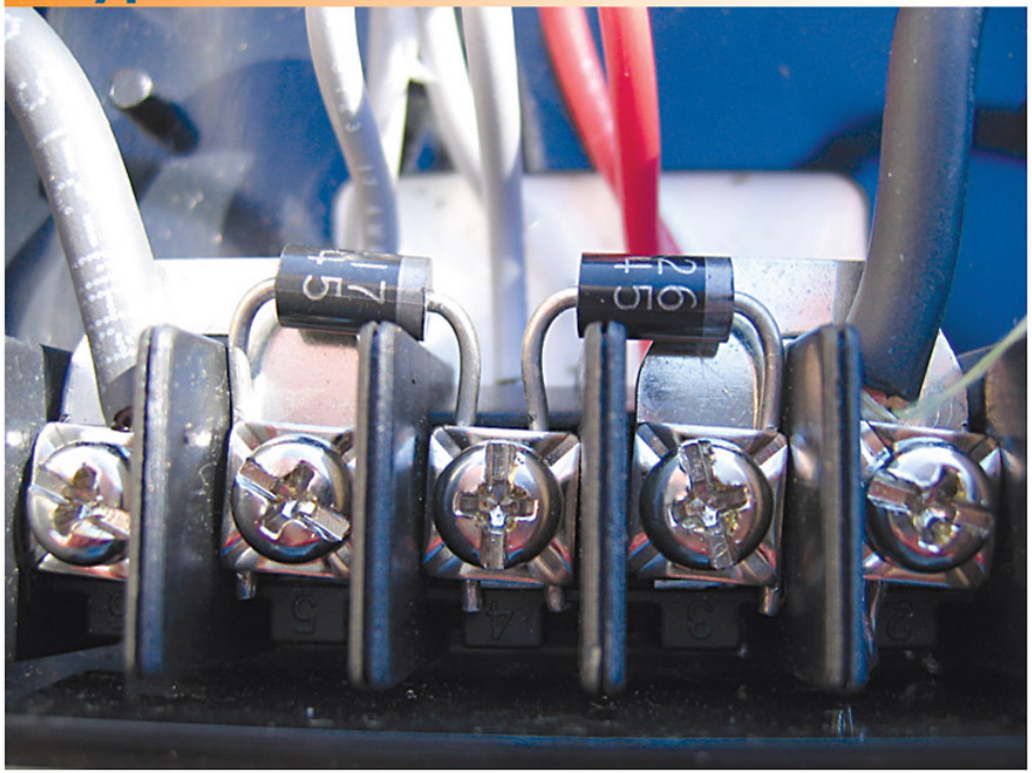


- Blocking diodes and bypass diodes are installed in different parts of a source circuit and have different functions.

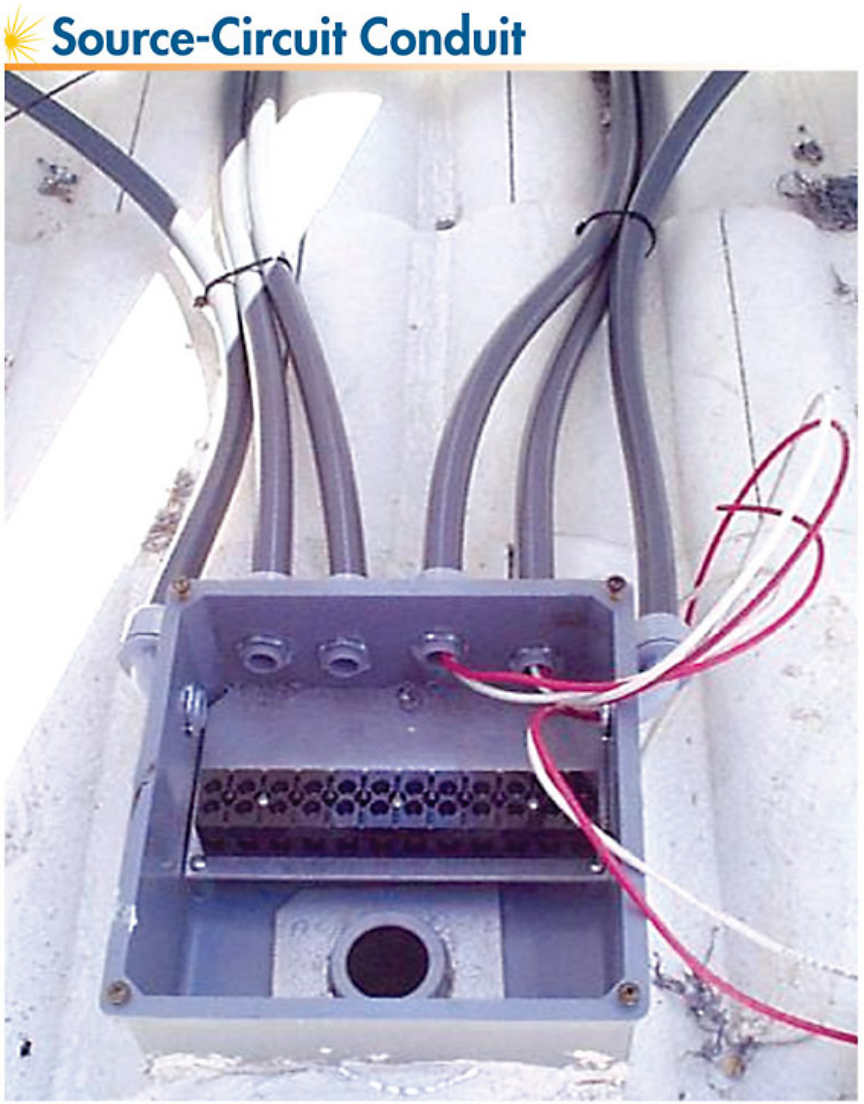


- Bypass diodes may be field-installed in the module junction box.

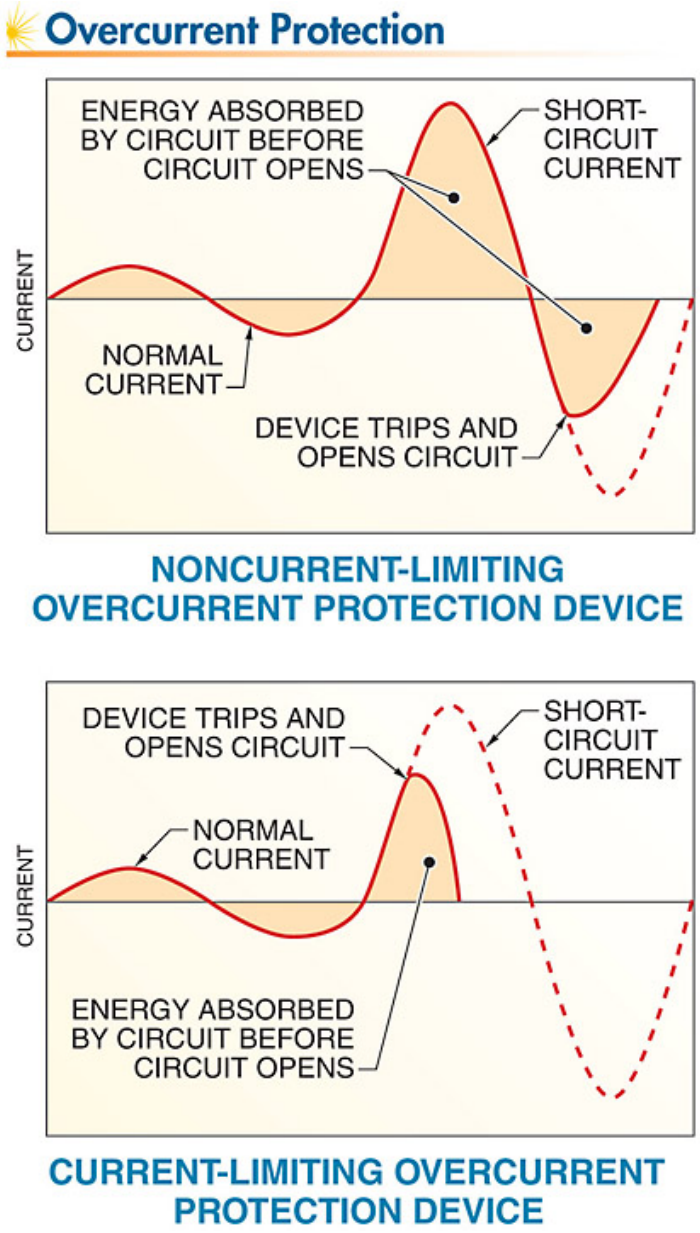
Bypass Diodes



- Source-circuit wiring methods must be flexible, so if the conductors are installed in conduit, the conduit must be made from a flexible material.

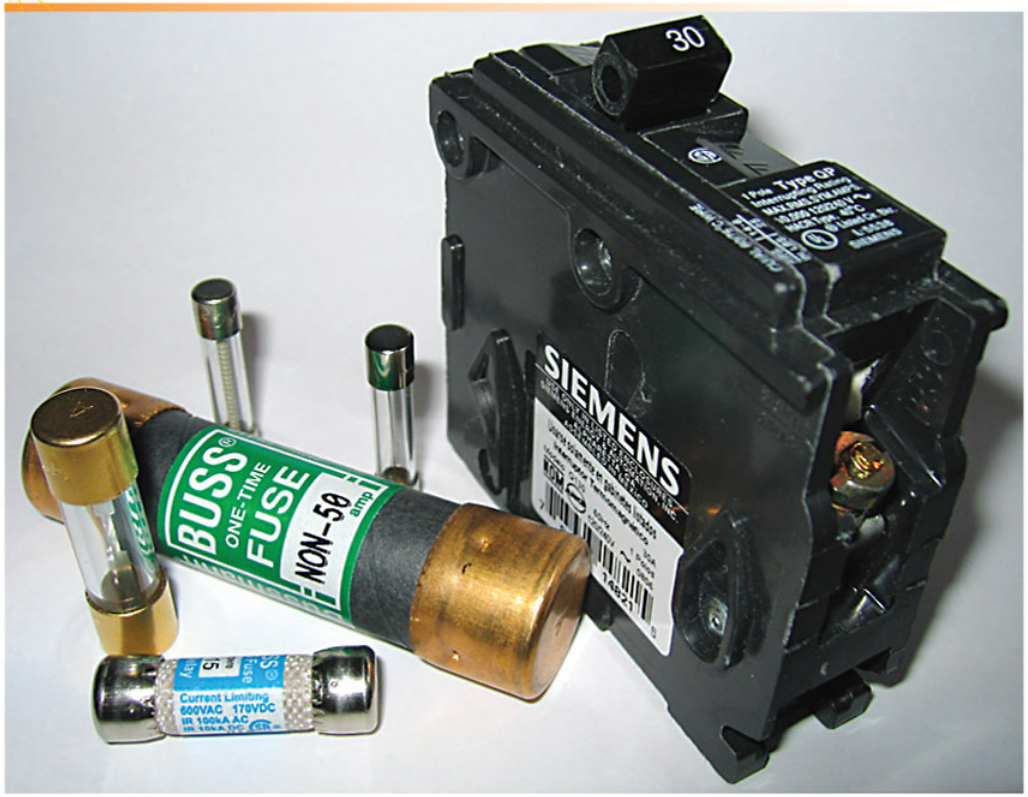


- Current-limiting overcurrent protection devices open a short circuit before current reaches its highest value.



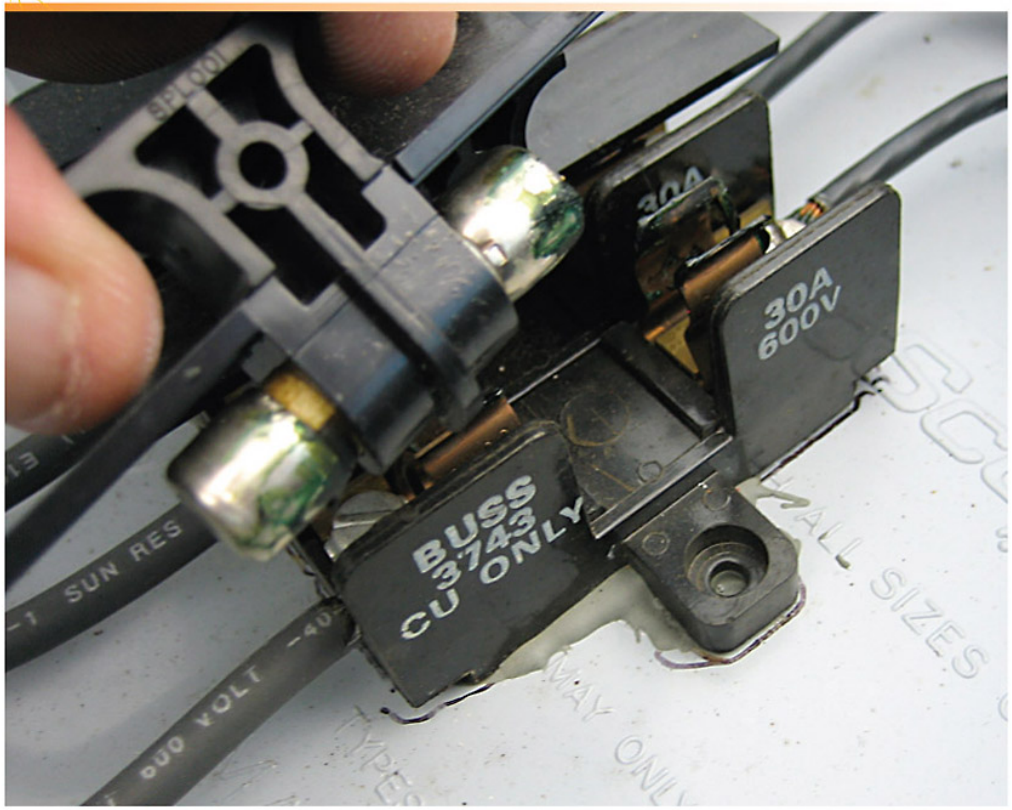
- Overcurrent protection devices include fuses and circuit breakers of various types and ratings.

Overcurrent Protection Devices

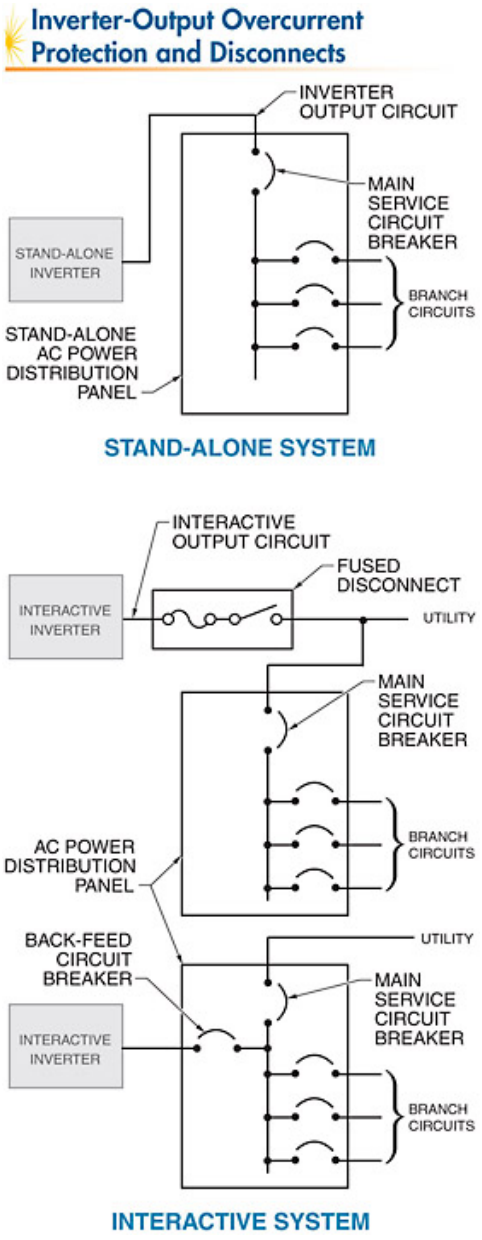


- Array source circuits are typically fused individually within the source circuit combiner box.

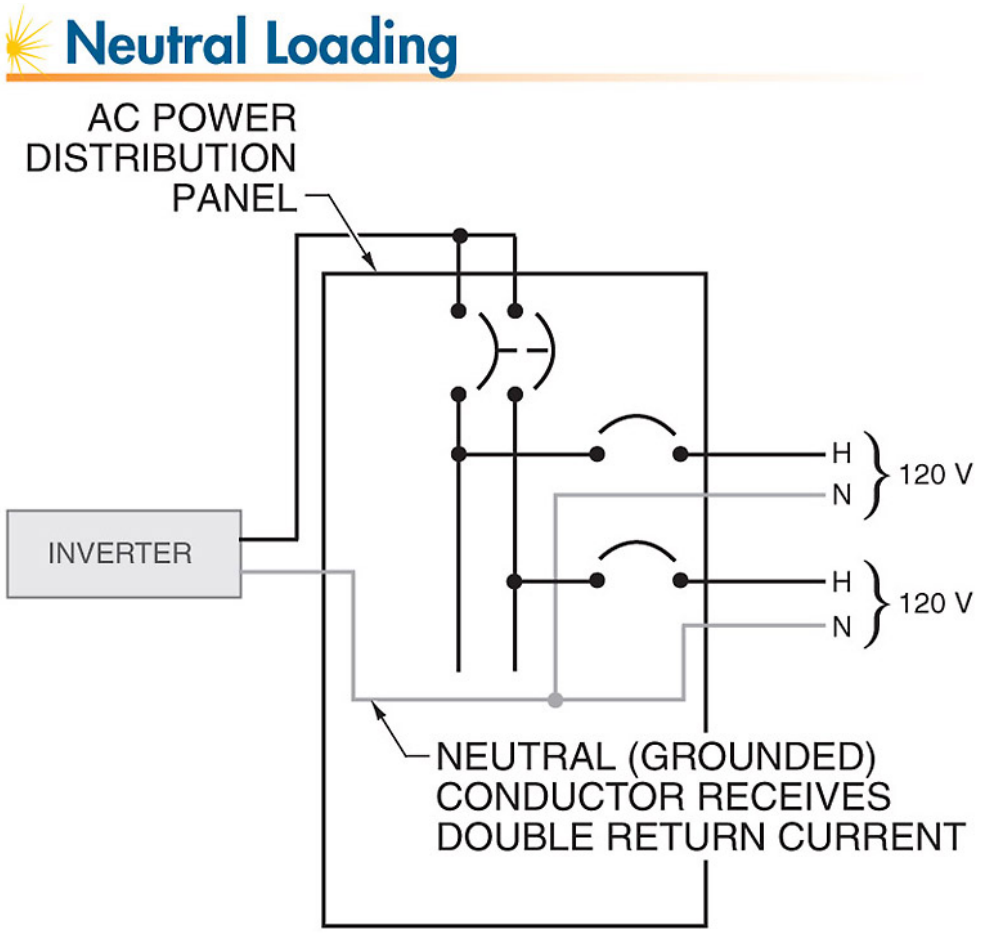
Source-Circuit Fuses



- Overcurrent protection for the inverter output circuit depends on the system or utility interconnection. Overcurrent protection and dis-connecting means for this circuit may also be combined by using circuit breakers or fused disconnects.

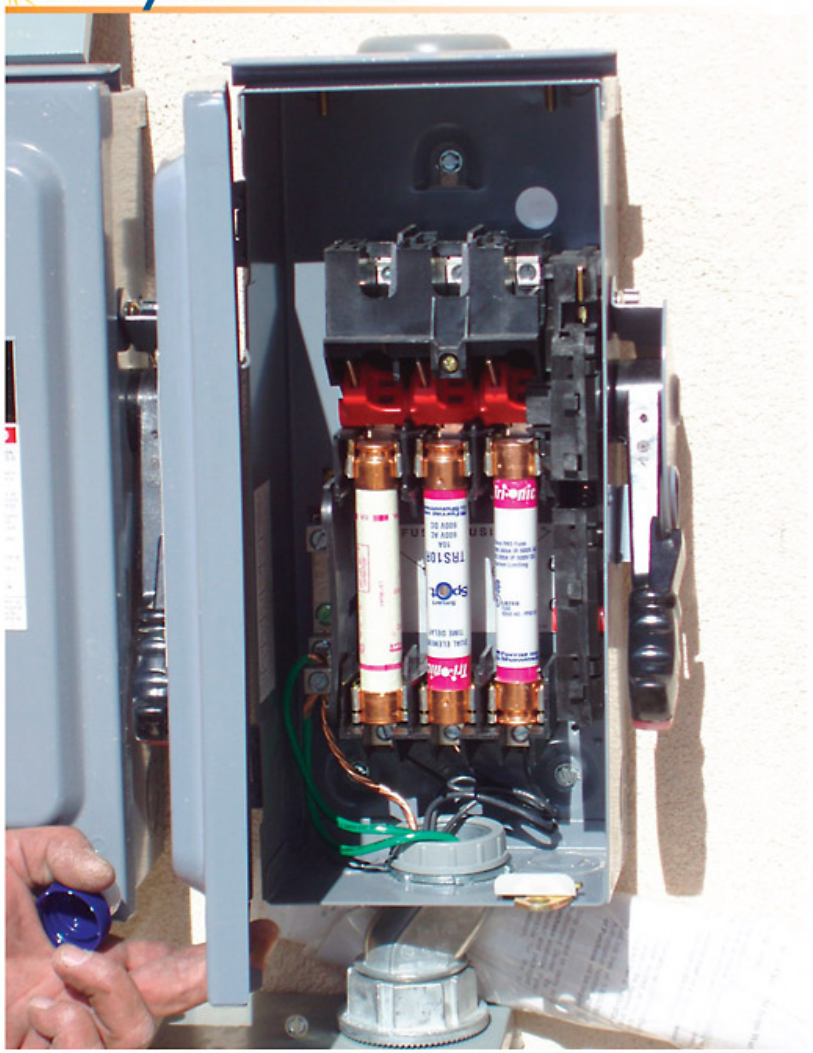


- Connecting a 120 V inverter to a 120/240 V system with multiwire branch circuits causes dangerous overloading in the grounded (neutral) conductor.



- The array disconnect opens all current-carrying conductors in the PV output circuit.

Array Disconnects



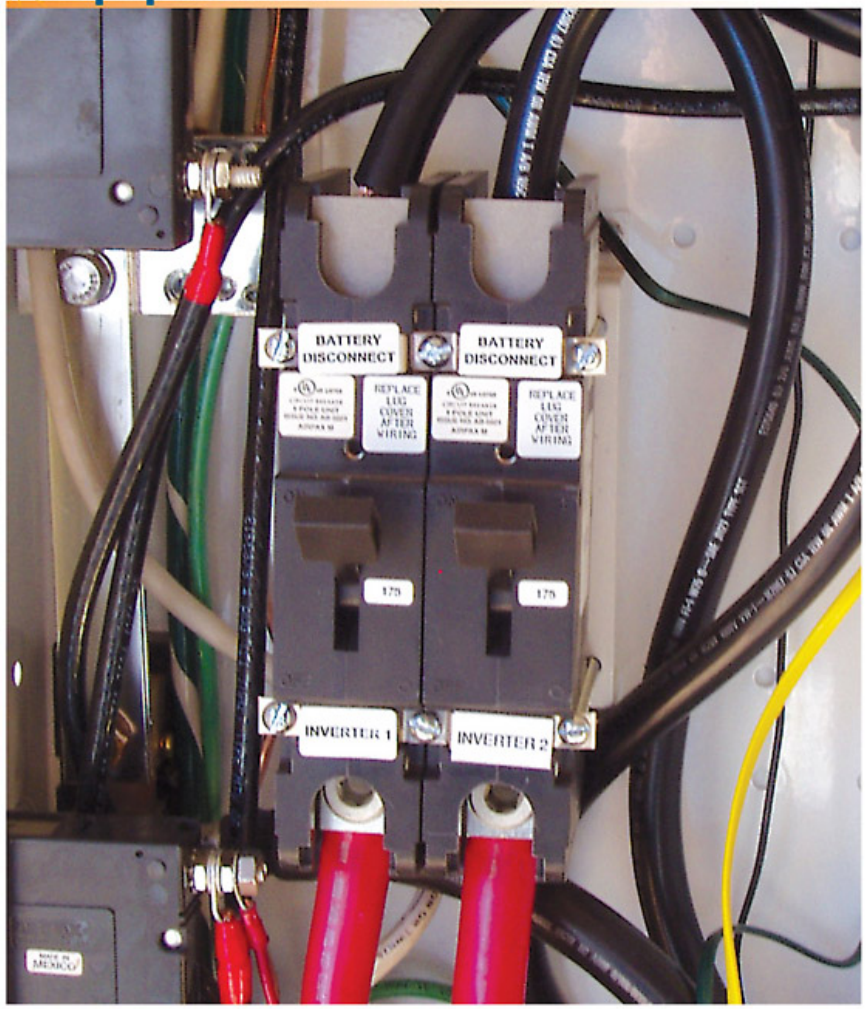
Direct Power and Water Corporation

- The AC disconnect of an interactive PV system should be located close to the main utility service disconnect so that all sources of power can be shut down quickly in an emergency.

AC Disconnects

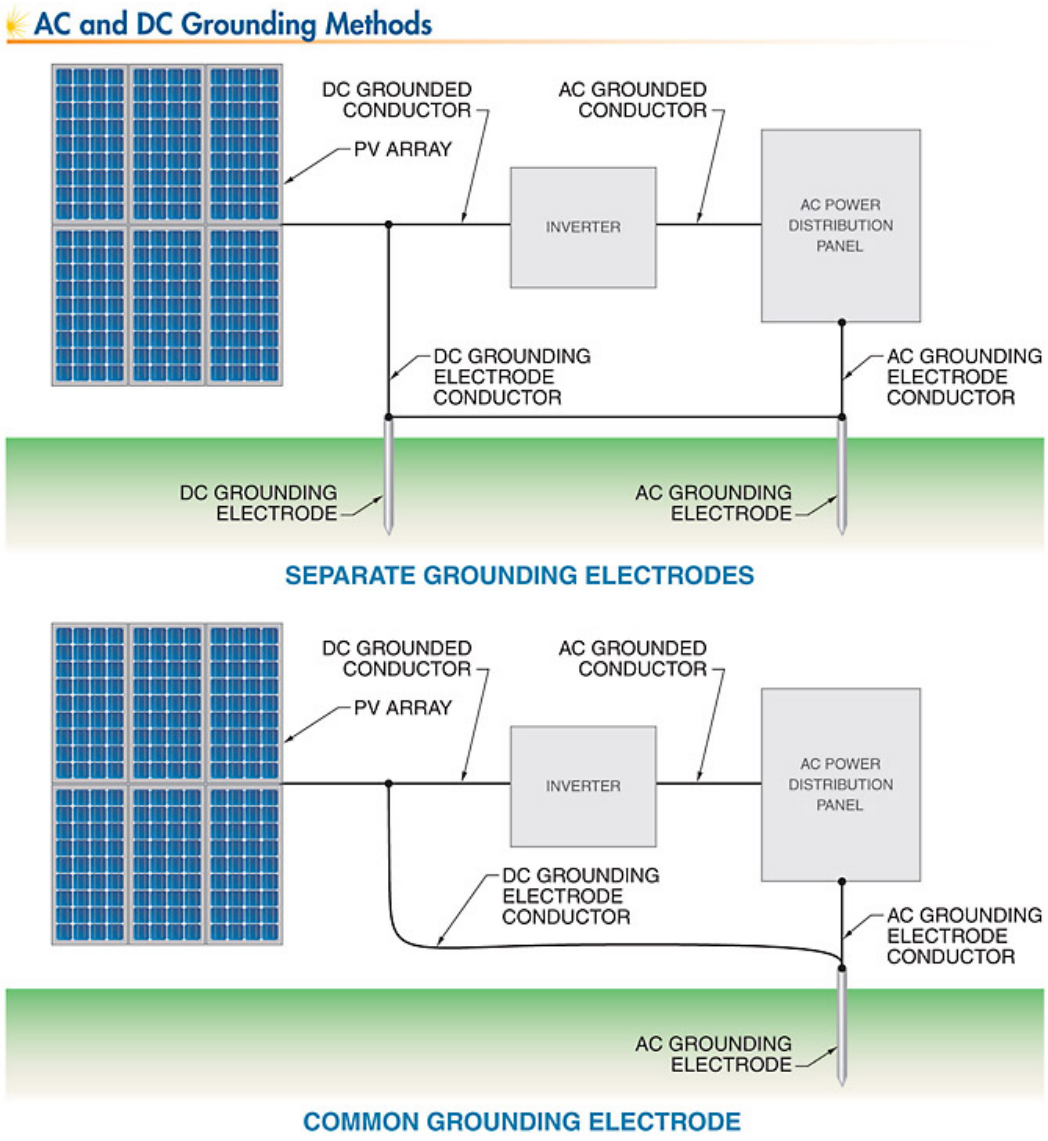
- All major component installations must include switches or circuit breakers as a means to isolate and disconnect them from the system.

Equipment Disconnects



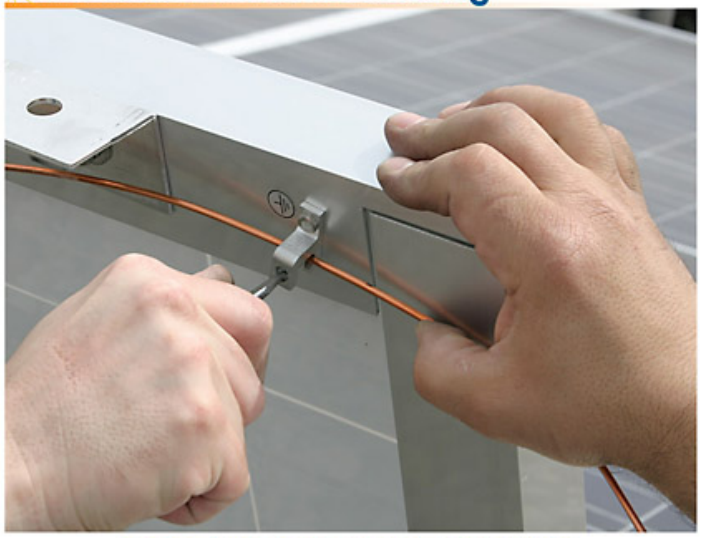
Direct Power and Water Corporation

- There are two acceptable methods of grounding both the AC and DC sides of a PV system.

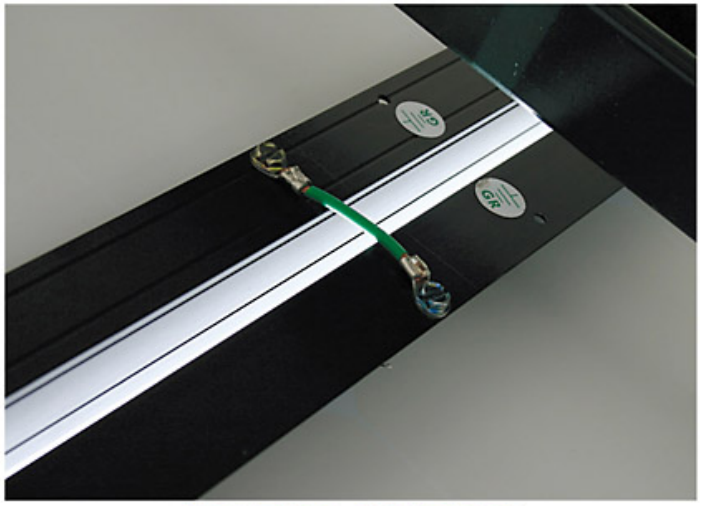


- Modules should be connected to each other and the mounting structure with grounding conductors to ensure a continuous grounding connection.

Module Frame Grounding



CONTINUOUS CONDUCTOR



BONDING JUMPERS

- Equipment grounding conductors are sized based on the rating of the overcurrent protection device in the circuit.

Grounding Conductor Sizing

RATING OF OVERCURRENT PROTECTION DEVICE IN CIRCUIT*	CONDUCTOR SIZE†
15	14
20	12
30	10
40	10
60	10
100	8
200	6

* in A
† in AWG for copper conductors

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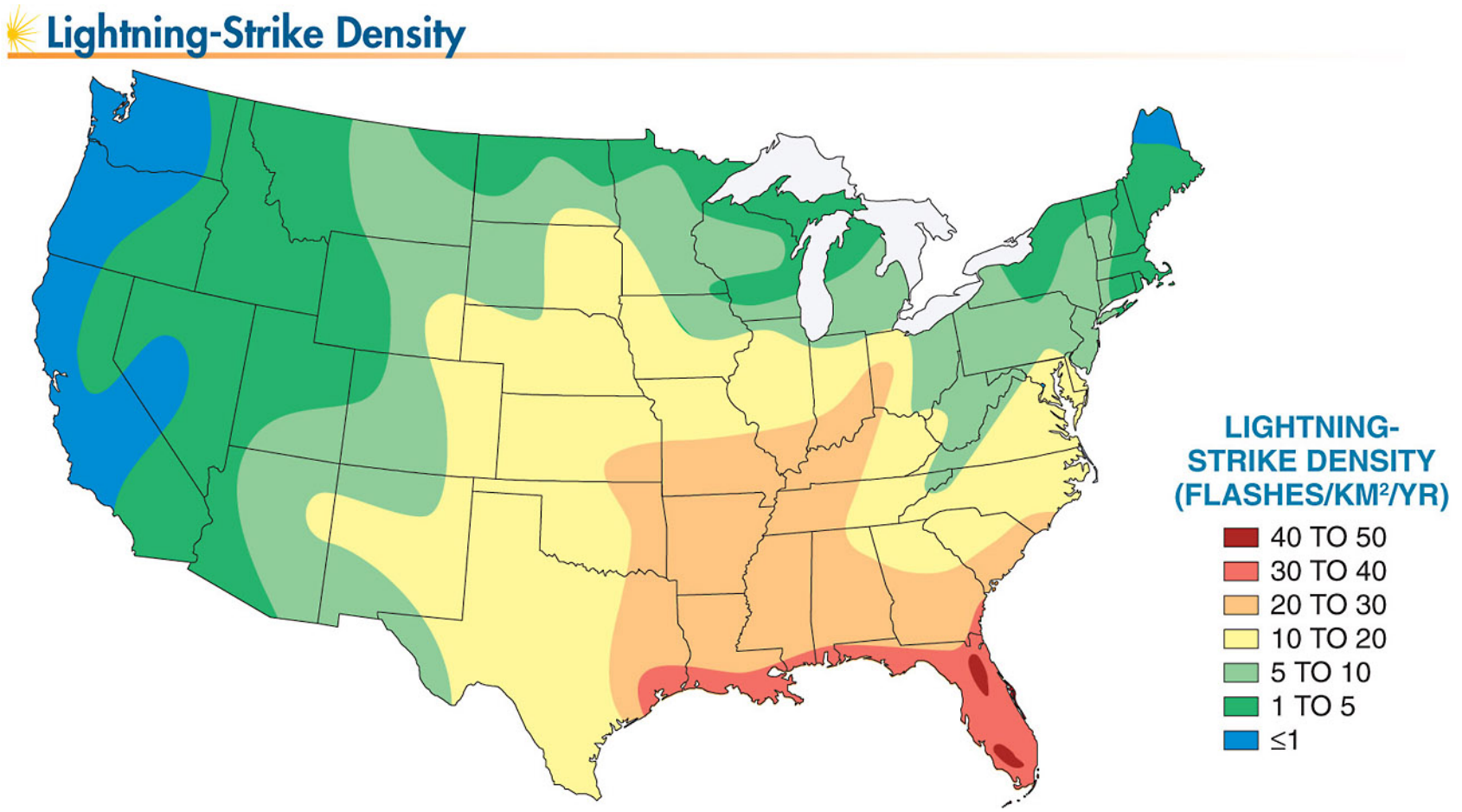
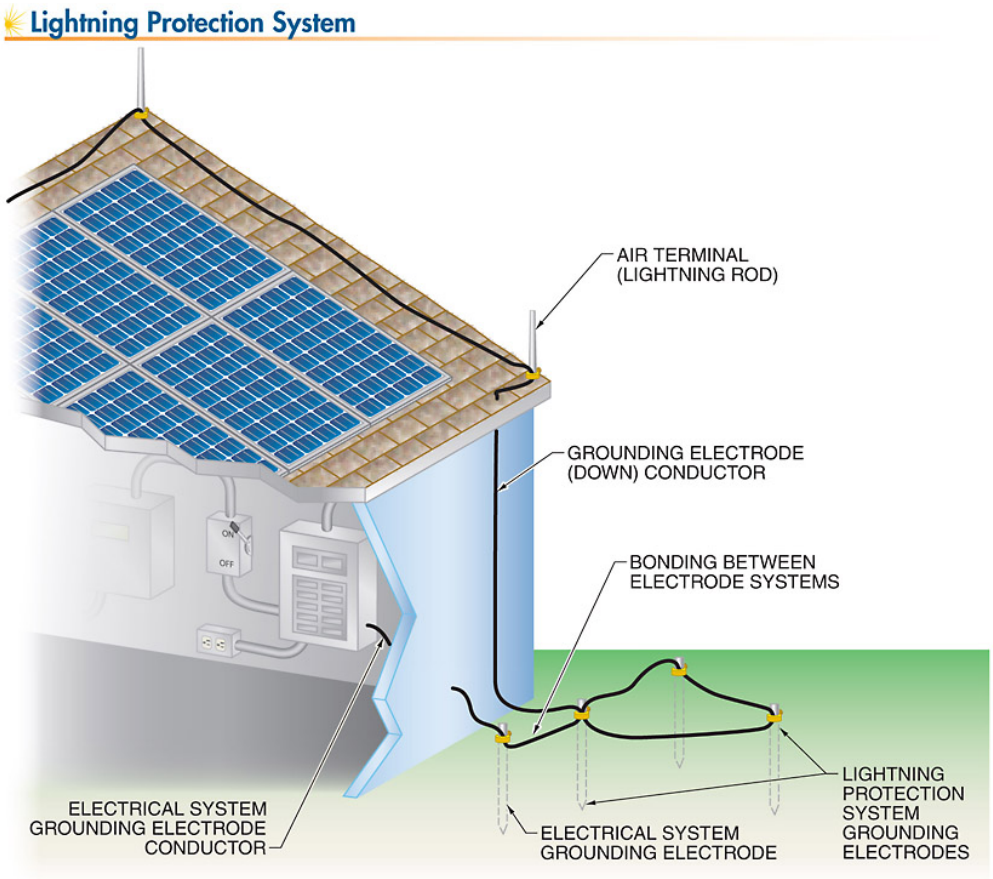
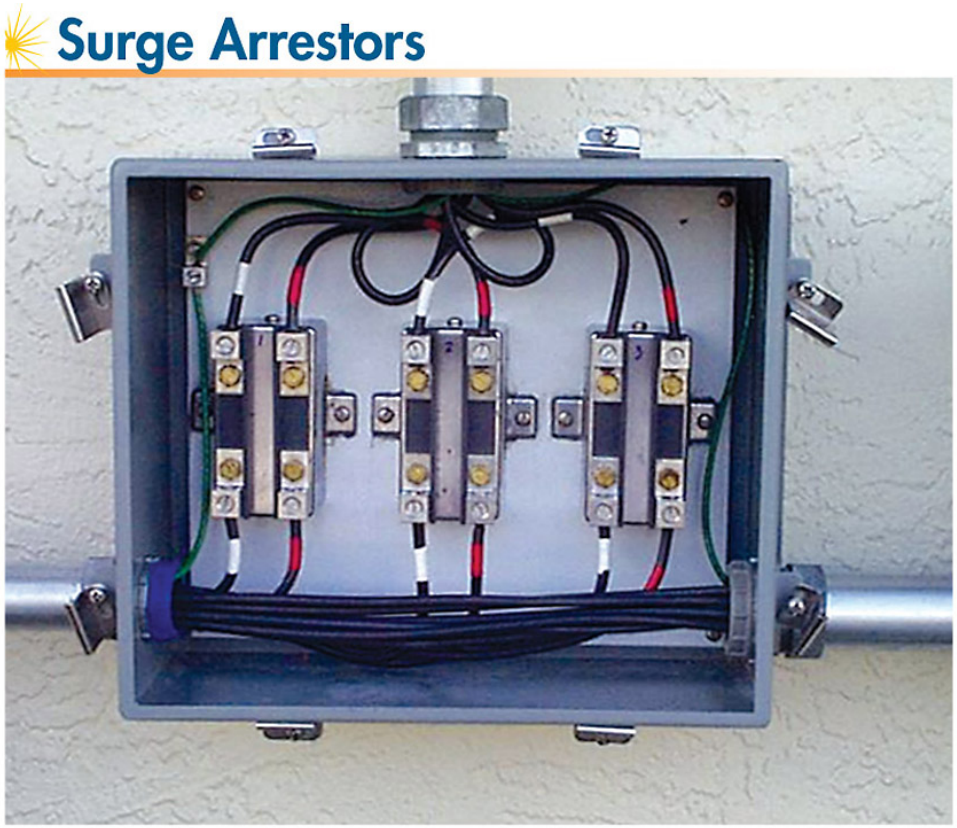
- Lightning protection is especially important in the southeastern states, which have the highest lightning-strike density in the United States.



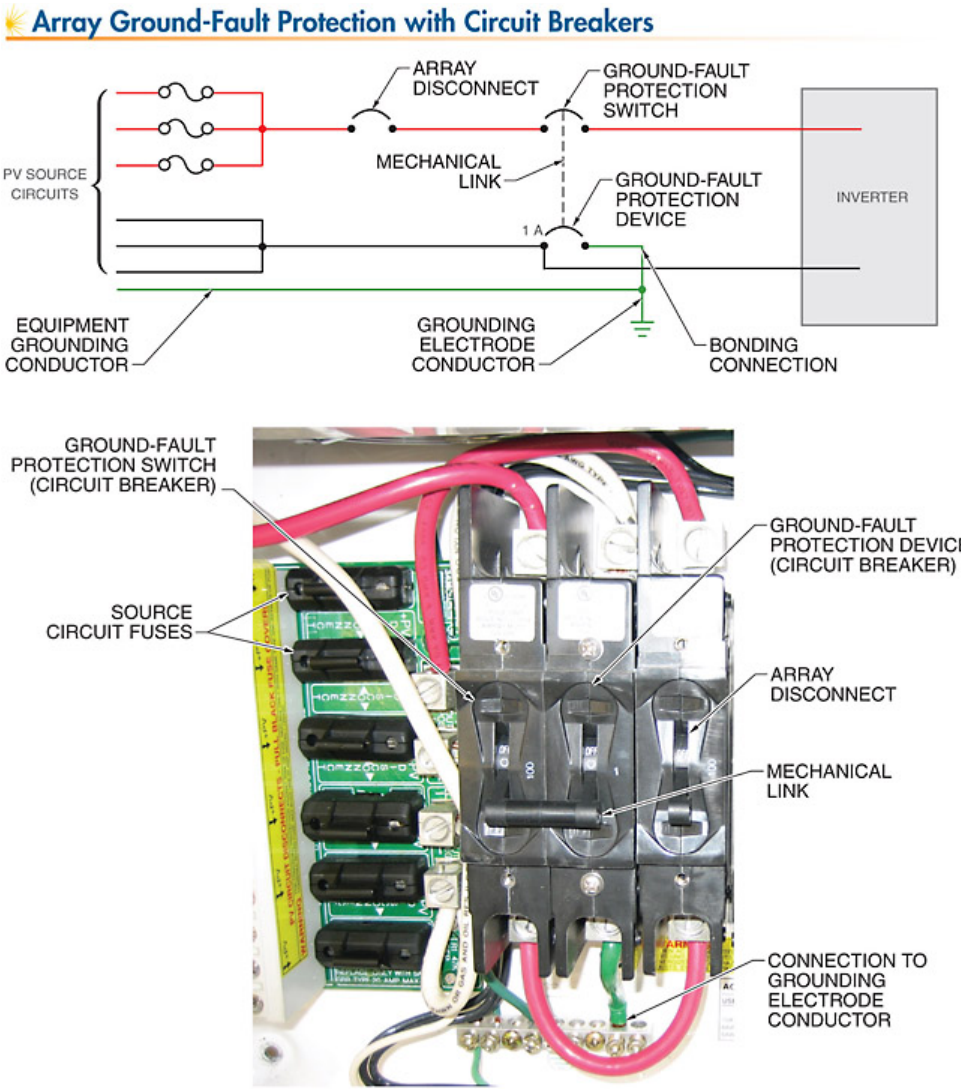
- A lightning protection system includes a network of air terminals, a grounding electrode (down) conductor, and a set of grounding electrodes.



- Surge arrestors may be incorporated into equipment or can be installed on circuits as separate devices.

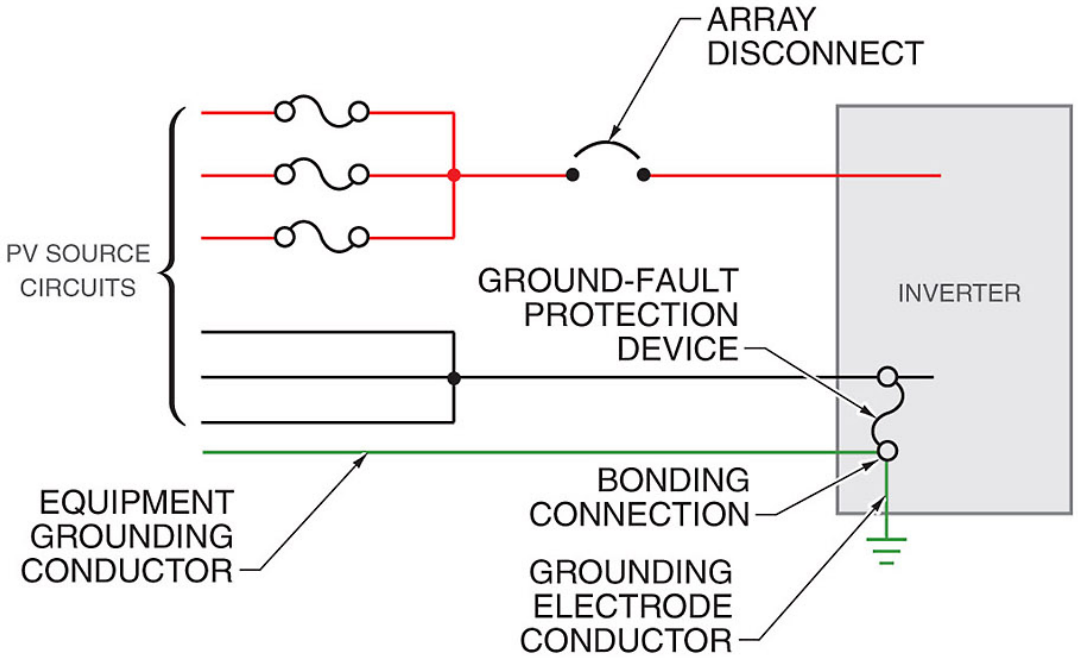


- Circuit breakers can be used for array ground-fault protection when the inverter does not already provide this protection.

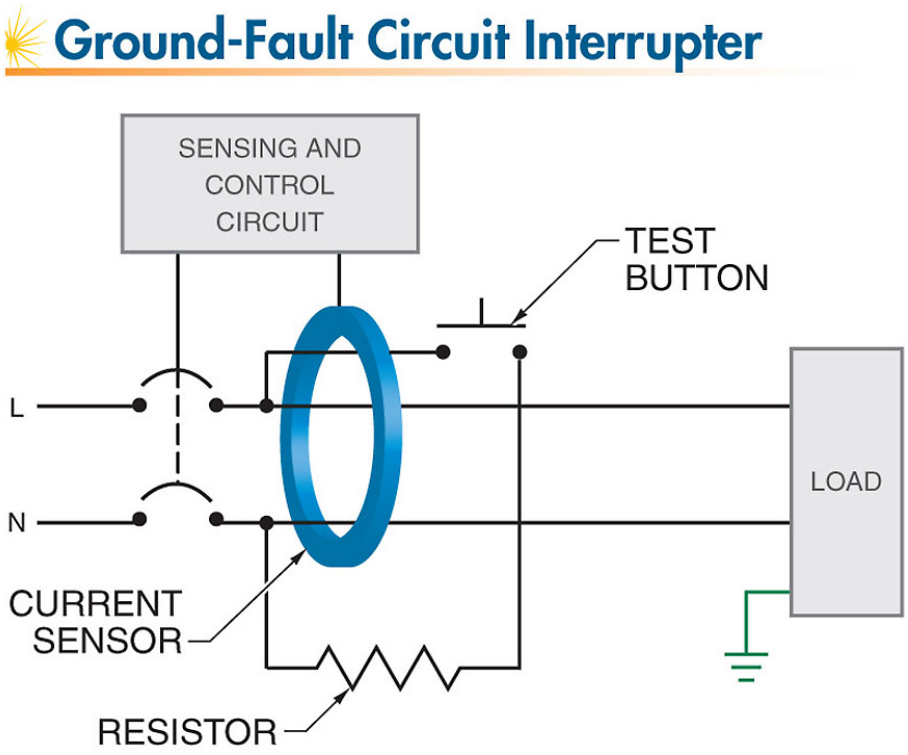


- Some inverters include fuses as array ground-fault protection in their DC input circuits.

Array Ground-Fault Protection with Inverter Fuse



- A ground-fault circuit interrupter (GFCI) senses differences between the current in the grounded and ungrounded conductors, indicating a ground fault, and opens the circuit in response.



- Connectors used for disconnecting battery banks must open both the ungrounded and grounded conductors simultaneously.

Battery Bank Disconnects

Fronius USA LLC - Info & Support - Fro... | Fronius Configuration Tool

Fronius Configuration Tool

Fronius
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Help

Please select your system parameters

System Components

Inverter Model: Fronius IG 3000 (240V)

Module Manufacturer: Mitsubishi

Module Type: PV-UD185MF5

Environmental Conditions ○ °F ◉ °C

Hottest Ambient Temp.: 40°C ... 45°C

Coldest Ambient Temp.: -20°C ... -11°C

Show Module Details ☐

Possible System Configurations

# MODULES \ # STRINGS	1	2
8		2959
9	1665	3329
10	1850	
11	2034	
12	2219	
13	2404	
14	2589*	

Please press a button!

- Array May Be Undersized
- Optimal Configuration
- Array May Be Oversized

*) DC Voltage exceeds UL rating at minimum temperatures chosen. Verify input temperature.