AMERICAN RIVER COLLEGE

Wire Sizing 1

Lesson Plan

- Conductors, PV, and NEC

- 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

- What do we know about conductors?

Conductor Insulation Markings

- 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 in.

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

Type	
T	Thermoplastic insulation
H	High temp 75C
HH	High temp 90C
N	Nylon Jacket
W	Moisture resistant
R	Rubber insulated
U	Underground use
USE	Underground service entrance
UF	Underground Feeder
SE	Service Entrance
-2	90C and wet

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

- Ampacity is the current-carrying capacity of a conductor and depends on conductor type and size.
- From NEC tables 310.16 and 310.17

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).

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 high temperatures.

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

NEC® Table 310.15(B)(2)(a). from NEC® Table 250.122. Reprinted with permission from NFPA 70-2005, the National Electrical Code® Copyright© 2004, National Fire Protection Association, Quincy, MA 02169. This reprinted material is not the official position of the NFPA on the referenced subject which is represented solely by the standard in its entirety.

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

Cable sizing and over current protection

1. Circuit current. For circuits carrying DC current from PV modules, multiply the short circuit current by 125% and use this value for all further calculations. This is called the CONTINUOUS CURRENT calculation.
   - Isc = 8.0
   - Continuous current = ISC * 1.25 = 10.0A

What is continuous current calculation for AC currents?

Rated continuous current – do not multiply by 125% at this step

What is continuous current calculation from battery banks?

Rated AC output at lowest battery voltage

Cable sizing and over current protection

2. Over current device rating. The over current device must be rated at 125% of the current determined in step 1. This calculation is often referred to as the 80% OPERATION current.
   - Isc = 8.0
   - Over current = ISC * 1.25 * 1.25 = 12.5A

What is over current rating for AC currents?

*Rated continuous current * 125%*

What is continuous current calculation from battery banks?

*(Rated AC output /lowest voltage / inverter eff) * 125%*

Cable sizing and over current protection

3. Cable sizing. Conductors shall have a 30C ampacity of 125% of the continuous current to ensure proper operation of the connected over current devices.
   - Isc = 8.0
   - Conductor ampacity = ISC * 1.25 * 1.25 = 12.5A

4. Cable derating. Based on the location of the conductor, conductor size, and temperature rating it may need to be de-rated. The resulting de-rated ampacity must be greater than value in step 1.
   - 14AWG, THWN-2 in conduit with 4 current carrying conductors, ambient temp = 150F
   - De-rated ampacity = 25A * .80 * .58 = 11.6A

Cable sizing and over current protection

5. Ampacity vs over current device. The de-rated ampacity of step 4 must be equal to or greater than the over current device rating calculated in step 2. If the de-rated ampacity of the cable is less then the over current device rating than a larger cable must be selected.
   - De-rated ampacity =
   - Over current device rating =

6. Device terminal compatibility. Most over current devices have terminal ratings of 75C so compatibility must be verified if 90C insulated cable was selected. The 30C current of the same size conductor with the 75C insulation must be greater than the current found in step 2.

Cable sizing and over current protection

7. If the over current device is mounted in a location that has an ambient temperature higher than 40C then the rating of the device must be adjusted per manufacturer's specifications.

Example 1 (we do together):

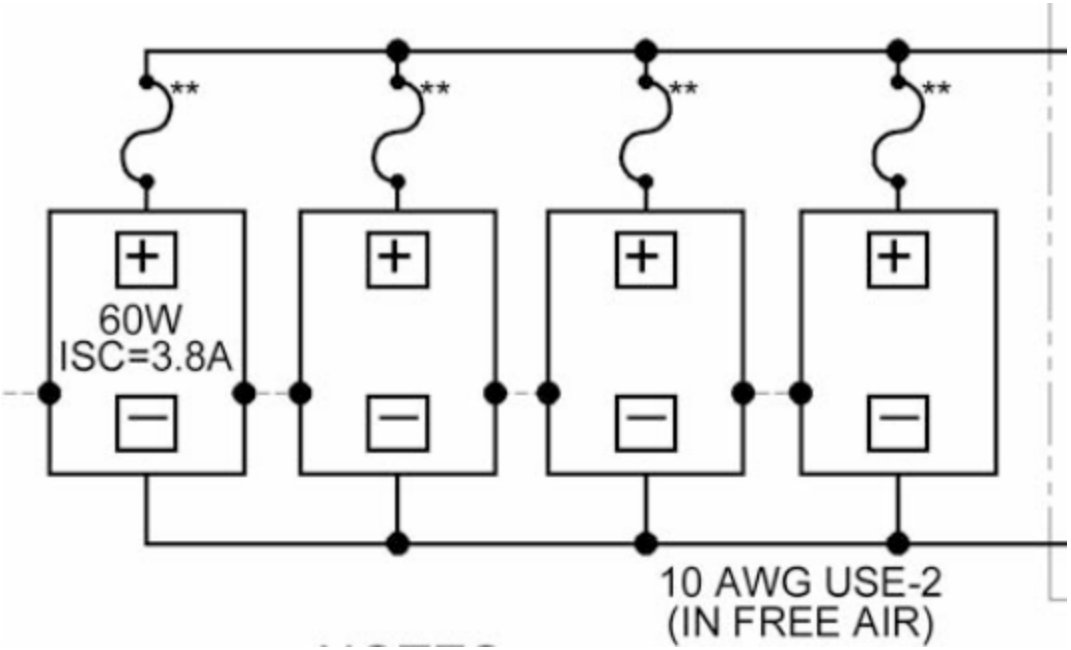
- 2 PV circuits in conduit
- Isc = 40amps
- Ambient temperature of conductors= 45C
- Over current device terminal rating = 75C
- Ambient temperature of over current device = 40C

What do we do?

Cable sizing and over current protection

1. Continuous current = 40A * 1.25 = 50A
2. Over current device rating = 50A * 1.25 = 62.5A
   Fuse = 70A
3. Cable ampacity = 50A * 1.25 = 62.5A
   THWN-2, 6AWG = 75A
4. Derated ampacity = Conduit * Amb Temp
   75A * .80 * .87 = 52.2A
   52.2A > 50.0 so this cable OK
5. Ampacity vs over current rating? No, 52.2A < 70A
   Acceptable size, 4AWG = 95A
6. Over current device compatibility? Yes, 95A > 62.5A
7. Over current device adjustment required? No

Cable sizing and over current protection



Example 2 (breakout into groups and try):

What do we do?

- Array size: 4 12-volt, 60Watt modules
- Isc = 3.8A, Voc = 21.1
- Ambient temperature of conductors= 150F
- Over current device terminal rating = 104F
- Ambient temperature of over current device = 96F