SIERRA COLLEGE

Class 3

Lesson Plan

- Conductors, PV, and NEC

  – Conductor sizing and ampacity

  – Voltage drop

- Next week Conduit

  – We will be bending conduit so shoes are required

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- 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). Excerpted from NEC® Table 310.16 and Table 310.17. 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.

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

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- 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

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

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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

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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%*

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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

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.

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?

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

4. Derated ampacity =   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

6. Over current device compatibility? Yes, 85A > 62.5A

7. Over current device adjustment required?   No

Consider an array of 20 BP3220 modules, two parallel strings of 10 series-connected modules. Use the attached NEC tables and cut sheets answer the following questions. (show your work for partial credit)

a) What is the maximum source circuit current for each string in the array?

$$8.4A * 1.25 = 10.5A$$

b) What is the maximum source circuit current for the PV output circuit (after the source cicuit combiner box)?

$$8.4A * 1.25 * 2 = 21A$$

c) What is the required over current device rating for the PV output circuit?

$$21A * 1.25 = 26A \qquad \text{Next higher fuse size} = 30A$$

d) What is the required PV output circuit conductor ampacity?

$$21A * 1.25 = 26A$$

e) Based on the circuit requirements, select an acceptable conductor for the PV output circuit. Assume 90C rated insulation and THWN-2 conductors.

Use 310.16 or 310.17 table to select conductor based on Required amapacity - 12AWG THWN-2 in conduit

f) If the PV output conductors are in conduit with an ambient temperature of 137F and there are a total of 4 current carrying conductors in the conduit, what is the de-rated ampacity of the conductor?

Two de-rate factors, temp and conduit fill
30A * .80* .71 = 17A

g) What is the conductor that you would recommend to satify all NEC ampacity requirements?

12AWG THWN-2 not acceptable, 17A < 21A – de rate < continuous current

Try next larger conductor, 10AWG THWN-2:
Ampacity = 40A, de rate = 40A * .80 * .71 = 23A:

10AWG THWN-2 not acceptable, 23A < 30A   - de rate < over current rating

Try next larger conductor, 8AWG THWN-2:
Ampacity = 55A, de rate = 55A * .80 * .71 = 31.2A

8AWG THWN-2 provides sufficient ampacity to account for continuous
Current after de rating and exceeds over current device rating

- *What if over current device terminal rating is 60C?*

- *What if we do not have over current device in the circuit?*

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Consider an array of 20 BP3220 modules, four parallel strings of 5 series-connected modules. Use the attached NEC tables and cut sheets answer the following questions. (show your work for partial credit)

a) What is the maximum source circuit current for each string in the array?

$$8.4A * 1.25 = 10.5A$$

b) What is the maximum source circuit current for the PV output circuit (after the source cicuit combiner box)?

$$8.4A *1.25 * 4 = 42A$$

c) What is the required over current device rating for the PV output circuit?

$$42A *1.25 = 52.5A \qquad \text{Next higher fuse size} = 60A$$

d) What is the required PV output circuit conductor ampacity?

$$42A *1.25 = 52.5A$$

e) Based on the circuit requirements, select an acceptable conductor for the PV output circuit. Assume 90C rated insulation and USE-2 conductors.

Use 310.16 or 310.17 table to select conductor based on Required amapacity   - 8AWG USE-2 in free air

f) If the PV output conductors are in free air and operating at an ambient temperature of 155F, what is the de-rated ampacity of the conductor?

One de-rate factors, temp and conduit fill

80A * .58 = 46A

8AWG USE-2 not acceptable, 46A < 60A – de rate < over current rating

Try next larger conductor, 6AWG USE-2:

Ampacity = 105A, de rate = 105A * .58 = 61A

g) The over current device has a terminal rating of 60C and the device is operating at an ambient temperature of 40C. What is the conductor that you would recommend to satify all NEC ampacity requirements?

Look at ampacity of the same conductor with lower temp rating of the Over current device. That ampacity must exceed over current device ampacity

6AWG USE-2 provides sufficient ampacity to account for continuous current after de rating and exceeds over current device rating

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60W
ISC=3.8A

(IN FREE AIR)
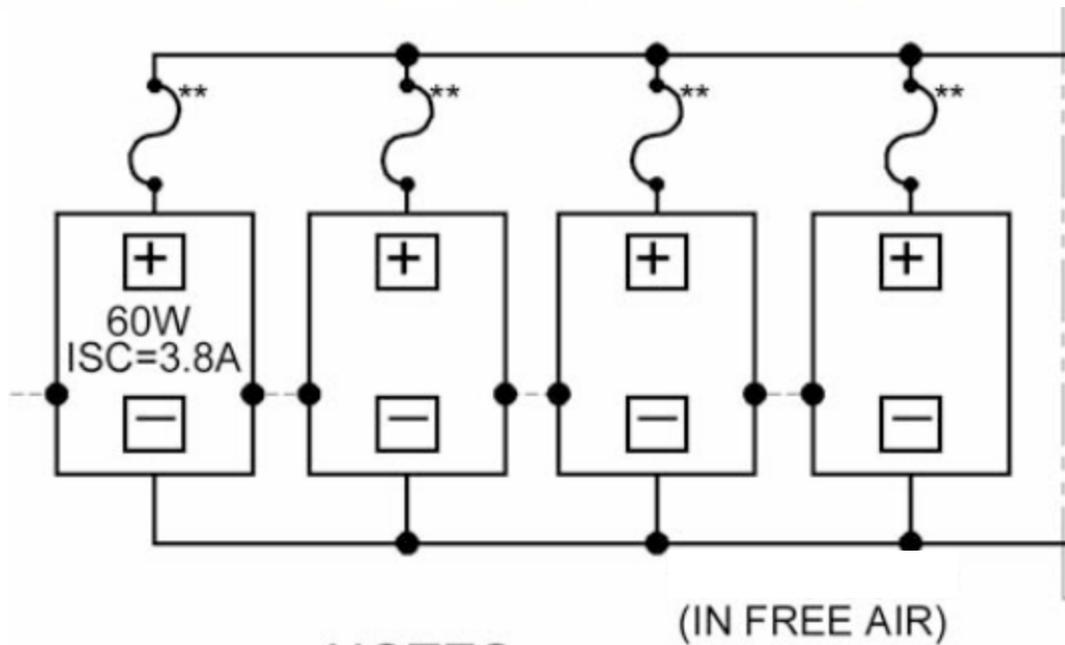
Example 2 (breakout into groups and try):   What do we do?

- Array size: 4 12-volt, 60Watt modules

- Isc = 3.8A, Voc = 21.1

- Ambient temperature of conductors= 150F

- Over current device terminal rating = 140F

- Ambient temperature of over current device = 96F

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1. Continuous current =   3.8A * 4 * 1.25 = 19A

2. Over current device rating =   19A * 1.25 = 23.75A
    Fuse = 30A

3. Cable ampacity =   19A * 1.25 = 23.75A
    USE-2, 10AWG

4. Derated ampacity =   55A * .58 = 32A
    32A > 19 so OK

5. Ampacity vs over current rating?   32A > 30A
    Acceptable size, 10AWG

6. Over current device compatibility? 10AWG USE-2 at 60C = 40A

7. Over current device adjustment required?   No

Array size:

    10 12V, 51Watt modules

    ISC = 3.25A

    VOC = 20.7V

Batteries:

    800 Ahr, 12V

Inverter:

    500W rating, 120VAC

    90% eff

    Min input voltage = 10.7V

68°C MODULE TEMPERATURE
USE-2 IN FREE AIR

51W
ISC=3.25A

JUNCTION BOX

30A 30A

UF 4-2
W/ GND CABLE

CONTROL BOX

CHARGE CONTROLLER

6V @ 200 A-H EACH

THHN   60A   THHN

80A   THHN

15A

+ INVERTER

NOTES:
** OVERCURRENT DEVICE MAY BE REQUIRED BY UL 1703
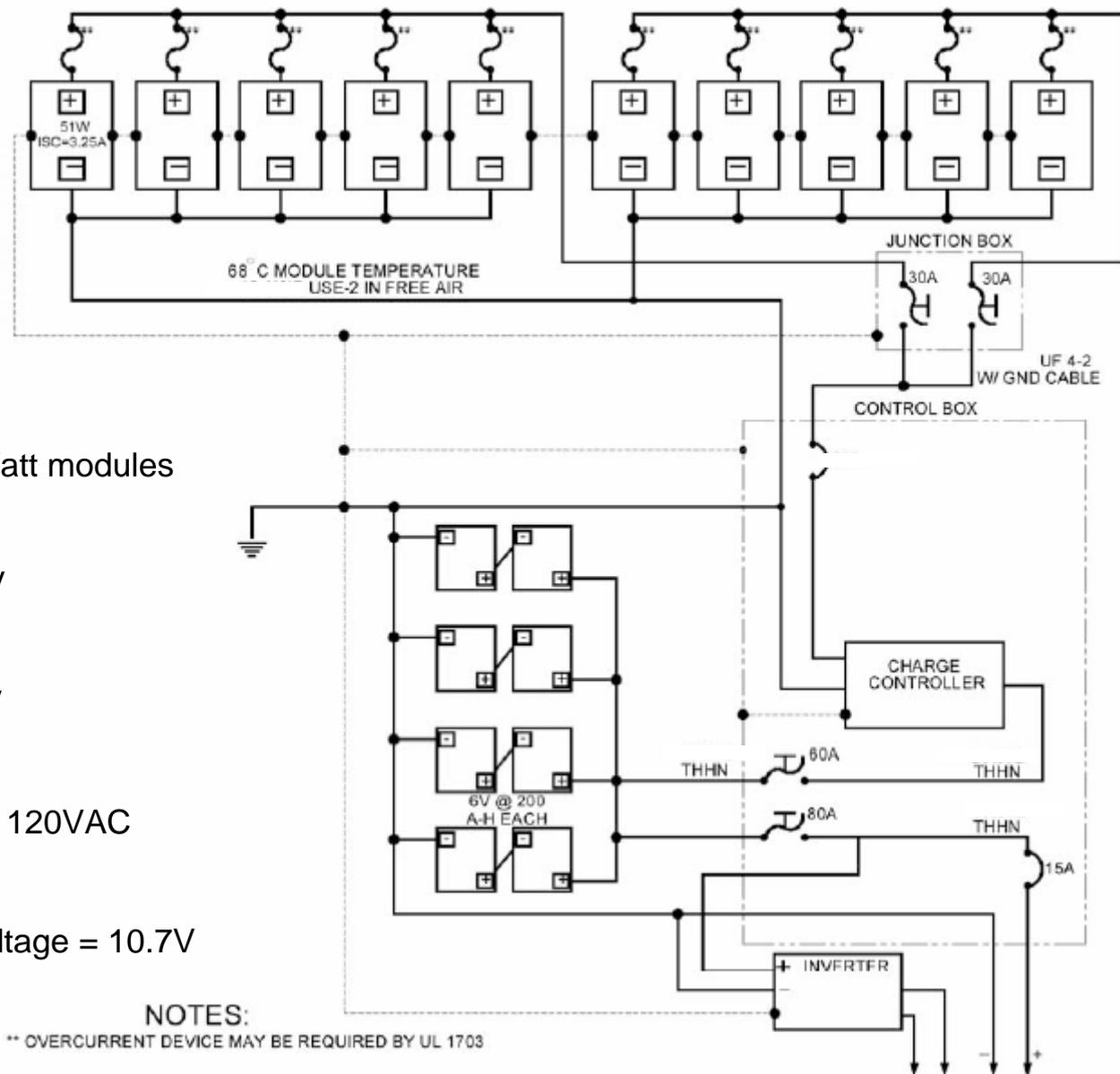
Example 3 (breakout into groups and try):

- Size source circuit conductors for the two sub-arrays
  (USE-2 rated in free air, 68C ambient)

- Size the combined circuit conductors from junction box
  (UF conductor directly buried, 40C ambient)

- Size the inverter output conductor
  (THWN in conduit with 4 current carrying conductors, 40C ambient)

- Size the battery to inverter to conductors
  (THHN in free air, 40C ambient temperature)