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13 Pratts Junction Road
Sterling, MA 01564-2305 USA
Tel: 978-422-3600
Fax: 978-422-0128
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Anderson Power Technical Considerations for Use of Connectors in High Current Applications Including the Use of Parallel Conductors

By: Urs Nager, Christine Svelnis- Anderson Power Products

When using connectors in high current applications, it is critical that the connectors and cables used can withstand the heat generated from the ampacity. When fast charging or heavy discharge rates exceed individual component ratings, paralleling conductors can be used to safely manage high currents, provided important guidelines are followed.

I. Selection of Components for High Current Applications

1. Cable Selection

1.1. Cable Ampacity Ratings

In the United States, The National Electric Code (NEC) is the recognized standard for cable ampacity ratings. The NEC provides extensive information with respect to conductor ratings based on: cable insulation types, temperature ratings, number of conductors, ambient operating environment and free air flow versus restricted air flow. The NEC also covers derating of ampacity of conductors with respect to number of energized conductors and elevated operating ambient conditions.

The NEC gives adequate design guidelines for sizing of all cable and supporting components to carry the required power for the application. In general, the NEC takes a conservative approach for cable ratings and use of parallel conductors to carry the application current requirements.

Examples of cable ampacity ratings for 4/0 awg per NEC:

- Single conductor ampacity in free air, 90°C- Insulation

  Per NEC table 310-17,

Conductor Size	Current Rating
4/0 awg	405 amps/cable

The noted ampacity is for each individual conductor at ambient temperature of 30°C (86°F) and free air flow around the conductor. Note that ampacity from this table is based on the conductor temperature reaching 90°C which is too hot to touch. Using cable at this temperature would require warnings to end users.

1. Three conductors in raceway, 90°C- Insulation

   Per NEC table 310-16,

Conductor Size	Current Rating
4/0 awg	260 amps/cable

The ampacity noted above for 3 or more conductors in a raceway shows a 36% reduction over the single conductor in free air. The ideal rating for a two conductor connector is somewhat greater than the three conductors in a raceway.

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2. More than three conductors in raceway

Refer to table 310-15 when more than three conductors in a raceway. The percent ampacity of three conductors in a raceway is used as a basis.

Conductor Size	No. of Cond. In Raceway	Current Rating
4/0 awg	4-6	80% x 260 = 208 amps/cable

D. Ambient temperature derating factors

NEC provides Correction factors for ambient temperatures higher than 30°. The correction factor is applied to the appropriate ampacity table, 310-17 (free air) or 310-16 (up to three conductors in a raceway).

Conductor Size	No. of Cond. In Raceway	Current Rating 30°C Max. Ambient	Current Rating 42°C Max. Ambient
4/0 awg	4-6	208 amps/cable	208 x .87= 181 amps/cable

E. Additive Effect of derating factors

Once a determination has been made on the required system ampacity for the application, proper copper conductor size for the application will be determined by: the number of conductors, the insulation temperature, free air vs. raceway, and derating for ambient.

1.2. Selection of suitable cable type for the application

Cables with extra flexible copper stranding and with temperature ratings of 90°C are appropriate for most opportunity charging applications.

The cable should meet the requirements of UL 758 (style 3311) and CSA C22.6 #116 (CL 905) and be rated to 600 Volts.

It is important to review the application environment and select insulation types which can resist abrasion, acids, and cleaning solutions.

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2. Connector Selection

2.1. Safety Agency Connector Standards

North American applicable connector safety standards include UL 1977, CSA 22.2- M1985. The UL 1977 category is a recognized component category. The UL suitability for specific equipment must be determined under other UL standards. Chargers are covered under UL 1582 and the Electric Lift Truck is covered under UL 583.

2.2. Ampacity ratings

Connector ampacity ratings are determined by the temperature rise associated with a constant current applied to the connector at the maximum wire size. In some cases, ratings for smaller wire sizes may also be included in safety agency files.

Per UL 1977 Amperage ratings are based on not exceeding the maximum operating temperature of the connector housing, factoring in an ambient temperature of 25°C or 77°F. Per CSA 22.2-M1985, ampacity is generally lower, as it is limited to a 30°C rise in temperature. ***Note:*** *Temperature warnings may be required in some applications if the connector or cable surface temperature exceed 60 ^{o}C and are accessible to being touched*

2.3. Effect of Ambient Temperature

Anticipated maximum ambient temperature of an application must be considered when determining connector ampacity under UL 1977. As the ambient temperature increases, the allowable ampacity will decrease. See examples below:

Max. Operating Temp.	Ambient	Max. Heat Rise from Ampacity
105°C	25°C	80°C
105°C	50°C	55°C

Derating curves should be used to determine allowable ampacity vs. ambient temperature.

2.4. Connector Assembly- Wire Termination

Crimping has become the preferred method of wire termination based on mechanical strength and electrical resistance. In order to achieve maximum connector ratings, the manufacturer's specified crimp tool, die, and locator should be used. Substitute crimp tooling has not been evaluated and voids the safety agency recognition.

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II. Considerations for Paralleling Connectors

3. Specific Considerations for Paralleling Connectors

3.1. Allowance for parallel conductors per NEC 310-4

The NEC permits the use of conductors in parallel for copper conductors of size No. 1/0 AWG and larger provided they are joined at both ends to form a single conductor. When used as parallel conductors, the cross section of the single conductors are added together to determine the total cross-sectional area.

3.2. Component Requirements:

All paralleled conductors for each polarity must be of the same:

- Conductor material
- Conductor cross-section
- Length
- Insulation type
- Terminated in the same manner*

*All terminations should be done at the same time using the same crimp tool

4. Methods for Verifying Balance between parallel Conductors:

4.1. Verification of harnesses before use

- Confirm wire lengths are the same
- Measure Resistance across each crimp
- Measure resistance end to end for each conductor under load

4.2. Verification of Cable Assemblies in Use

- Use a clamp on amp meter to determine current passing through each conductor
- Use an IR camera to quickly scan for hot spots, comparing several charger/battery stations
- Fuse all legs to match cable and connector ratings

4.3. Method to assure that both connectors are connected

Use connectors with auxiliary contacts and create a closed loop circuit which will be continuous when all connectors are connected to trigger the charging sequence. Have automatic shut down in the event any parallel connector is inadvertently disconnected.

5. Other Factors which can create Imbalance

Repeated battery opportunity charging cycles subject connectors to many more mechanical cycles over a shorter time period. Connectors should be checked for contact pitting at the contact interface due to rapid disconnect prior to current returning to zero. Certain chargers have significant capacitance and can damage contact surfaces during plug in.

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6. Specifying your System using Parallel Conductors:

Step One:

Calculate the effective current (I_e) which will be present on the system based on the charger output, battery discharge rate, and truck duty cycle. The effective current is equal to the square root of the sum of the individual I^2' x the individual time durations (t) divided by the total time period (T). This effective I will be the optimum average current which should be considered for sizing of cables or connectors in the system being evaluated. This can be used on truck harnessing and battery cable sizing.

$$I_e = \sqrt{(\sum(I^2\ t)/T}$$

Note: If the maximum current is applied for one hour then maximum current can be used in place of effective current

Step Two:

Determine conductor size required for effective or maximum current. Consider ambient temperature and location of conductors as derating may be required (see 2.1).

Step Three:

Based on conductor size required in step two, decide whether to use single conductors or parallel conductors. Large single conductor cables can become quite stiff and hard for operators to use in some applications. For wire sizes of 1/0 AWG or greater, it is common to use smaller conductors in parallel as noted in NEC.

Step Four:

Calculate effective current for each leg based on a safety factor of 28%

I_e (leg)= I_e x 1.28/2

Step Five:

Determine conductor size for parallel legs, considering ambient temperature and location of conductors as derating may be required (see 2.1).

Step Six:

Determine connector pair that accepts and is rated for the conductor size chosen. Determine if the connector needs to be derated for the ambient.

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Example for practical application

Example 1: Charger output for 1 hour is 500 Amperes. Ambient temperature for the application is 30°C.

Per NEC Table 310.15, 300KCML cable size with 90°C insulation is required for 500A if single conductors are used. Because of cost and stiffness of 300 KCML conductors, parallel conductors are chosen to carry the 500A: 500 x 1.28/2= 320 amps per leg
Per NEC Table 310.15, there are three cable choices for carrying 320 A:

- 3/0 awg rated 90°C (350 A rated)
- 4/0 awg rated 75°C insulation (360 A rated)
- 4/0 awg rated 90°C (410 A rated)

Anderson Power Products has three connectors rated for paralleling conductors that are rated for 4/0 AWG conductor size; SBX 350, SBE 320, and the E320/A320 DIN Series. All three connectors are rated for 105°C. Per the temperature rise charts provided, at 320 A there will only be a 15°C temperature rise from current. The total connector temperature at 320 A will be 30°C + 15°C = 45°C, this is well below the 105°C connector rating, making this an acceptable application.

7. Installation checks

7.1. Check and record resistance of contacts and cables
7.2. Check to assure that both battery and charger components are sized for the expected maximum current flow
7.3. At maximum system current:

- Measure voltage drops
- Measure current sharing of all 4 legs
- Measure temperature of all cables, and connectors to assure that they are under the ratings

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8. Preventive Maintenance and Trouble Shooting:

8.1. Preventive Maintenance:

A. Repeat installation measurements periodically
B. Inspect cables and connectors- look for signs of overheating
C. Inspect connector contacts for pitting at the contact interface

8.2. Trouble Shooting for Overheated Cables or Connectors:

A. Check Resistance of individual contacts and cables

Note: The burned cable or connector might not be the culprit. It might just have been over heated because it had the lowest resistance. The cable or connector without indications of overheating might have cause unequal current sharing because the resistance was very high.

B. Look for hot environments due to cable routing or connector placement

8.3. Replacement of Connectors/Cables:

Overheated cables must be replaced, not repaired. Even though there may only be visible damage at one end of a cable, it should be assumed that the full length of cable has been overheated. Overheated cables will lose flexibility and may crumble during normal cable flexing.

A. Replace all cables and/or both connectors at same time. All crimps should be done with the same crimp tool
B. Check and record resistance of contacts and cables
C. At maximum system current:
   - Measure voltage drops
   - Measure current sharing of all four legs
   - Measure temperature of all cables and connectors to assure that they are under the ratings

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III. Anderson Connectors for High Current Applications

Anderson Power Products has received safety agency approval for double stacked connectors wired in parallel used with either 4/0 awg or 95 mm² cables and at an ambient temperature of 25 ºC. The maximum plate current ratings are established per Underwriter's Laboratories UL 1977 and Canadian Standard Authorities' CSA 22.185 M3-16.

The connectors below have the following specific ratings when double stacked and wired in parallel with the specified wire size. Following these ratings assure the user that the contact has proper cross section for the applied current and that the cable when installed per the manufacturer's recommendations will operate in an acceptable temperature range and will give good service life in the application.

Anderson Power Products' Connectors for Parallel Conductors[1]			
Connector Series	**Cable Size**	**USR Amp Rating[2]**	**CNR Amp Rating[3]**
SBE320	4/0 AWG	700	450
SBX350	4/0 AWG	700	450
A Series DIN 320	4/0 AWG	800	500
E Series Din 320	95mm²	650	500

1- Double Stacked Connectors must be used with APP Manual Release Brackets for Double Stacking. All terminations must be made in a factory with APP specified crimp tooling, dies and locators
2-UL ampacity ratings are based on the total temperature with applied current not exceeding the maximum temperature rating of the insulating plastic per UL 1977
3- The CNR ampacity ratings are based on a 30 Degree Rise in temperature with applied current per CSA Standard 22.2 M 3-16

Consult Datasheet DS-STACK at anderssonpower.com for complete technical data