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Application Considerations

The middle, line-side conductor to this disconnect became loose. The loose connection created an excessive thermal condition that caused excessive damage to the device termination, the middle conductor and the adjacent conductors.

Conductor & Termination Considerations

A fuse, as well as a circuit breaker, is part of a system where there are electrical, mechanical and thermal considerations. All three of these are interrelated. If there is too much electrical current for the circuit, the components can overheat. If a conductor termination is not properly torqued, the termination can be a "hot spot" and contribute excess heat. This additional heat is detrimental to the integrity of the termination means, conductor insulation and even the overcurrent protective device. If the conductor size is too small for the circuit load or for how the fuse/termination or circuit breaker/termination has been rated, the undersized conductor will be a source of detrimental excess heat, which bleeds into the devices through the terminals. This excess heat can cause integrity issues.

How important is the proper conductor size and proper termination methods? Very! Many so called "nuisance" openings of overcurrent protective devices or device failures can be traced to these root causes. Improper electrical connections can result in fire or other damage to property and can cause injury and death. If there are loose terminal connections, then:

- The conductor overheats and the conductor insulation may break down. This can lead to a fault; typically line to ground. Or, if conductors of different potential are touching, the insulation of both may deteriorate and a phase-to-neutral or phase-to-phase fault occurs.

- Arcing can occur between the conductor and lug. Since a poor connection is not an overload or a short circuit, the overcurrent protective device does not operate.
- The excessive thermal condition of the conductor termination increases the temperature beyond the thermal rating of the fuse clip material. The result is that the fuse clip can lose its spring tension, which can result in a hot spot at the interface surface of the fuse and clip.
- These excessive thermal conditions described above may cause the device (block, switch, fuse, circuit breaker, etc.) insulating system to deteriorate, which may result in a mechanical and/or electrical breakdown. For instance, the excessive thermal condition of a conductor termination of a circuit breaker can degrade the insulating case material. Or a fuse block material may carbonize due to the excessive thermal conditions over a long time.

Normally, a fuse is mounted in a fuse clip or bolted to a metal surface. It is important that the two surfaces (such as fuse to clip) are clean and mechanically tight so that there is minimal electrical resistance of this interface. If not, this interface is a high resistance spot, which can lead to a hot spot. With a fuse to clip application, the temperature rise from a poor clip can cause even further deterioration of the clip tension. This results in the hot spot condition getting worse.

The fuse clip on the right has excellent tension that provides a good mechanical and electrical interface (low resistance) between the fuse and clip. The clip on the left experienced excessive thermal conditions due to an improper conductor termination or undersized conductor. As a result, the clip lost its tension. Consequently, the mechanical and electrical interface between the fuse and clip was not adequate which further accelerated the unfavorable thermal condition.

Some Causes of Loose Terminal Connections

Below are some possible causes for loose terminal connections for various termination methods and possible causes of excessive heating of the overcurrent protective device / termination / conductor system:

1. The conductor gauge and type of conductor, copper or aluminum, must be within the connector's specifications. The terminals for a fuse block, terminal block, switch, circuit breaker, etc. are rated to accept specific conductor type(s) and size(s). If the conductor is too large or too small for the connector, a poor connection results, and issues may arise. Additionally, it must be verified that the terminal is suitable for aluminum conductor, copper conductor, or both. Usually the termination means is rated for acceptable conductor type(s) and range of conductor sizes; this is evidenced by the ratings being marked on the device (block, switch, circuit breaker, etc.) or specified on the data sheet.
2. The connector is not torqued to the manufacturer's recommendation. Conductors loosen as they expand and contract with changes in temperature due to equipment running and not running. If the connections are not torqued appropriately, loose connections may result. For a mechanical screw, nut, bolt or box lug type connection, follow the manufacturer's recommended torque. Typically the specified torque for a connector is marked on the device. For a specific connector, the specified torque may be different for different wire sizes.
3. The conductor is not crimped appropriately. A poor crimp could be between the conductor and a ring terminal. It could be between the conductor and the quick connect terminal. Or, it could be between the conductor and an in-line device. If using a compression connection, use the manufacturer's recommended crimp tool with the proper location and number of crimps.

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4. The quick connect terminal is not seated properly. If the male-female connections are not fully seated, a hot spot may be created.
5. The quick connect terminal is being used beyond its amp rating. Quick connects typically have limited continuous current ratings that must not be exceeded. Typical maximum ratings possible for a quick connect are 16 or 20A (some are less); this is based on a proper conductor size, too. If the quick connect is used beyond its amp rating, excessive temperature will result which can degrade the quick connect's tension properties and further overheating issues result.
6. The conductor is not properly soldered to a solder terminal. Again, if there is not a good connection between the two, a hot spot will be created.
7. The terminal is only rated to accept one conductor, but multiple conductors are being used. Again, the product specifications must be checked to see if the terminal is rated for dual conductors. If the product is not marked suitable for dual conductors, then only one conductor can be used for this termination. Inserting too many conductors will cause a poor connection, which can result in heat or other problems.

Other important aspects in the electrical and thermal relationship for circuit components in a circuit are the conductor size, conductor rated ampacity, the conductor insulation temperature rating and the permissible connector device conductor temperature limits. Conductors have specified maximum ampacities that are based on many variables including the size of the conductor and its insulation temperature rating. The NEC® establishes the allowable ampacity of conductors for various variables and applications. In addition, there are some overriding requirements in the NEC® and product standards that dictate the ampacity of conductors when connected to terminals. For instance, the ampacity for a conductor with 90°C insulation is generally greater than the ampacity of a conductor of the same size but with 60°C insulation. However, the greater ampacity of a conductor with 90°C insulation is not always permitted to be used due to limitations of the terminal temperature rating and/or the requirements of the NEC®. (Reference 110.14 in the NEC® for specific requirements.) However, there are some simple rules to follow for circuits of 100A and less. These simple rules generally should be followed because these are the norms for the device component product standards and performance evaluation to these standards for fuses, blocks, disconnects, holders, circuit breakers, etc.

Simple rules for 100 amps and less:

1. Use 60°C rated conductors [110.14(C)(1)(a)(1)]. This assumes all terminations are rated for 60°C rated conductors.
2. Higher temperature rated conductors can be used, but the ampacity of these conductors must be as if they are 60°C rated conductors. In other words, even if a 90°C conductor is used, it has to be rated for ampacity as if it were a 60°C conductor [110.14(C)(1)(a)(2)].

   For instance, assume an ampacity of 60A is needed in a circuit that has terminations that are rated for 60°C conductors. If a 90°C conductor is to be used, what is the minimum conductor size required?

Wire Size	60°C Ampacity	90°C Ampacity
6 AWG	55	75
4 AWG	70	95

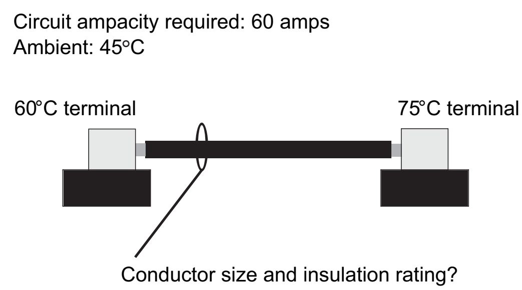
   The answer is 4 AWG, 90°C conductor. A 6 AWG, 90°C conductor has an ampacity of 75 amps per (NEC® Table 310.16); but this ampacity can not be used for a 60°C termination. For this circuit, if a 90°C, 6 AWG conductor is evaluated, the ampacity of this conductor must be according to the 60°C conductor ampacity, which is 55A. Ampacities are from NEC® Table 310.16.

3. Conductors with higher temperature ratings can be used at their rated ampacities if the terminations of the circuit devices are rated for the higher temperature rated conductor [110.14(C)(1)(a)(3)]. However, the industry norm is that most devices rated 100A or less, such as blocks, disconnects and circuit breakers, have 60°C or 75°C rated terminations.
4. For motors with design letters B, C or D, conductors with insulation rating of 75°C of higher are permitted as long as the ampacity of the conductors is not greater than the 75°C rating [110.14(C)(1)(a)(4)].
5. If a conductor is run between two devices that have terminals rated at two different temperatures, the rules above must be observed that correlate to the terminal with the lowest temperature rating.

For circuits greater than 100A, use conductors with at least a 75°C insulation rating at their 75°C ampacity rating.

So why would anyone ever want to use a conductor with a 90°C or a 105°C rating if they can't be applied at their ampacity ratings for those temperatures? The answer lies in the fact that those higher ampacity ratings can be utilized when derating due to ambient conditions or due to exceeding more than 3 current carrying conductors in a raceway.

Example (ampacity and derating tables next page)



Assume that an ampacity of 60A is needed in a circuit with a 75°C termination at one end and a 60°C termination at the other end, where the ambient is 45°C. First, since one termination temperature rating is higher than the other, the lowest one must be used, which is 60°C. The first choice might be a 4 AWG TW conductor with an ampacity of 70A at 60°C. However, in the NEC® the Correction Factors table at the bottom of conductor ampacity Table 310.16 reveals that the 70A ampacity must be derated, due to the 45°C ambient, by a factor of 0.71. This yields a new ampacity of 49.7, which is less than the required 60. This is where a conductor with a higher temperature rating becomes useful. A 4 AWG THHN conductor has a 90°C ampacity of 95A. Again, looking at the table at the bottom of Table 310.16, a factor of .87 must be used, due to the 45°C ambient. This yields a new ampacity of 82.65, which is adequate for the required 60A ampacity.

Could a 6 AWG THHN conductor be used in this application? Its 90°C ampacity is 75A. Using the factor of 0.87 for the 45°C ambient gives a new ampacity of 65.25, which seems adequate for a required ampacity of 60A. However, a 6 AWG conductor of any insulation rating could never be used in this application because the 60°C terminal requires that the smallest amount of copper is a 4 AWG for a 60A ampacity (simple rule 2 in previous paragraphs). The amount of copper associated with a 4 AWG conductor is required to bleed the right amount of heat away from the terminal. The use of less copper won't bleed enough heat away, and therefore overheating problems could result.

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Allowable Ampacities

The table below shows the allowable ampacities of insulated copper conductors rated 0 through 2000 volts, 60°C through 90°C, not more than three current-carrying conductors in a raceway, cable, or earth (directly buried), based on ambient of 30°C (86°F) (data taken from NEC® Table 310.16). The note for 14, 12, and 10 AWG conductors is a very important note that limits the protection of these conductors.

Conductor Size AWG	Ampacity For Temperature Rated Copper Conductors (NEC® Table 310.16) 60°C	75°C	90°C
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

*See NEC® 240.4(D) which essentially limits (with several exceptions) the overcurrent protection of copper conductors to the following ratings after any correction factors have been applied for ambient temperature or number of conductors: 14 AWG - 15A, 12 AWG - 20A, 10 AWG - 30A. Depending on the circumstances of a specific application, the ampacity determined due to the correction factors may be less than the values in Table 310.16. In those cases, the lower value is the ampacity that must be observed. For instance, a 75°C, 10AWG in 50°C ambient would have a derating factor of 0.75, which results in an ampacity of 26.25 (35A x 0.75). So in this case, the ampacity would be 26.25. Since 26.25 is not a standard size fuse per NEC® 240.6, NEC® 240.4(B) would allow the next standard fuse, which is a 30A fuse. The 30A fuse is in compliance with 240.4(D). In a 35°C ambient, the correcting factor for this same conductor is 0.94, so the new ampacity is 32.9A (35A x 0.94). However, a 35A fuse can not be utilized because NEC® 240.4(D) limits the protection to 30A.

Ambient Derating

Conductor allowable ampacities must be derated when in temperature ambient greater than 30°C. The correction factors for the conductor allowable ampacities in NEC® Table 310.16.are below.

Ambient Temp. °C	For ambient other than 30°C, multiply conductor allowable ampacities by factors below (NEC® Table 310.16) 60°C	75°C	90°C	Ambient Temp. °F
21-25	1.08	1.05	1.04	70-77
26-30	1.00	1.00	1.00	78-86
31-35	0.91	0.94	0.96	87-95
36-40	0.82	0.88	0.91	96-104
41-45	0.71	0.82	0.87	105-113
46-50	0.58	0.75	0.82	114-122
51-55	0.41	0.67	0.76	123-131
56-60	–	0.58	0.71	132-140
61-70	–	0.33	0.58	141-158
71-80	–	–	0.41	159-176

Conductor Ampacity Correction Factors For Ambient Temperatures

Conduit Fill Derating

Also, conductor ampacity must be derated when there are more than three current-carrying conductors in a raceway or cable per NEC® 310.15(B)(2). There are several exceptions; the derating factors are:

# Of Current-Carrying Conductors	% Values in NEC® Ampacity Tables 310.16 to 310.19 As Adjusted for Ambient Temperature if Necessary
4 – 6	80
7 – 9	70
10 – 20	50
21 – 30	45
31 – 40	40
41 & greater	35

Termination Ratings

As discussed above, terminations have a temperature rating that must be observed and this has implications on permissible conductor temperature rating and ampacity. Shown below are three common termination ratings and the rules. Remember, from the example above, the conductor ampacity may also have to be derated due to ambient, conduit fill or other reasons.

60°C Can use 60°C, 75°C, 90°C or higher temperature rated conductor, but the ampacity of the conductor must be based as if conductor is rated 60°C.

75°C Can use 75°C, 90°C or higher temperature rated conductor, but the ampacity of the conductor must be based as if conductor is rated 75°C. A 60°C conductor not permitted to be used.

60°C/75°C Dual temperature rated termination. Can use either 60°C conductors at 60°C ampacity or 75°C conductors at 75°C ampacity. If 90°C or higher temperature rated conductor is used, the ampacity of the conductor must be based as if conductor is rated 75°C.