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Cable Selection and Termination Considerations In A Mission Critical Environment

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This **White Paper** describes the importance of both the quality of power distribution equipment and the overall integrity of its installation in a mission critical environment.

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Cable Selection and Termination Considerations In A Mission Critical Environment

The reliability of mission critical power systems depends upon not only the quality of power distribution equipment but the overall integrity of the installation. Incorrect selection of wiring types and the manner in which their terminations are made can imbed underlying risks which may not be immediately evident. As there are many varieties of wiring types, each having properties advantageous for particular applications, there are also many types of wiring termination materials to be considered for system reliability. Incorrect wiring connections frequently become the weakest element in a critical power path. However, to select the proper and most effective conductor termination hardware and evaluate its strengths and understand its shortcomings, an awareness of the various types of cables available, their construction, and the particular applications to which they are suited.

Types of wire termination devices, frequently referred to as connectors or often “lugs”, are one of the most important material selection decisions, especially in mission critical construction. Often, wiring termination failures are found to be the root cause of costly equipment failures and facility downtime. Occasionally assumed to be acceptable if UL listed, various types of wire connectors are not equivalent. UL Listings are very specific about connector suitability for different classes of building wire.

Electrical Conductor Varieties

The terms *cable* and *wire* are frequently interchanged. To be specific, however, *wire* generally refers to a single conductor strand. Whereas *cable* refers to are made from multiple wire strands, either individually insulated and manufactured as a single multi-conductor assembly, or constructed as a group of single bare strands of smaller wire bundled and grouped together to form a single conductor. Cable stranding yields a greater flexibility than that of an equivalently sized solid conductor. Bunching smaller wires prior to concentric stranding gives a cable an additional flexibility than is achieved by concentric construction alone.

Cables are classified based on the wire stranding size, number of strands, and the manner in which the wires are twisted together forming a variety of configurations. The most common types are the four types of concentric cables, bunched cables, and rope laid cables. To decrease cable size, conductors can also be compressed or the stranding compacted.

General building wiring conductors larger than American Wire Gauge (AWG) Number 4 are multi-stranded cables fabricated using a mixture of wire sizes and stranding which were specifically developed for a particular application and are designated as specific Cable Stranding Classes. Conductor stranding is classified by the manner in which the individual wire strands are sized and arranged for a given cable conductor function and are designed to satisfy a particular application’s needs better than standard building wire, which is a concentric wire construction. Stranded conductors are manufactured in a variety of configurations; the most common being *Concentric*, *Bunched*, and *Rope* as follows:

Concentric Construction stranding is further subdivided into four categories: *True Concentric*, *Equilay*, *Unidirectional*, and *Unilay*. True Concentric is generally referred to Concentric and is the



most commonly used concentric stranding conductor. The remaining three wire lays are for specialty uses and are included for reference only.

Concentric or True Concentric is produced using a central wire surrounded by layers of alternately-reversed helically laid wires using a geometric pattern.

Equilay Concentric is produced using a center strand surrounded by additional geometric pattern helically laid wires layers having *alternately reversed lay directions* of the *same* layer lengths.

Unidirectional Concentric is produced using a center strand surrounded by additional geometric pattern helically laid wires layers having the *same lay direction* and *increasing* layer lengths.

Unilay or Unidirectional Equilay is produced using a center strand surrounded by additional geometric pattern helically laid wires layers having the *same lay direction* and *same* layer lengths.

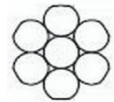
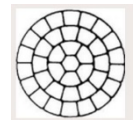
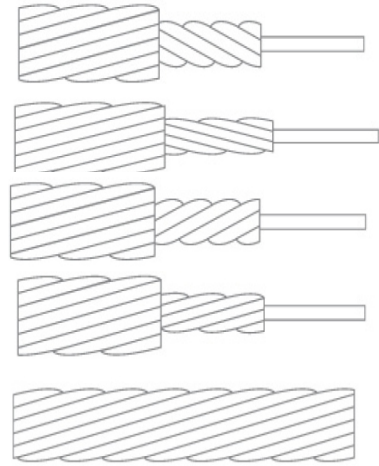
Bunched Strand Construction stranding utilizes a random pattern having a varying number of strands twisted while forming. All strands are the same lay length and laid in the same direction.

This produces rougher surface having a lower dimensional tolerance than concentric wire lays. The total required cross-sectional area together with the individual wire diameter determines required the number of strands.

Rope Strand Construction incorporates groups of single strands arranged into concentric or bunched bundle configurations. The term bunch stranding is applied to a collection of strands twisted together in the same direction. This arrangement provides increased flexibility due to the greater number of fine wire strands and maintains a firmer assembly than simple concentric or bunched fabrication.

Compact Stranding: A compact stranded conductor is manufactured by pre-forming each strand into a trapezoidal shape before the wires are laid together forming the finished conductor. This produces the minimum possible space between strands thereby reducing the cable diameter by about 10%.

Compressed Stranding: Compressed conductors are an intermediate size between standard concentric conductors and compact stranded conductors. The conductor is compressed by putting it through a die which reduces partial the space between strands resulting in an approximate 3% reduction in diameter.



Cables are organized in the following Cable Classes for reference by application. Major Stranding Classes are defined as:

A. Concentric-Lay Conductors

Class B: Power Cables.

Class C: Power cables where more flexible stranding than Class B is desired.

Class D: Power cables where extra flexible stranding is desired.

Rope-Lay and Bunch Stranded Conductors

Class G: All cables for portable use.

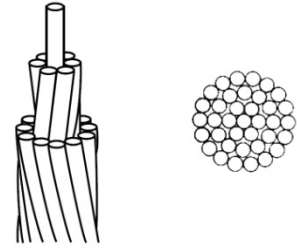
Class H: Cables where extreme flexibility is required. (i.e. take-up reels)

Class I: Apparatus cable and motor leads.

Class K: Cords and cables using No. 30 AWG copper stranding for stationary service use.

Class M: Cords and cables using No. 34 AWG copper wires for constant service.

In building construction, Class B stranding is the most prevalent. Conductors are concentrically laid wire strands which contain air voids between the individual circular strands within the cable, as opposed to *compact stranding*. These cables are suitable for conduit, raceway, and cable tray installation where ordinary flexibility is sufficient for installation. The cable consists of a concentric stranded conductor core surrounded by one or more layers of helically laid wires. Each layer thereafter has six more wires than the preceding layer. Each layer is then applied in a direction opposite to the preceding layer.



For specialized application use such as battery post termination more flexible fine stranding, such as Class K or Class M, is preferred to minimize wire bending push-back to avoid excessive force on the equipment.

Wiring Termination

Basically the purpose of a cable connector is to electrically and mechanically join the cable conductor to the equipment in a manner which provides the following properties:

- 1) Provide a strong mechanical grip providing substantial cable pull-out resistance thereby ensuring a reliable method of mechanically holding a cable conductor in place.
- 2) Provide retention of wire strands within the connector when the cable is flexed.
- 3) Provide a low contact resistance between itself and the bus or device to which the conductor is connected.
- 4) Prevent electrical degradation due to thermal expansion cycling of the connector and wire thereby reducing the clamping forces and increasing the electrical resistance of the connection.
- 5) Provide a gas-tight electrical contact to prevent oxidation and corrosion of the electrical contact surfaces.

Reduce required maintenance and the necessity of re-tightening connections due to conductor extrusion or cold-flow.

For selection of a highly reliable cable termination, consideration of the cable type to be used and an understanding of the conditions most commonly contributing to wire termination failures are needed, for example:

- 1) Poor mechanical clamping of the conductor resulting in thermal cycling and increased junction surface heating.
- 2) Chemical corrosion or oxidation of the termination conduction surfaces.
- 3) Conductor creep from connector due to cable flexing, vibration, mechanical stress, or metal cold-flow as in the case of some aluminum conductor connections.
- 4) Poor workmanship involving improper insulation removal, lost wire strands or stranding not inserted into the connector body, insufficient wire insertion depth, and insufficient tightening of set-screw connectors, or improper crimping of connectors to name a few workmanship root cause failures.
- 5) Use of connectors which have not been identified by UL for use with a particular cable type or location.

Not considering the insulated twist-type of wire connectors used for small branch circuit wiring, there are two principal classes of cable terminations: Mechanical set-screw type, and crimped connectors.

- **Mechanical Connectors:** Set-screw or mechanical connectors are generally the most widely used general purpose connector and frequently preferred by installers owing to their relative inexpensive installed cost, range of acceptable conductor sizes, smaller stocked inventory, and their ability for ready wire removal and re-use. By default, circuit breaker manufacturers usually provide mechanical connectors where cables are directly connected the circuit breaker. Their body is frequently a plated alloy of aluminum or wrought copper.
- **Compression Connectors:** These connectors are generally made of high-conductivity wrought copper and electro-tin plated to improve conductivity and resist corrosion. They are available with a factory applied pre-filled oxide inhibitor, necessary for use with aluminum conductors, and crimped with a variety of crimp styles recommended by the connector manufacturer. The conductor cross-section is compressed during the connector swaging process at the point of crimping. The selection of the crimp style and the total internal connector surface area which is compressed which is a function of the length of the actual connector swaging will affect the performance of the connector connection. An evaluation of the intended application and conductor properties is required to apply the proper termination type.

The use of a compression connector rather than a mechanical significantly reduces the risk cable termination failure and circumvents the necessity of tightening set screws in mechanical connectors. A firmly crimped connector creates a metal-metal colloidal bond at the surface interface of the cable stranding wires and the body of the connector expelling any gas between the surfaces. With the use of an oxide inhibitor, the risk of connection corrosion will be minimized.

Various styles of crimping tools are available, requiring varying installation times and a more extensive tool and die inventory than others. Many emboss the wire size and manufacturer's name and die type for quality verification. The most popular are:

- 1) **Standard Hexagonal Style Crimp:** This type of crimp produces a compression of the cable wire stranding thereby eliminating gas voids between conductors stranding. It produces a very low termination resistance and is preferred for Class B, Compressed, and Compact Stranded Cables. The length of the crimping area with respect to the total connector body determined the overall effectiveness of the connector. Usually multiple compressions along the length of the connector body are requires. Most of these dies also emboss the wire size and manufacturers identification for quality assurance. However, this basic style has not been identified by UL for termination of fine wire stranded cables such as Classes K and M where a different crimping style is needed to resist wire pull-out which can occur during flexing finely stranded wire cables.



Modified or Hybrid Hexagonal Style Crimp: This style die integrates a hexagonal die and a indenter die to create an inspectable and verifiable embossed hex crimp style for use with finely stranded wire flexible cables. A unique hexagonally crimped compression format is produced for one half of the crimp and an indenter tool type of compression is made into the opposite half of the circumference thereby compressing and cinching the finely stranded wires to resist pull-out. The design of this crimp style removes nearly all air gaps from the conductor stranding. Individual wires are compacted tightly together. Only a single indent application is required with this style. These types of dies have been identified for use on finely stranded Class M and K cables. These terminations are recommended for stationary battery UPS system battery connections where fine stranded wiring is used.



Indent-style: The indenter tool produces a short elongated indentation along one side of the connector. This is a popular style of short barrel indentation however only produces an indent into one quadrant of the connector and achieve a large area gas-free compression. Although frequently used for factory installed power wiring and equipment terminal connections, the above two crimp styles are more preferred for facility feeders where space permits their use.



Diamond-style: This style is frequently found on manually-handle compound-action crimping tools which are generally used for heavy-duty battery terminals, cable lugs and butt connectors. These tools can generally exert five tons of force per crimp. The diamond crimp design evenly distributes crimping pressure to fuse a terminal to the copper cable without cracking or distorting terminals. The principal disadvantage of this crimp is that a small surface area of the lug is compressed and is used where short barrel or restricted space connections and more commonly seen in automotive applications than in mission critical construction.



Heavy Duty Hammer Style: This crimper is basically a stored-energy crimper which produces a high pressure indentation force on the connector barrel by striking the anvil plunger with a large hammer. Forces greater than can be obtained with handle crimps are attainable, however no quantitative compression force can be determined for quality assurance.



Variations in feeder termination resistance for paralleled feeders can greatly influence cable insulation life by causing an un-equal current distribution for the paralleled conductors. For feeders loaded near the NEC allowable ampacity, connector terminations having a higher resistance will result in a reduced share of the current total load of the paralleled conductors thereby possibly overloading the remaining conductors.

Termination Testing

A crimp joint of poor quality could be caused by several factors. It is indicated by increased resistance, which cause increase in voltage drop value. For example, the presence of air pockets or voids in the crimped joint will cause a higher resistance (smaller area of contact between terminal and wire). Increased resistance results in a higher voltage drop and a temperature rise, which in turn increases the corrosion rate and further increases the resistance. A crimped joint that has been over-crimped and the conductor (wire) elongated out of shape could cut the circular area of the conductor and cause a greater resistance at this weakened point. Power cable termination quality assurance is frequently difficult perform since it is nearly impractical to visually inspect each connector after installation. Some approaches are:

- 1) Connector Resistance: joint resistance can be measured with a low resistance ohm meter to determine the contact resistance between a connector and its conductor. The measured results are in the micro-ohm range and are difficult to isolate from the meter's test probes. Since cable to connector joint resistance will be small, resistance values will be expressed in units of miliohms or microhms. Furthermore, since there are a wide number of combinations of wire and lugs available, maintaining a table of acceptable values is nearly impractical.

Nevertheless, acceptance testing is required. A typical method of acceptance testing is to place the connection at load design conditions or at NEC listed ampacities and to observe the temperature rise with an infrared thermometer. Although this approach does not provide a numerical value for contact resistance, a visual comparison can be made of the connection relative to a length of conductor located at a distance from the joint sufficient to make a subjective determination of a connection's performance.

Voltage Drop Test: A test of the voltage developed across a component or conductor being a result of electric current flow in the component or conductor and its non-zero electrical resistance. It is the test of the electrical integrity of the crimp. Again since crimp voltage drop values are also quite small it is difficult to form an opinion on acceptable values for joint acceptance.

A more effective method is to determine the relative resistance of a joint. It is defined as the electrical resistance across the crimp as compared to the resistance of an equivalent length of wire, and expressed as relative resistance for a particular wire size. Relative resistance values of less than 1.0 denote a crimped joint with less resistance than the wire. Values more than 1.0 indicate greater resistance than the wire. Generally, it is more convenient to determine the voltage drop across the lug connection as compared to the voltage drop across an equivalent length of conductor. Knowing the current, the resistance value is then calculated from Ohm's Law. It then becomes possible to specify the lug performance requirements in terms of relative equivalent conductor length ratio such as a range 1.01 to 0.99.

Return On Investment

After considering many installation options which may offer the highest payback in mission critical facility construction, the initial use of properly selected and applied compression cable termination connectors is paramount. The differential cost between compression connectors as compared to the cost of standard mechanical set-screw connectors is likely to have the greatest payback in the life cycle cost of the facility by ensuring the longest operational uptime which would otherwise be diminished by both planned maintenance for re-tightening of mechanical connectors and lost revenue caused by equipment failure recovery.