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THE CONNECTOR CORRECTOR

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Fault Current and the Effects on ClampStar®

By Waymon Goch

The terms fault and short circuit in electric power systems are frequently used interchangeably but there are slight differences. A fault can be defined as any abnormal flow of current whereas a short circuit is a current that completely bypasses the load by flowing directly to ground (earth) or by returning to the source. Thus, a very low or zero impedance short circuit is a fault but a high impedance fault may not be a short circuit since current may continue to be supplied to the load.

Single phase faults can be line to ground, line to neutral, arcing, or open and can be momentary (transient) or persistent. A transient fault is cleared after power is disconnected for a short time whereas a persistent fault must be corrected. The effect on insulation depends upon whether the insulation is self-restoring or not.

In polyphase systems a fault that effects all phases equally is a symmetrical fault. If only some phases are involved, an asymmetrical fault occurs. Asymmetrical faults are more difficult to analyze because equal current magnitudes in all phases no longer applies and methods such as symmetrical components are normally used for analysis.

The suggestion for this particular article came from recent laboratory fault current tests during which the participants were surprised by melting (fusing) of the test conductors while the ClampStar® units remained near room ambient temperature. From our viewpoint, those results were as expected. *(See Video Gallery, High Current Test at www.ClassicConnectors.com).*

Conductor fault current ratings are used to determine the suitability of a given conductor material and construction to withstand the anticipated fault current magnitude and duration without jeopardizing the mechanical integrity of the conductor.

Fault currents can result in very high currents in conductors from initiation until the fault is cleared by protective devices such as circuit breakers, fuses, reclosers, etc. Modern relaying typically limits the fault duration to fewer than 20 cycles on transmission circuits but may be longer for distribution. When multiple attempts at reclose occur, the total fault current exposure time is the sum of the interruption times.

Figures 1 and 2 are fault current versus time curves for a range of AAC and ACSR conductors. These particular curves are taken from the Southwire Overhead Conductor Manual. They are also available in the Aluminum Association, Aluminum Electrical Conductor Handbook as well as other handbooks and publications (and if such tables are not available, they can be generated by the following equations).

ACSR: $I = 0.0862\ A / \sqrt{t}$

AAC: $I = 0.0671\ A / \sqrt{t}$

Where: I = Current in Amperes, A = Cross-sectional area, cmil, and t = Time, seconds

The following metal characteristics are needed to calculate fusing (melting) time;

- melting point, ^{o}C
- density, grams/cm^{3}
- specific heat, calories/gram/ ^{o}C
- resistivity (ρ), ohm-cm
- sp ht x melting point x density = cal/cm^{3} to melt wire or section
- multiply cal/cm^{3} x volume (cm^{3}) = calories to melt
- multiply by 4.61 joules/cal = joules required to melt
- resistance (R) = ρl/A (resistivity x length / area = ohm-cm x cm/cm^{2} = ohms
- time to melt = I^{2} Rt = joules or watt-seconds to melt
- t = joules / I^{2} R (time to melt is inversely proportional to I^{2})

The difference in acceptable fault current limits for ACSR and AAC results primarily from the difference in established allowable temperature. For AAC and other all aluminum construction a limit of 340^{o}C has been established since momentary exposure to this temperature does not result in significant loss of strength.

For ACSR, and other conductors with high steel core content, an upper limit of 645^{o}C represents the threshold of melting of the aluminum and the unaffected steel core is expected to maintain sufficient mechanical strength, although the contribution to overall conductor strength (RBS) of the aluminum strands may be substantially reduced.

Of significant interest to most people, and the reason the referenced fault current tests were conducted, is that the electrical interface of a connection is commonly known to be significantly degraded by severe fault currents. This is particularly true of aged connectors where some portion of the interface has already been degraded due to natural aging, and while the remaining available interface may be sufficient to carry the normal current load of the system, the mechanical and electrical stress induced in a connector during a fault event will often destroy the remaining interface resulting in a catastrophic failure, or degrade it such that a mechanical failure is imminent in the near future under moderate to heavy loads. It is also important to note that a partially degraded interface resulting from natural aging is almost impossible to detect with either resistance readings or infrared under normal loading conditions.

Heating of the conductor occurs more rapidly than cooling and although fault currents can also result in mechanical forces (which can be calculated from readily available information in handbooks and other sources) the primary consideration for conductors is thermal.

Fault current limits for copper conductors and accessories can be calculated in the same manner and three common formulae have been developed over the years.

A formula developed by W.H. Preece ($I = \alpha d^{3/2}$) in which I = fusing current, d = wire diameter in inches, and α = a constant depending upon the material which, for copper is 10,244. Although this formula was widely used it proved to be inaccurate in many cases because it assumed that all heat loss was due to radiation. The formula, $I = kd^{n}$ can be used with accuracy if k and n are known for a particular case.

Figure 3 is a fusing current curve for copper conductors from 30 AWG to 500 kcmil prepared by E.R. Stauffacher that assumes no radiant heat loss due to the short times involved, a copper melting temperature of 1083^{o}C and ambient temperature of 40 ^{o}C.

I.M. Onderdonk also developed a simpler equation for calculating the fusing time for copper conductors and copper connectors:

$33\,(I/A)^2\,S = \log\,[(Tm - Ta\,/\,234 + Ta) + 1]$
or:
$I = A\,\sqrt{\ }\,\log\,(Tm - Ta\,/\,234 + Ta + 1)\,/33S$

Where: I = current in amperes, A = conductor area, circular mils, T = time current applied, seconds, Tm = melting point of copper, °C, and Ta = ambient temperature, °C

Not surprising, this is called the Onderdonk equation which can also be used to estimate the performance of soldered, brazed, and bolted copper connections, using appropriate melting temperatures for the solder and brazing alloys of interest. For bolted connections, a generally accepted value of Tm is 250 ℃.

It is important to determine the available fault current at the location of interest. Such studies normally begin with a line diagram showing all loads and potential sources of fault current. (During a symmetrical fault, induction motors will contribute only during the asymmetric portion of fault current but synchronous motors may contribute 4 – 6 times their full load current to all fault locations). Capacitors may also be a factor under some conditions. Protective devices are not normally included in the line diagram.

Worst case short circuits are normally based on bolted 3 phase fault conditions in which all three phases are "bolted" together to obtain a zero impedance fault. This results in maximum thermal and mechanical stress in the system and typically assumes infinitely available fault current from the primary source.

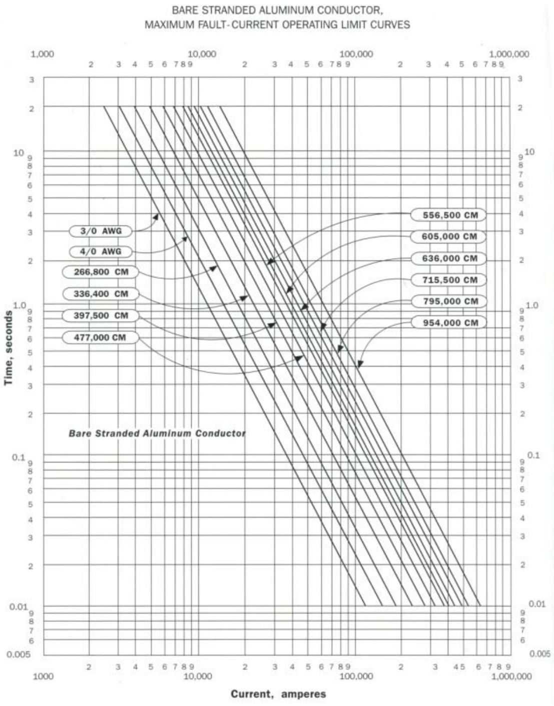
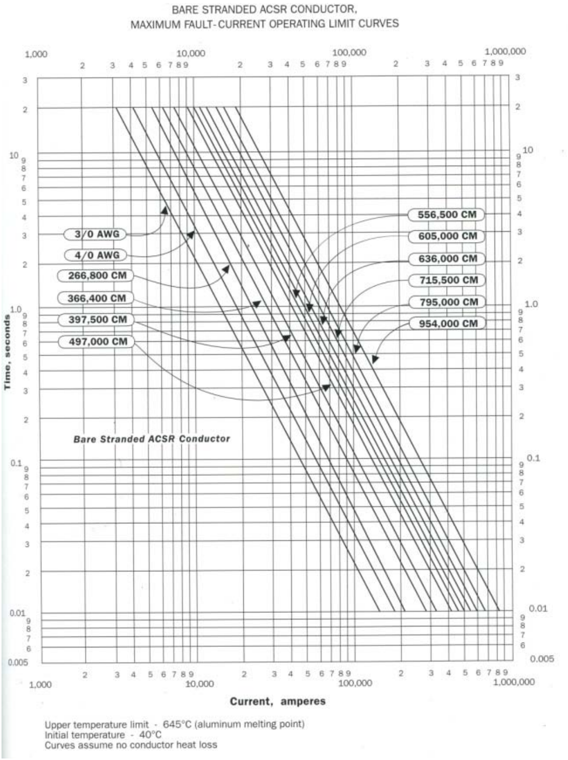


Figure 1 Bare Al current – time



Upper temperature limit - 645°C (aluminum melting point)
Initial temperature - 40°C
Curves assume no conductor heat loss

Figure 2 Bare ACSR current – time

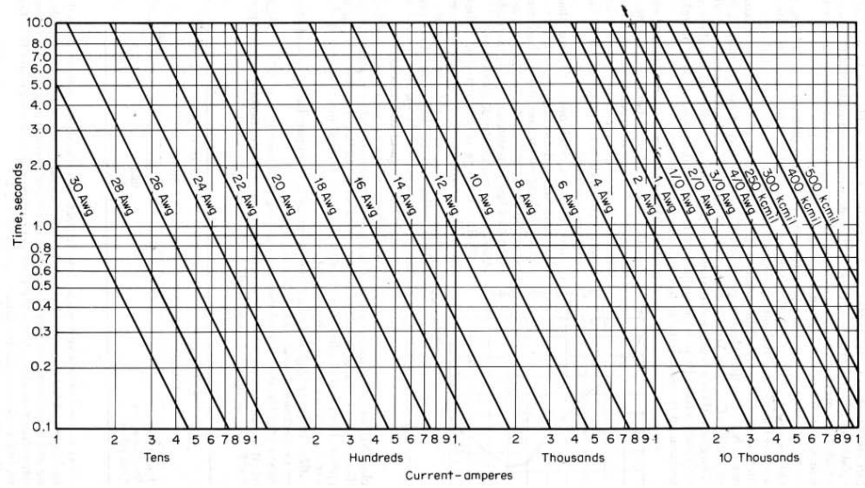


Figure 3 Copper current - time

Recommended reading: “Hard to Find Information About Distribution Systems, Volume 1”, Jim Burke, September 18, 2006 (www.quanta-technology.com).

References: “Standard Handbook for Electrical Engineers“, Fink and Beaty, McGraw-Hill

IEEE Std 738, “IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors” may also be useful. It can be used to calculate both steady-state and transient thermal ratings and conductor temperatures.