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MUNICIPAL POWER

Fuse Coordination Fundamentals for Line Workers

Have You Ever Wondered….

- *Why does the lateral fuse blow when the transformer has a fault?*
- *What causes a fuse link to “pull part”?*
- *Should I increase the fuse size to prevent reoccurring lateral outages?*
- *What is the difference between K, KS, T and X fuses?*

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Agenda

- Common fuse types
- Fuse ratings and construction
- Operation of fuses
- Inrush and cold load pickup
- Factors affecting fuse size selection
- Distribution protection philosophies

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Common Distribution Fuse Types

Common Types of Distribution Fuses

Expulsion

Power

Current Limiting

Photo credits: Hubbell Power Systems (left), S&C Electric Company (middle), Eaton (right)

Expulsion Fuses

- Typical interrupting capability: 8kA - 16kA
- Subject to limitations
  - Fuse links typically good for all distribution line application
  - Due to high X/R ratio, power fuses or CLF often needed inside sub

Current Limiting Fuses

- Used for short circuit protection where
  - Necessary to limit the fault current and fault duration (total energy)
  - Venting of arc gases not allowed
  - Quiet operation is required
- Interrupting capability as much as 50kA
- Additional protection may be needed for overload or low-level faults

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Operation of Fuse Links & Current Limiting Fuses

Expulsion Fuse Link Operation – Bone Fiber Tube

- Heat from high current melts fuse link
- Arc develops and erodes fuse core
- Fragments react with water contained in the arc extinguishing material from the fuse tube core
- Resulting gases expel debris from fuse tube
- Arc is extinguished at the next zero current

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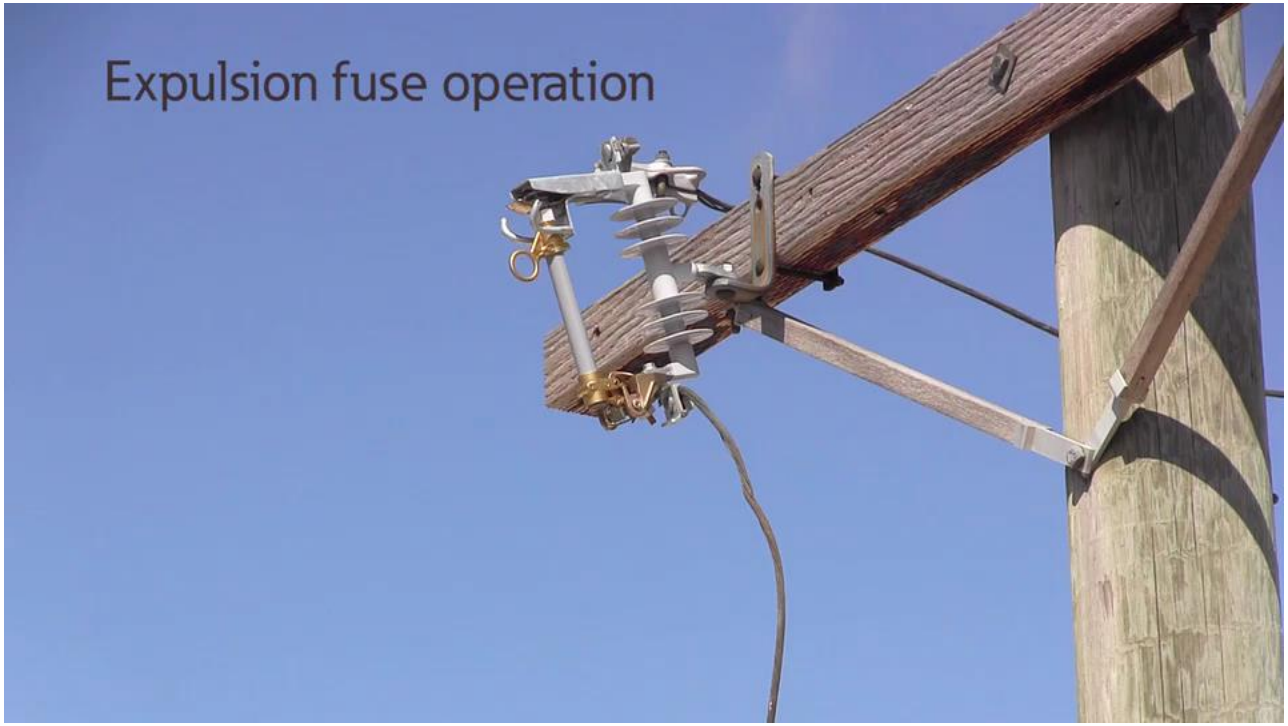
Expulsion Fuse Link Operation

- Extinguishing material inside tube is either bone fiber (pre-2000) or polymer
- Condition of tube (liner and exterior) matters
- Clearances are important because ionized gases expelled from tube are conductive

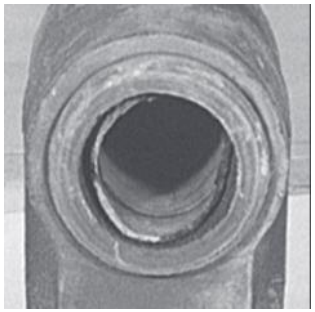
Expulsion Fuse Link Operation



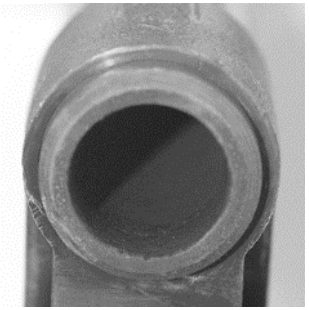
Video credit: Eaton

Fuse Tube Inspection

S&C recommendations for 100A barrel replacement



Bone fiber liner
Diameter of liner is greater than 11/16”

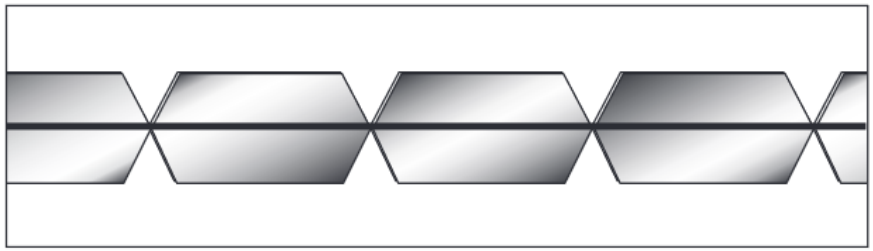


MultiWind liner
Diameter of liner is greater than 23/32”

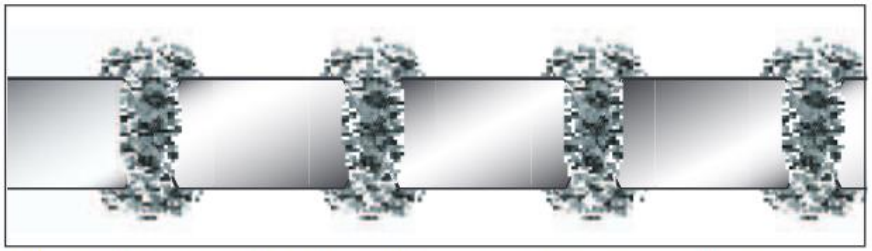
Exterior surface
Significant fuzzing or swelling

Photo credits: S&C Electric Company

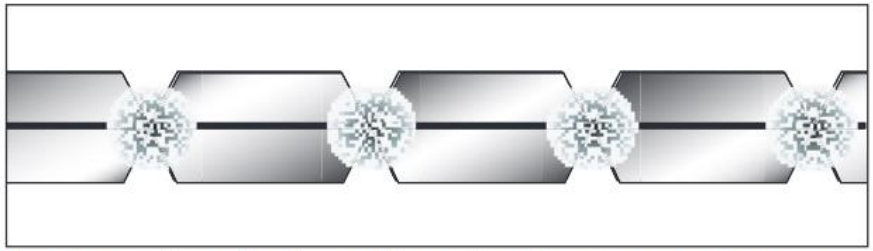
Current Limiting Fuse Operation



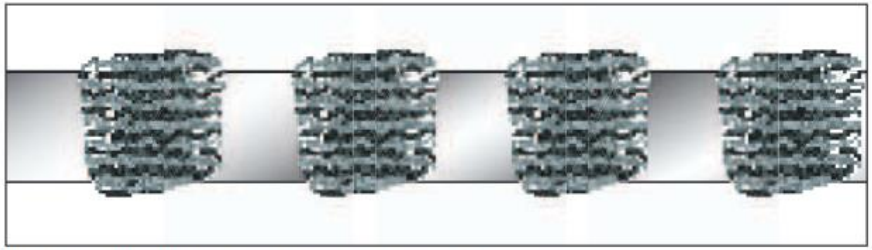
Element melts forming multiple series arcs at element necks



Fulgurite absorbs the heat from the arcs but also encloses them, depressing current peak value



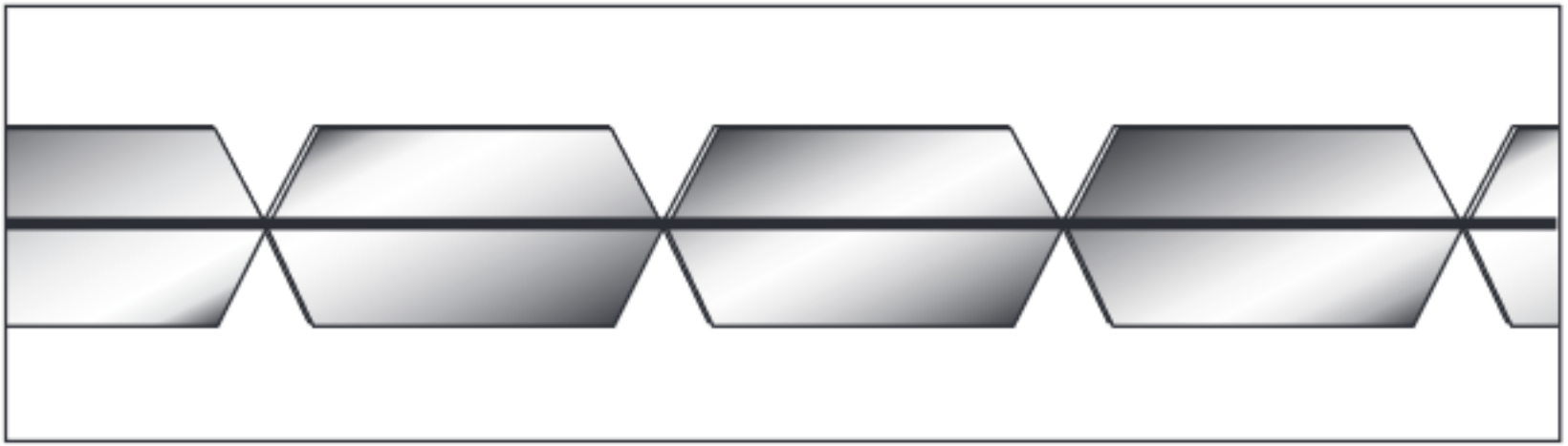
Heat from arcing melts the sand into a glass-like structure referred to as "fulgurite"



Arc is extinguished as current is forced to zero

Photo credit: Eaton

Current Limiting Fuse Operation



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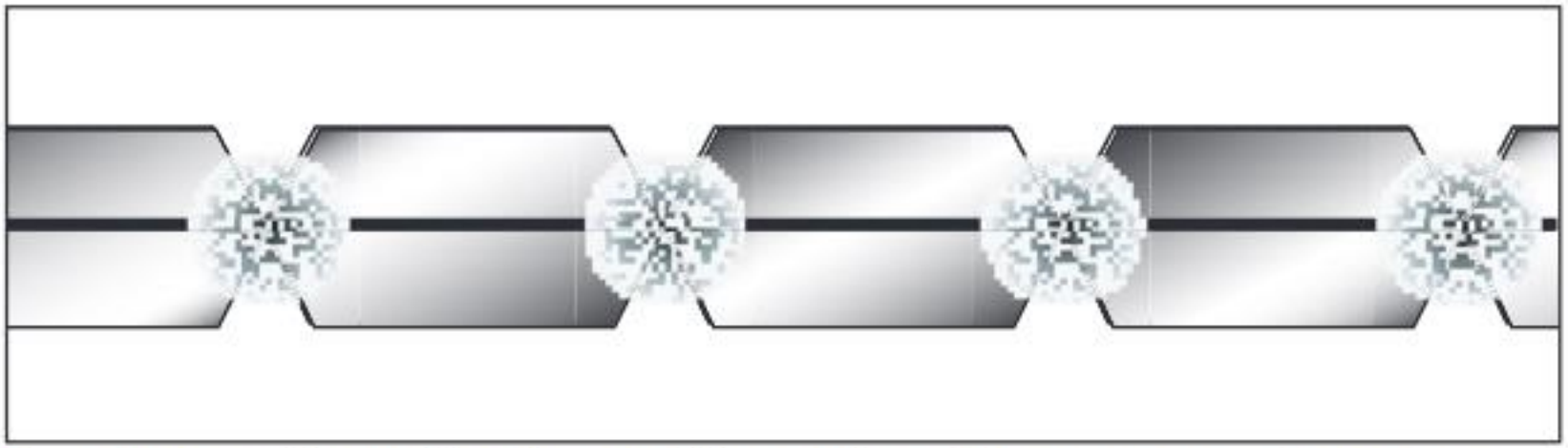

Heat from arcing melts the sand into a glass-like structure referred to as "fulgurite"

Photo credit: Eaton

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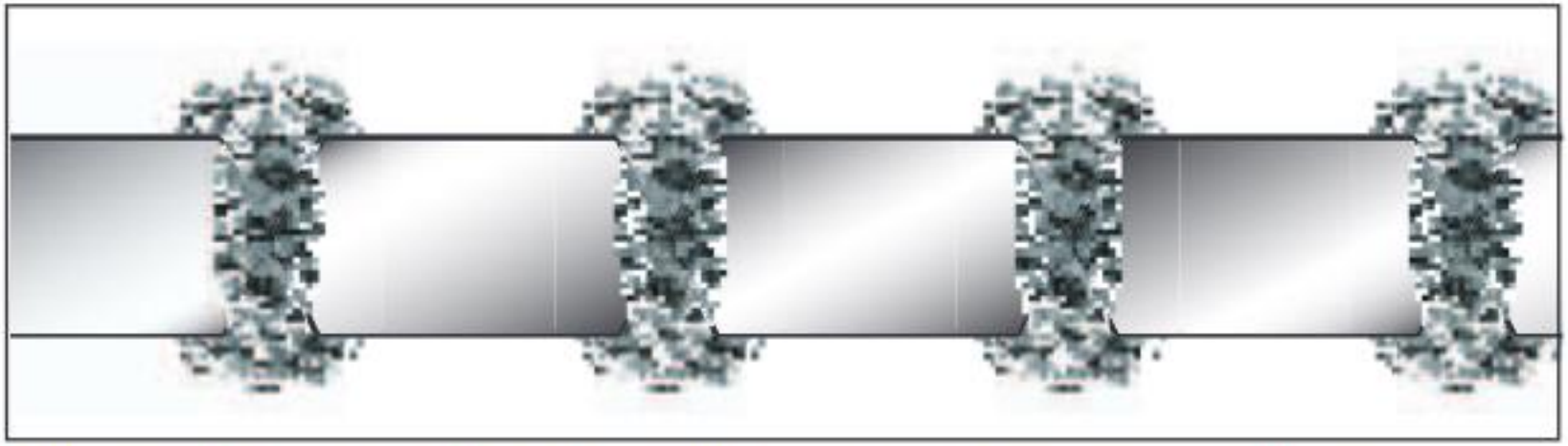

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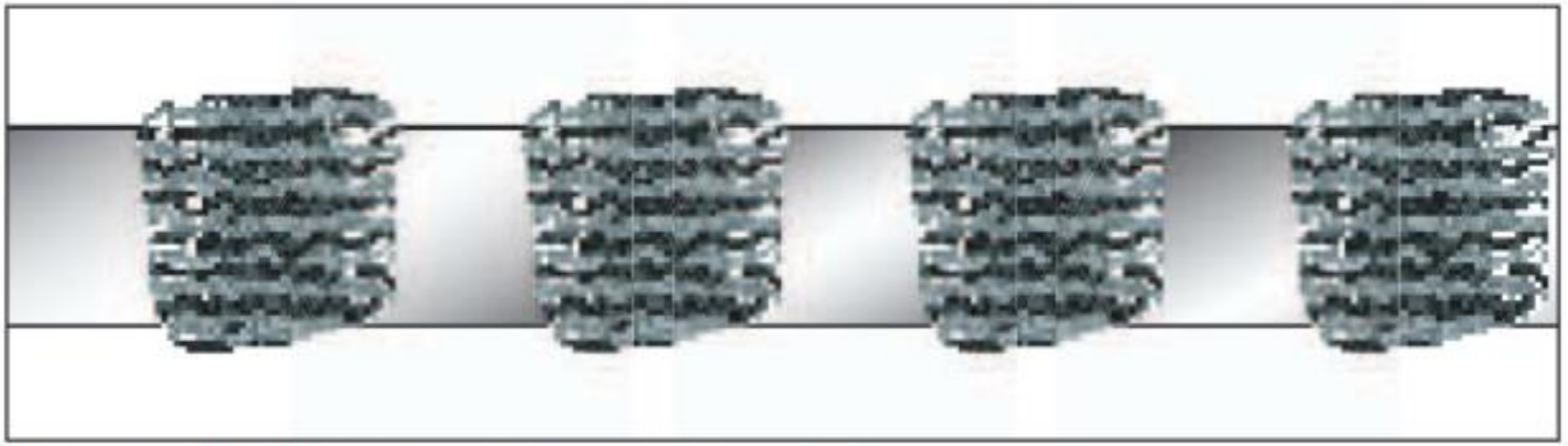

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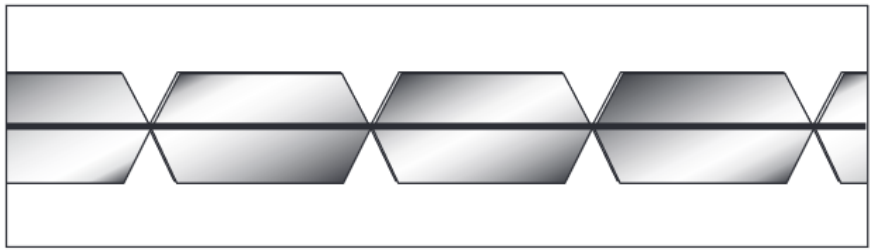

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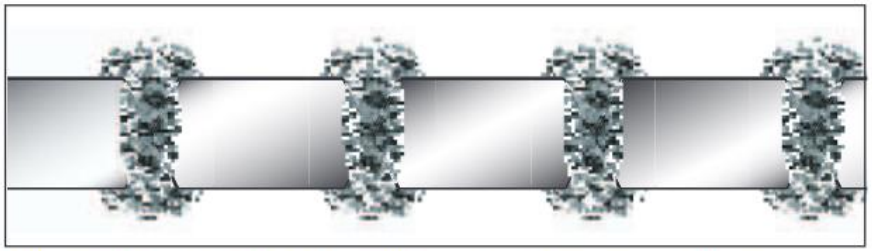

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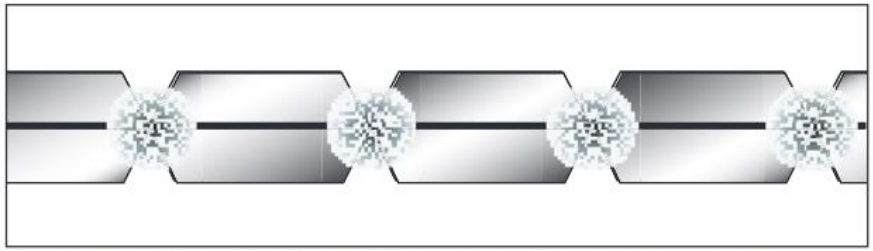

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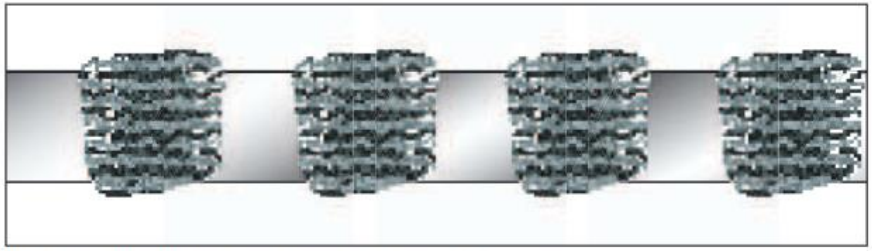

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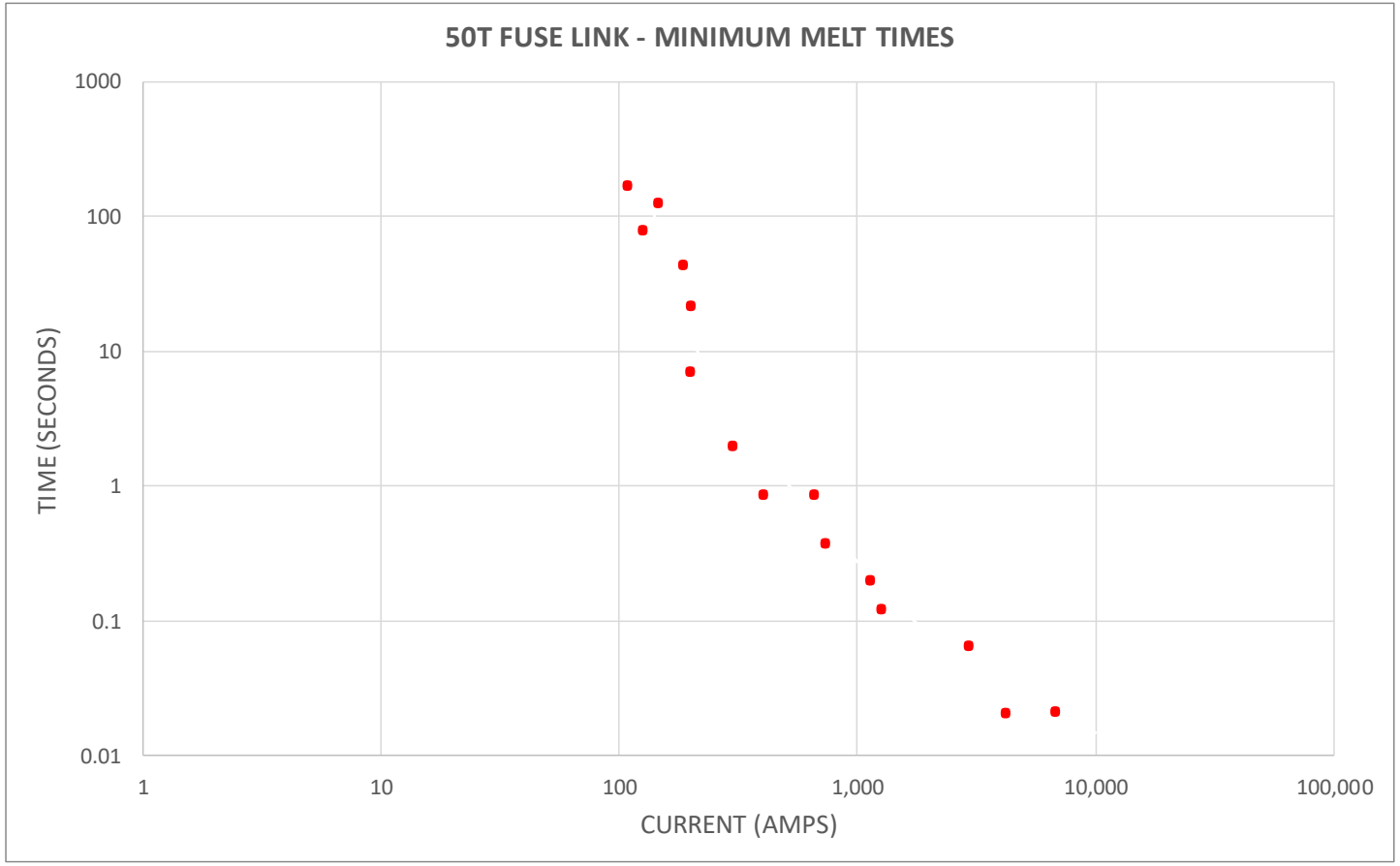
Fuse Link Ratings

Rating Fuse Links



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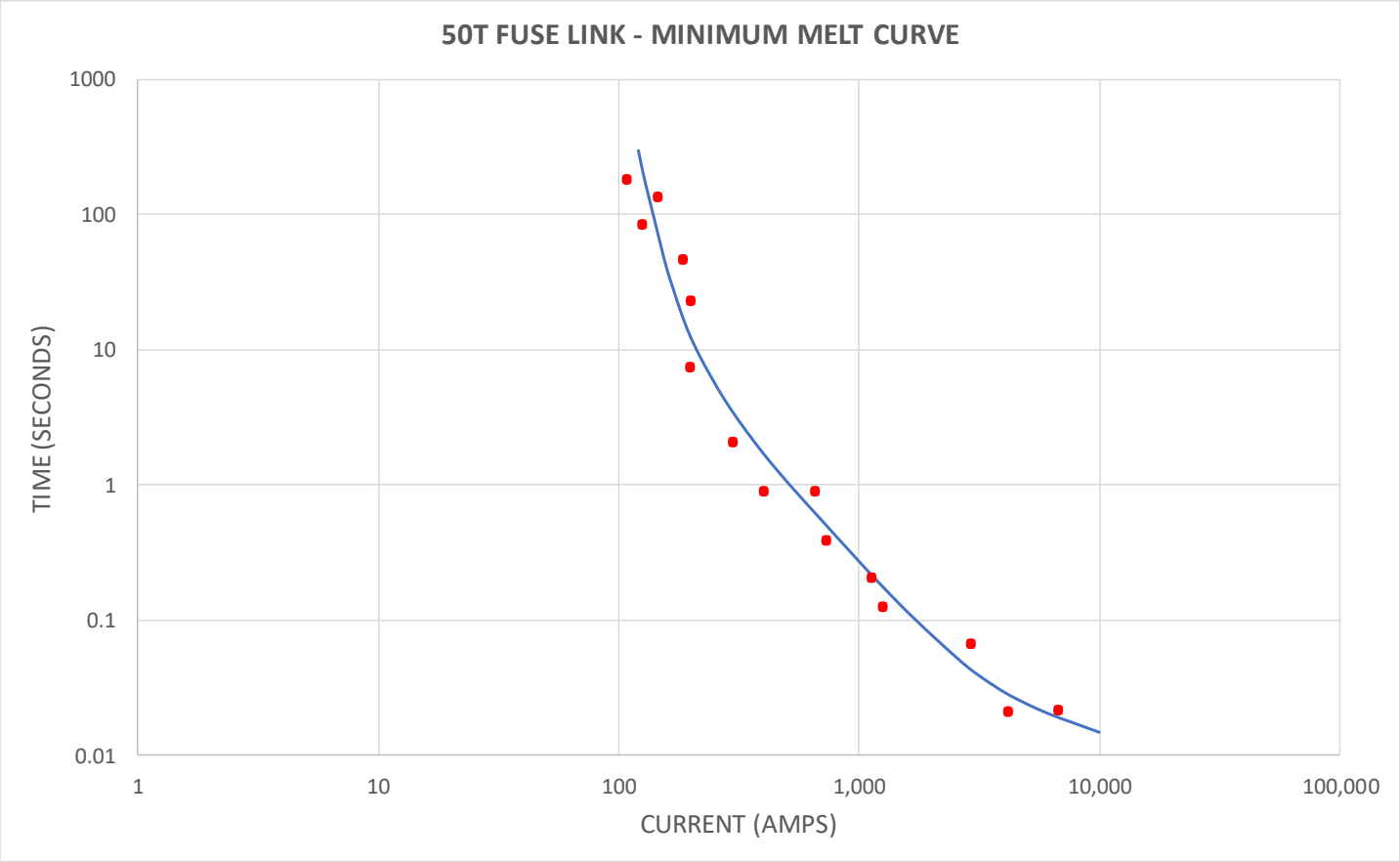
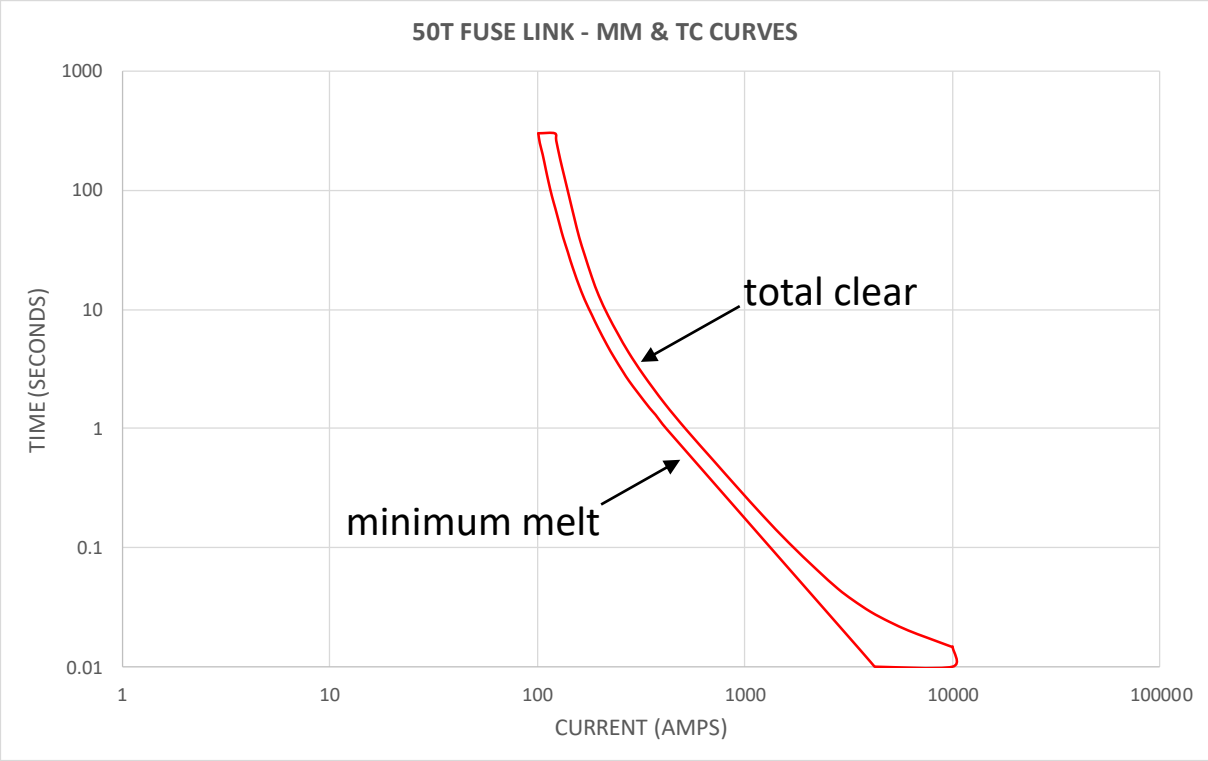


Rating Fuse Links

- Total clear curve established in similar fashion
- Combination produces coordination curves



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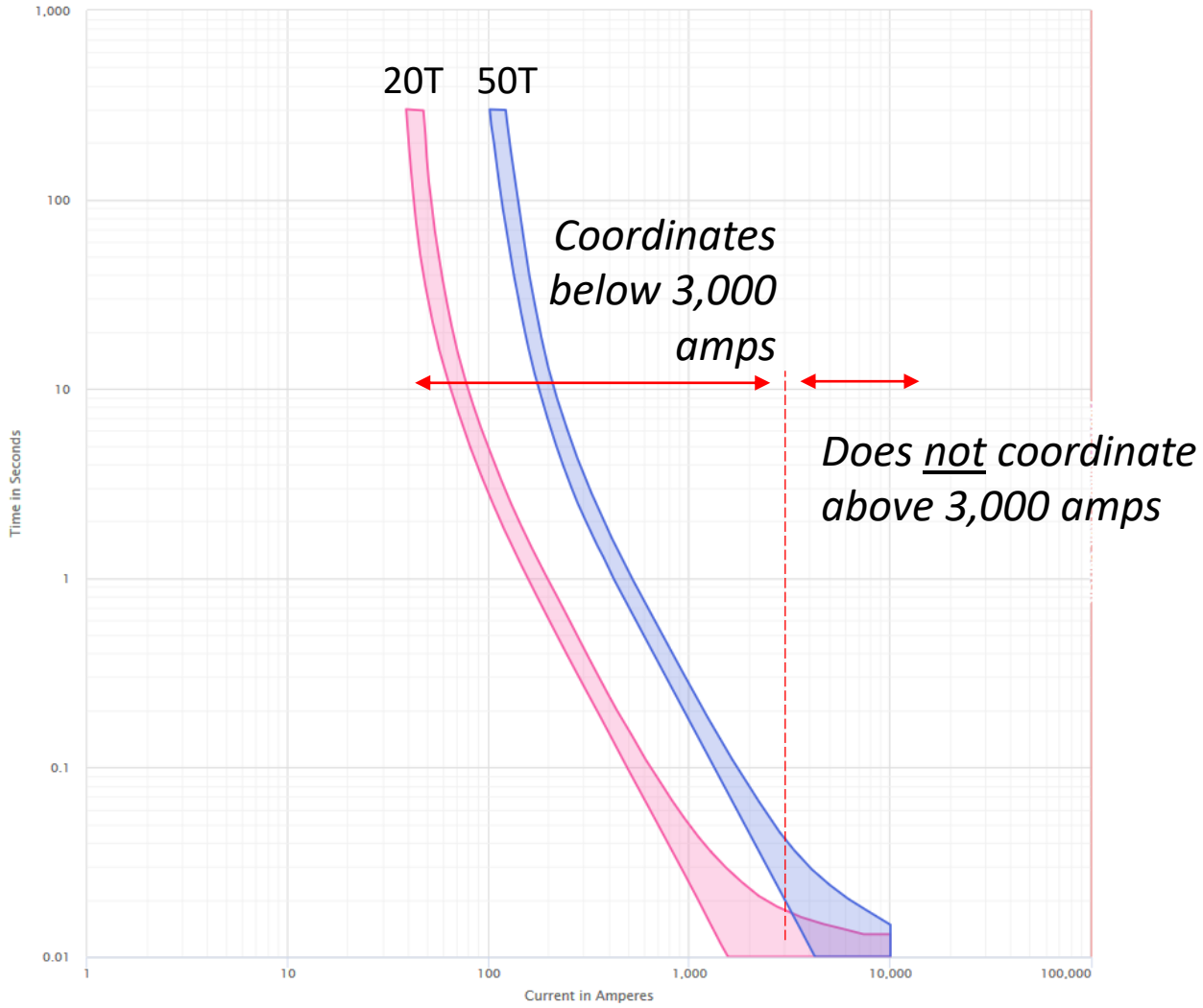
Coordination Example



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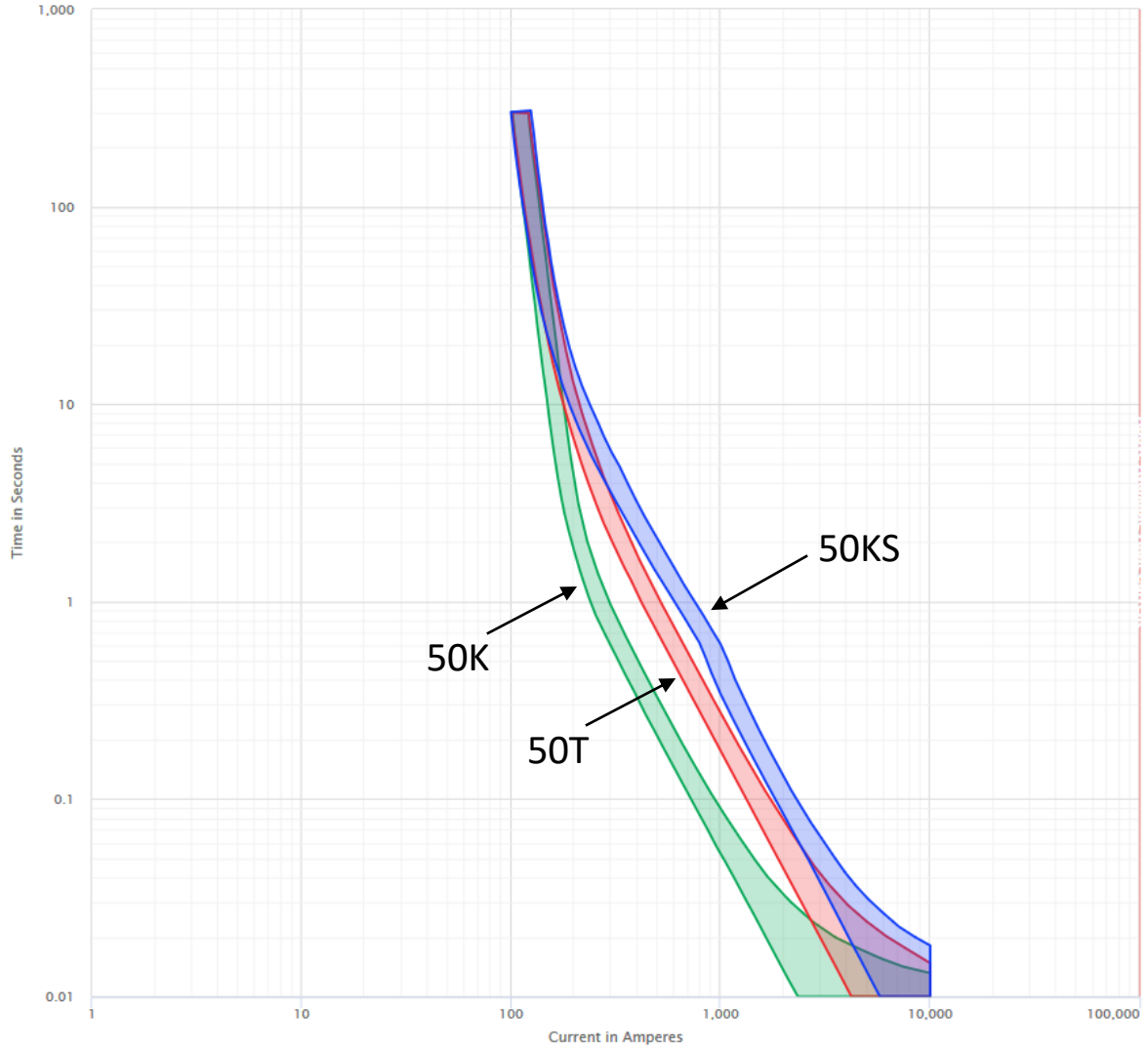
Fuse Speed Comparison



Fuse Coordination Concepts

Protection Coordination

- Proper trip sequencing of protective devices to isolate fault and minimize outage
- Is ⅓ science, ⅓ art, ⅓ luck

Distribution Protection Philosophies

Fuse Blow	Fuse Save
• Breaker instantaneous elements are delayed to allow fuse to clear • Typical fuse speed is K or T • Works well for high fault current systems and short feeders • Avoids blinking the whole feeder at the expense of lateral outages	• Breaker instantaneous element is faster that fuse • Typical fuse speed is T or KS • Works well for longer circuits • Avoid outages at the expense of momentary interruptions

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- In practice, many utilities employee a hybrid of both:
  - FB for high short circuit areas, FS where it works
  - FS on overhead, FB on underground
  - FS on rural, FB on urban
  - FS during storms, FB on blue sky days
  - FS on some circuits, FB on others

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Transformer Inrush

- Inrush is the magnetizing current drawn by a transformer when energized
- Large motor loads may contribute
- Lasts very short time
- Example: 500kVA transformer @ 12.47kV
  - FLA = 23 amps
  - Inrush = >260 amps

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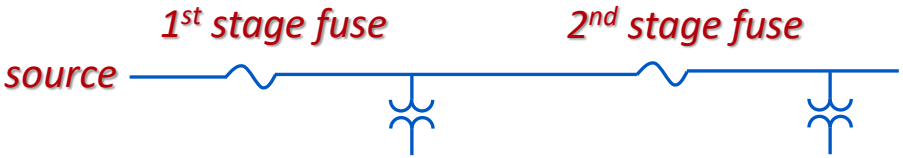
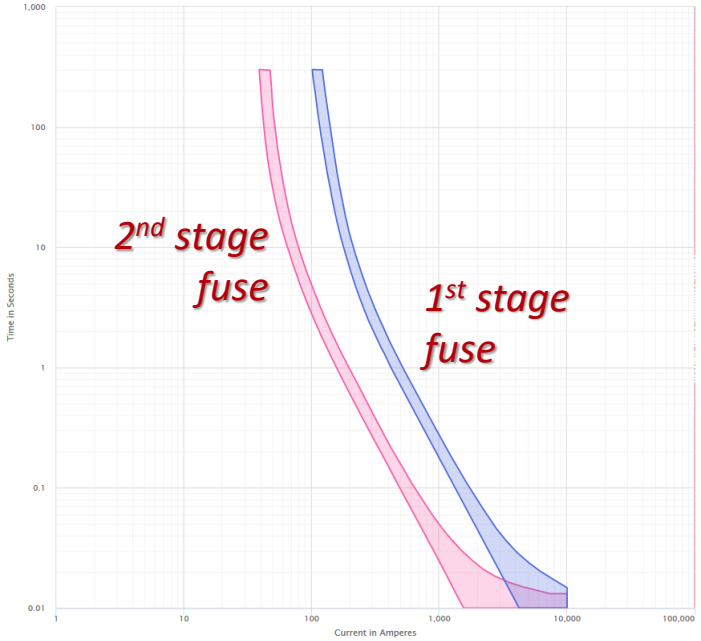
Cold Load Pickup

- Cold load pickup is used to refer to the overload that will be present when diversity of load is lost
- Follows an extended outage (>30 min.)
- Cold load can persist for over 15 min.

Fuse to Fuse Coordination

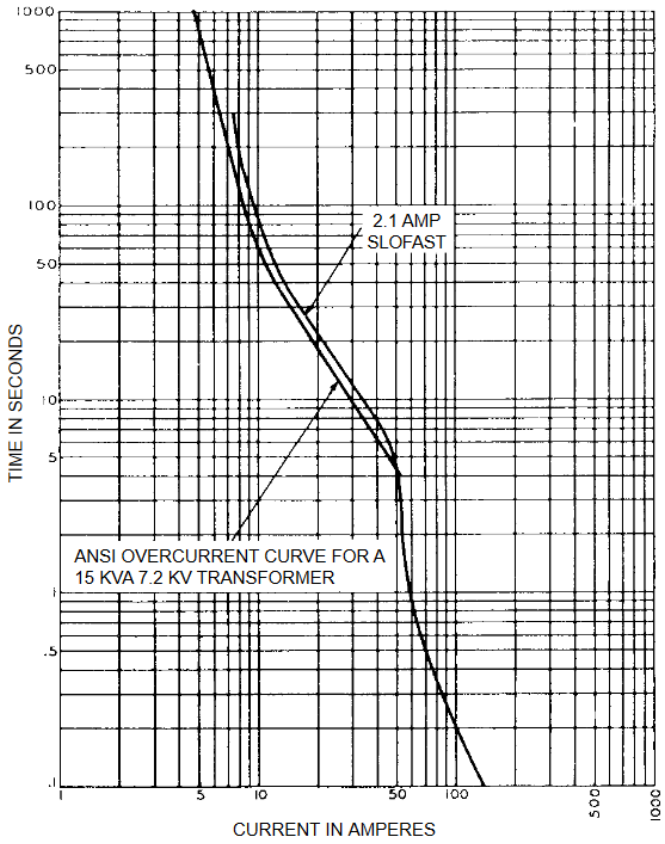


- 2nd stage fuse must be small enough to
  - Coordinate with 1st stage fuse
  - Prevent conductor damage
  - Detect minimum fault current
- But, large enough to
  - Carry peak load
  - Allow cold load pickup



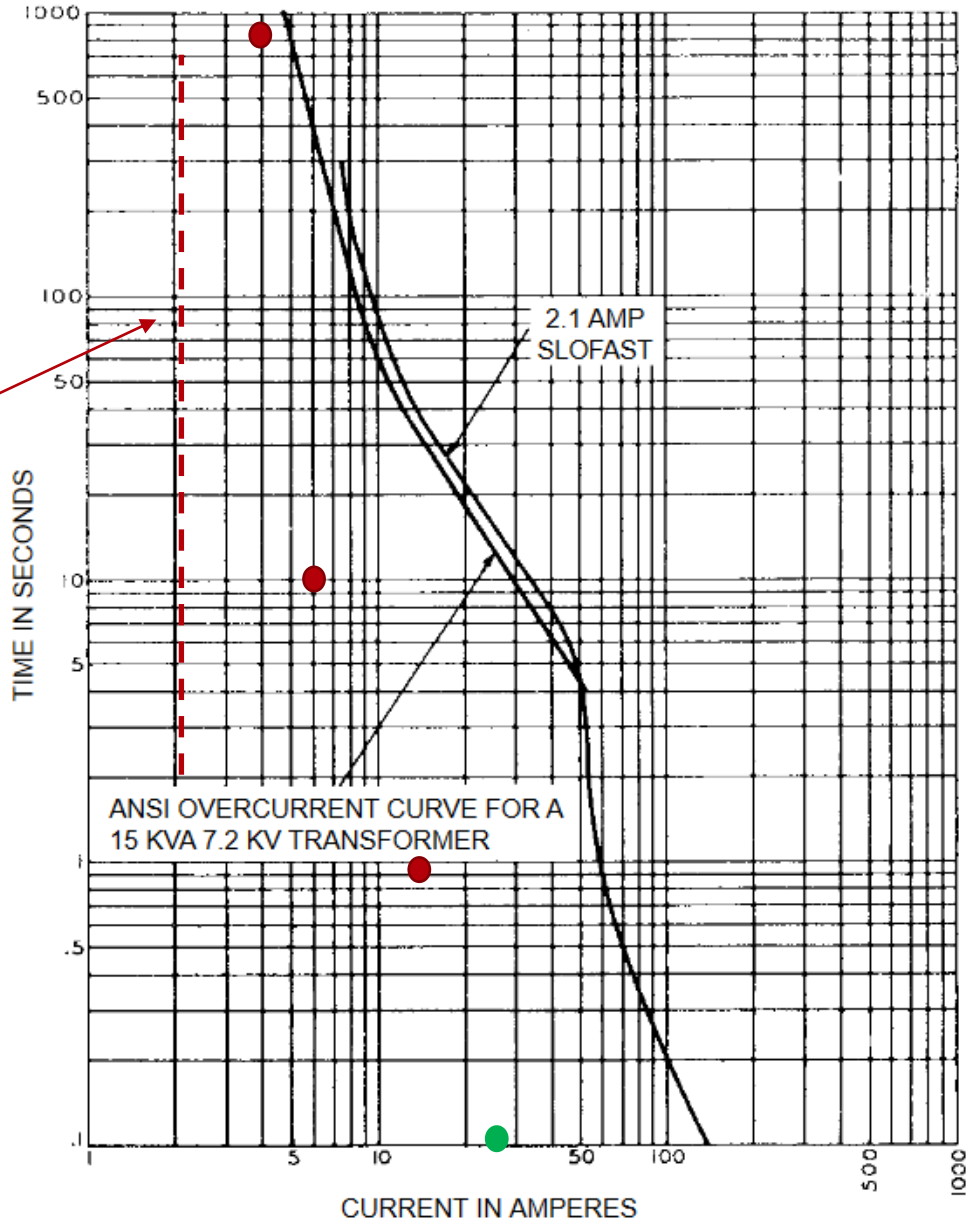
Transformer Fusing

- Minimum fuse size = FLA x 1.2
- Cold load pickup
  - Normal load x 6 for 1 second
  - Normal load x 3 for 10 second
  - Normal load x 2 for 15 minutes
- Inrush current
  - FLA x 25 for 0.01 second
  - FLA x 12 for 0.1 second



ANSI CURVE AND SLOFAST TOTAL CLEARING CURVE

FLA = 2.08 Amps

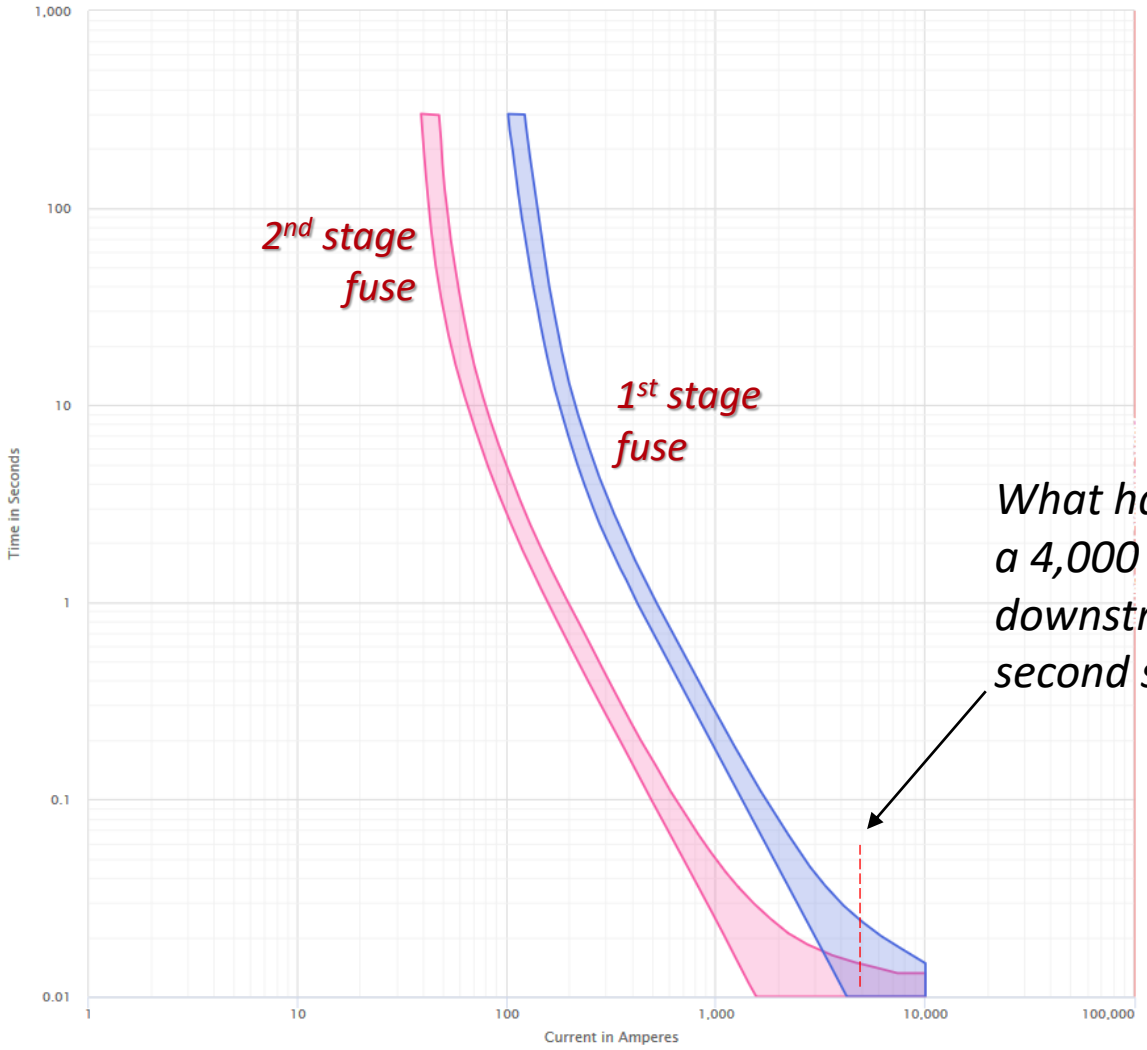


ANSI CURVE AND SLOFAST TOTAL CLEARING CURVE

Fuse Damage

- Fuses are susceptible to damage when they partially melt and solidify due to
  - Inrush & cold load pickup events
  - Lightning transient surge currents
  - Improper coordination

Fuse Damage



What happens during a 4,000 amp fault downstream from the second stage fuse?

What Spent Links Can Tell Us About the Fault

Indication of Fault Level

- Depends on fuse link construction
- High-level faults (>1,000 amps)
  - Auxiliary fuse tube is nearly or totally destroyed
  - Fuse element consumed
- Mid-level faults (500 - 1,000 amps)
  - Auxiliary fuse tube will burst
  - Fuse element consumption depends on size

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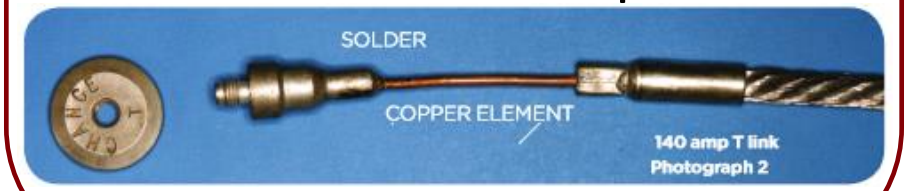
Chance T & K Link Construction

T Links

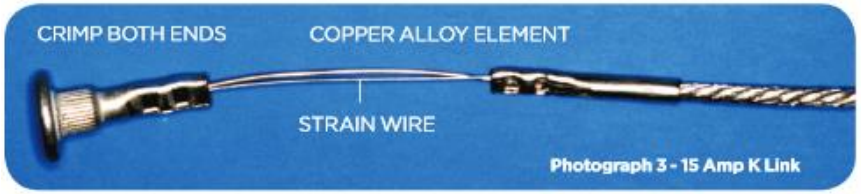
6 to 100 Amp

140 & 200 Amp



K Links

6 to 100 Amp



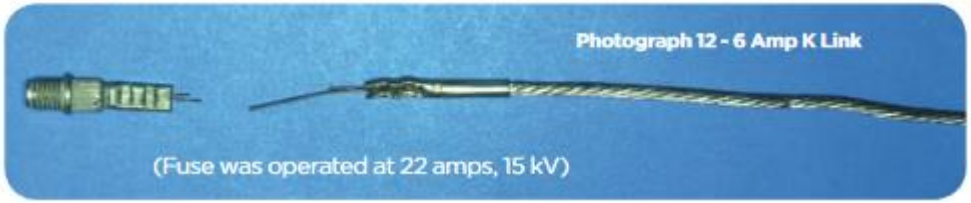
140 & 200 Amp

- Will carry 150% of rated current without damage

Photo credit: Hubbell Power Systems

T & K Link Operation – Low Level Fault or Overload

- Auxiliary tube will not burst
- Fuse element consumption depends on fault level vs. fuse rating
- Strain member melts; crimps undisturbed
- T link - tin element retains smooth surface



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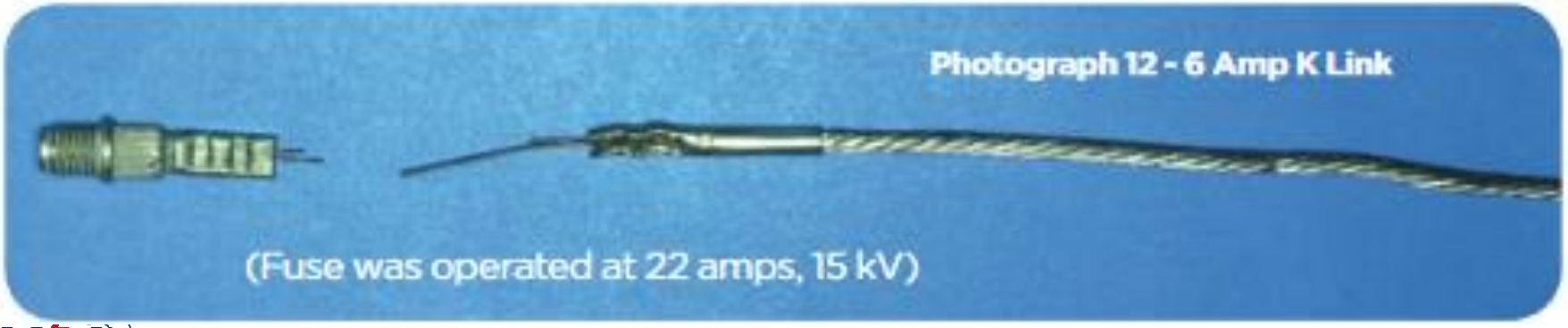


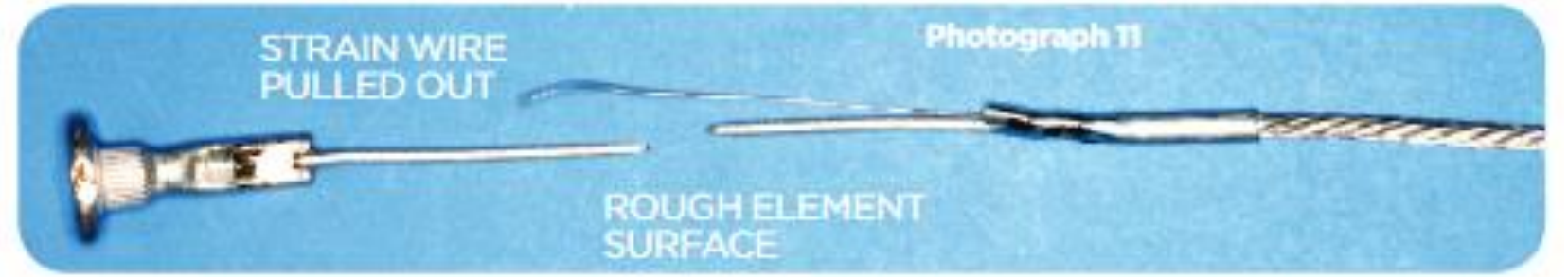
Photo credit: Hubbell Power Systems

T & K Link Operation – Pull Apart

- Pull apart from excess tension (>20 lbs.)
  - Strain member will break or pull out
  - T link - tin element will be stretched with neck where it pulled apart; surface will be rough
  - K link - copper alloy will not neck/elongate much
  - Unlikely to happen for fuses >100 Amps

Photo credit: Hubbell Power Systems

T & K Link Operation – Pull Apart



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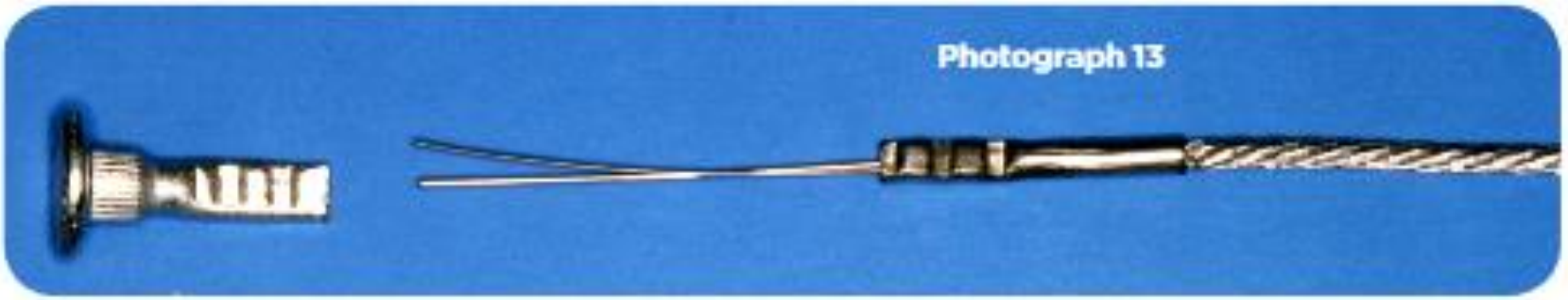


Photo credit: Hubbell Power Systems

SloFast (X) Link Construction

- Dual-element design
  - Slow section has heater coil
  - Fast section is similar to a K link
- Allows for safe levels of transformer overload per ANSI standards

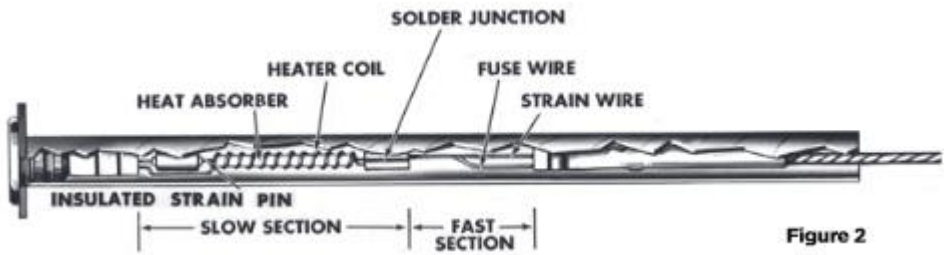


Figure 2

Photo credit: Hubbell Power Systems

SloFast (X) Link Construction

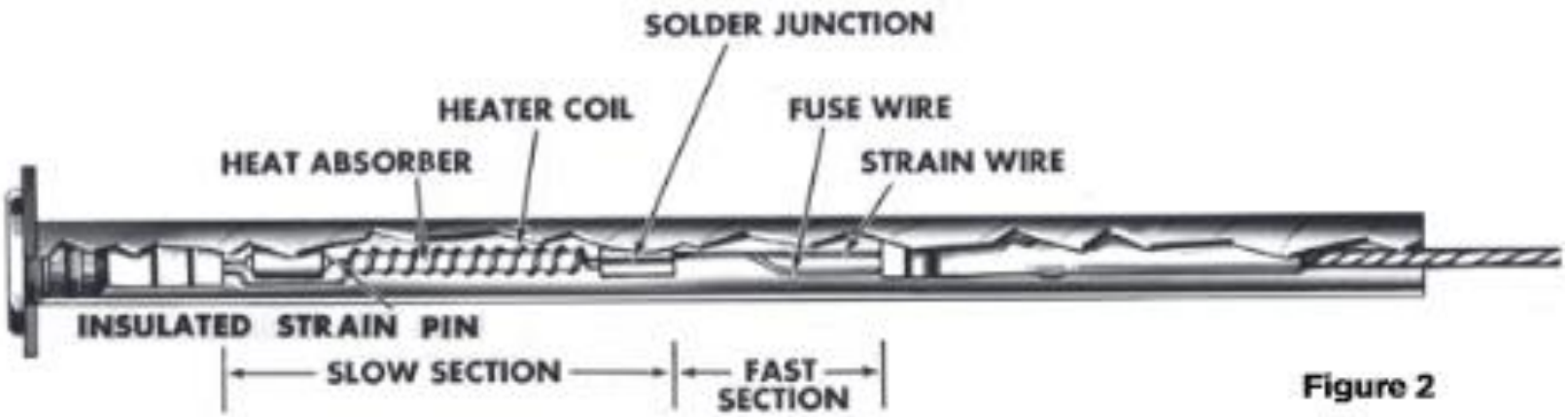
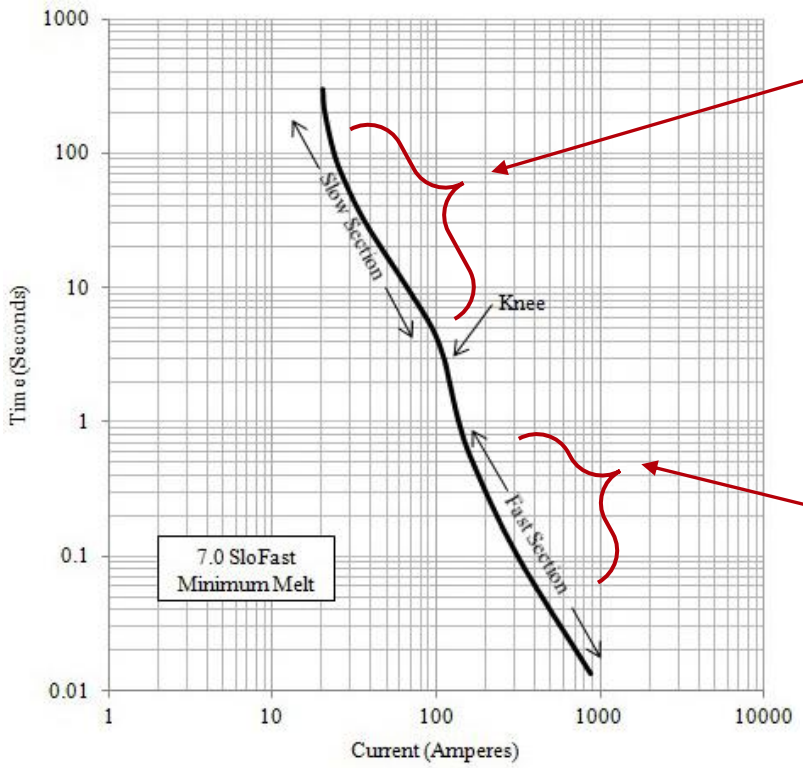


Figure 2

Photo credit: Hubbell Power Systems

SloFast (X) Link Operation – Low Level Fault



Overload: Heater coil causes soldered junction to melt

Low level fault: operation of element similar to K link

Photo credit: Hubbell Power Systems

SloFast (X) Link Operation – Low Level Fault

Photo credit: Hubbell Power Systems

SloFast (X) Link Operation – Pull Apart

- Pull apart from excess tension (>20 lbs.)
  - Separation occurs in the lower (fast) section
  - Strain element breaks or pulls out of crimp

Photo credit: Hubbell Power Systems

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Wrap Up

- Many factors play a role in fuse coordination
- Protection coordination is not an exact science
- Input from the field is invaluable

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