

ICC 2003 FALL EDUCATIONAL SESSION

High Voltage Extruded Dielectric Transmission Cables



**AMPACITY AND
SHEATH BONDING**

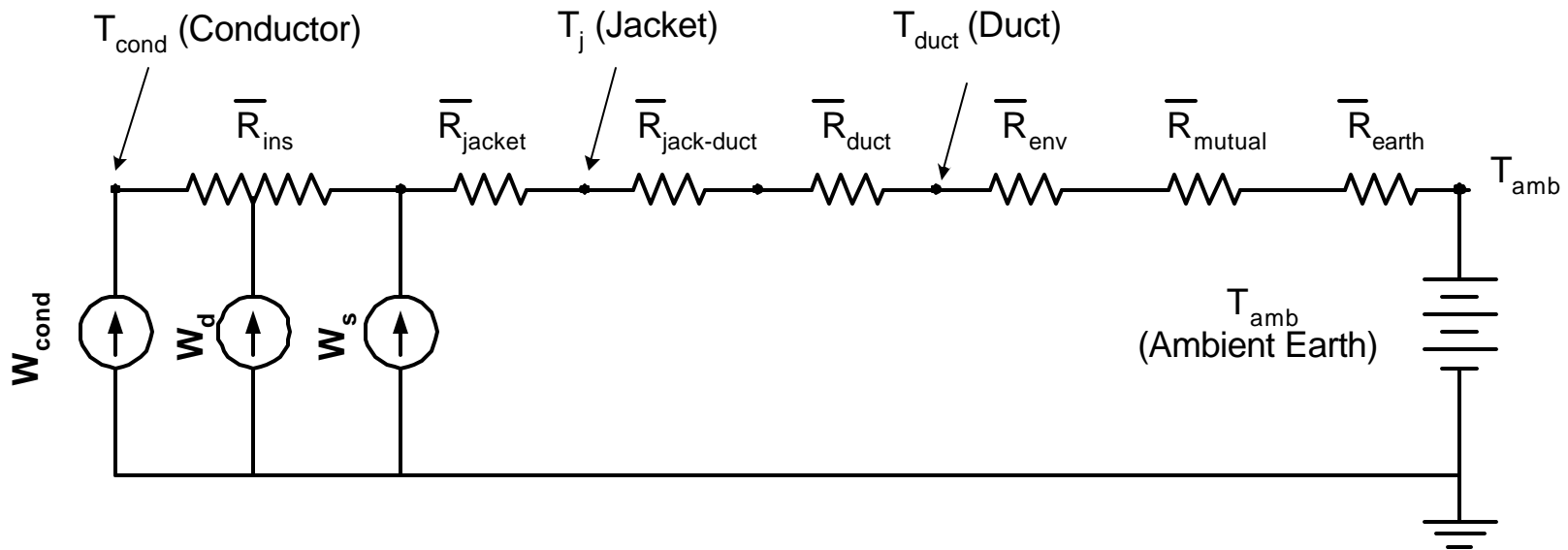
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Ampacity Principles

- Ampacity calculations require solving the electrical equivalent of the cable thermal circuit:

Electrical Analog Of Cables In Duct Bank





Ampacity Principles, (Cont'd)

- We need to know the temperatures, T , the electrical resistances, R_{elect} , and the thermal resistances, R_{thermal}
- We then determine ampacity, I , that gives the allowable conductor temperature for the given operating conditions:

$$T_{\text{cond}} = T_{\text{amb}} + (I^2 R_{\text{elect}} + W_d) \bar{R}_{\text{thermal}}$$

$$I = \sqrt{\frac{T_{\text{cond}} - T_{\text{amb}} - \Delta T_{\text{diel}}}{\bar{R}_{\text{thermal}} * R_{\text{elect}}}}$$

Where: $\Delta T_{\text{diel}} = W_d \bar{R}_{\text{thermal}}$



Temperatures

- Allowable conductor operating temperatures are given in AEIC CS-7, for XLPE-insulated cables up to 138 kV. The same values are generally used for 230- and 345-kV XLPE-insulated cables. Allowable normal conductor temperature is 90 °C; allowable emergency conductor temperature is typically 105 °C for transmission cables.
- Ambient earth temperature varies with location, season, and depth. Common summertime temperature is 25 °C and common wintertime temperature is 15 °C in temperate areas
- External heat sources (i.e. cable duct banks, steam mains, etc.) increase the effective ambient earth temperature



Electrical Losses

- Conductor losses depend upon material, size, construction (and possible strand coatings)
- We determine dielectric losses based upon cable dimensions, dielectric constant, and insulation dissipation factor
- Shield/sheath losses are strongly affected by sheath bonding methods – discussed later
- Additional losses are present if the cable is installed in a steel pipe or casing – and this reduces ampacity

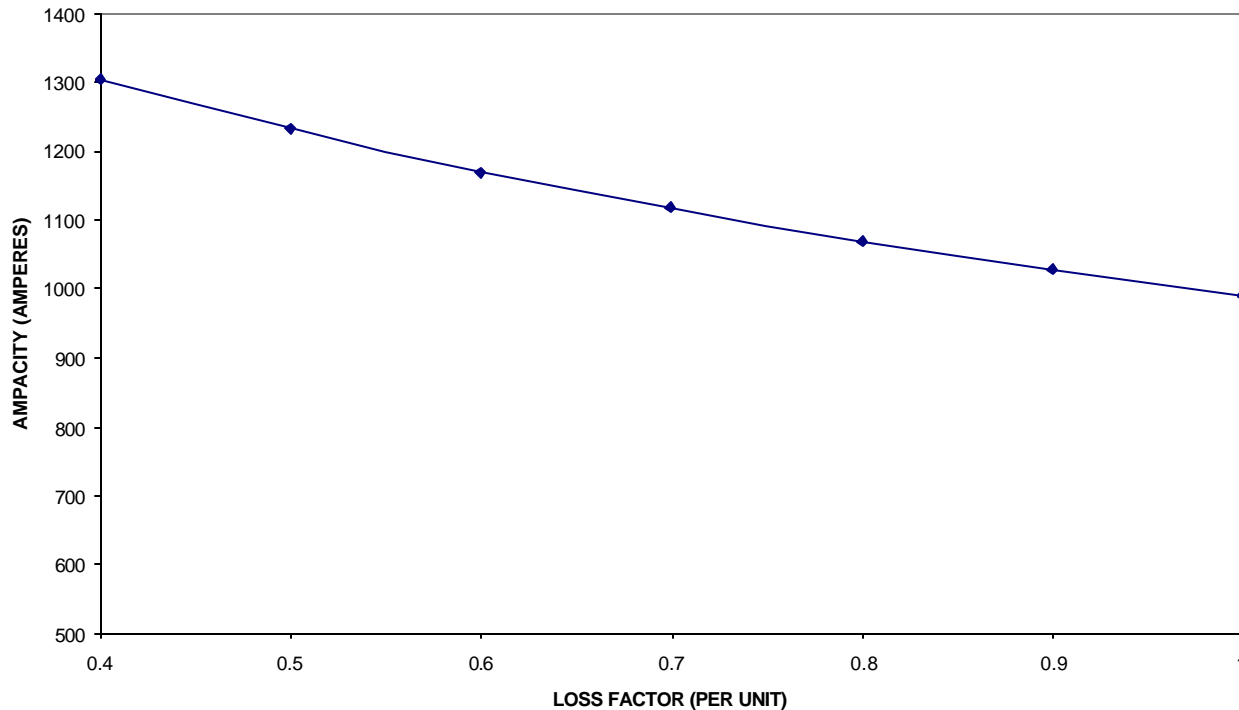


Thermal Resistances

- Insulation and jacket thermal resistances depend upon dimensions and insulation thermal resistivity
- Jacket-to-duct thermal resistance is based upon empirical calculations – and can result in ampacities 10 – 20% lower than if the cables were directly buried.
- Earth thermal resistance varies widely depending upon depth, concrete envelope or controlled backfill, and the native soil. It also varies with time, with changes in moisture content.

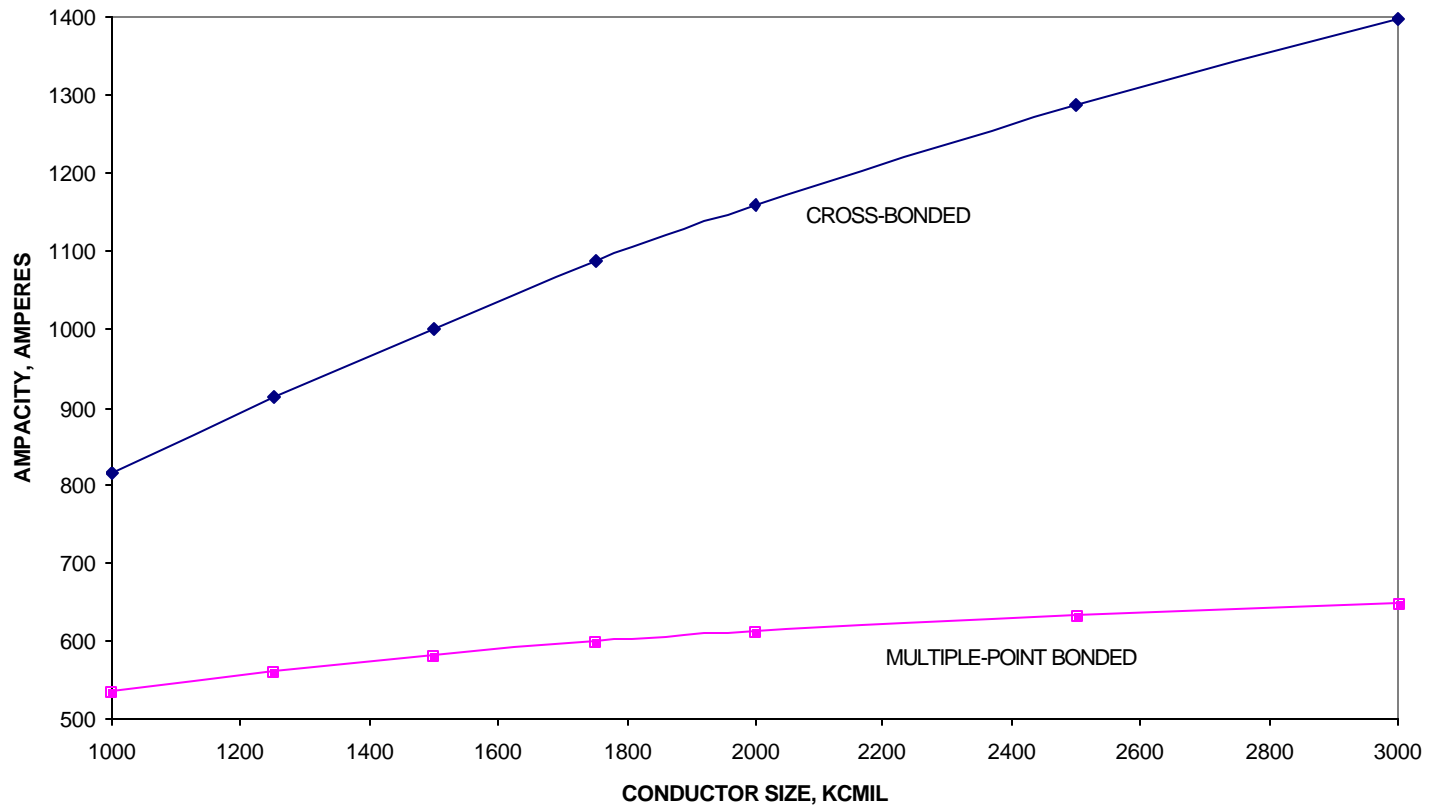
Parameters Affecting Ampacity

- Load Shape: Higher load (loss) factor gives lower peak ampacity:



Parameters Affecting Ampacity (Cont'd)

■ Sheath Bonding:





Induced Sheath Currents

- Conductor currents tend to induce currents in parallel metallic paths – including the cable sheath
- Allowing these sheath currents to flow generates losses that can reduce ampacity 30-40%
- If the current path is interrupted, voltages appear on the sheath – a line carrying 1000 amperes could have 100V on the sheath for a line only 2000 ft long.
- ICC Working Group C2 is preparing a major revision of IEEE 575, “IEEE Guide for Bonding of Single-Conductor Power Cables”



Ampacity Comparison

Extruded Dielectric vs. Pipe-type Cables

- For the same conductor type and size, an extruded-dielectric cable generally has a higher ampacity, because:
 - Dielectric losses are lower
 - The conductors are spaced farther apart, reducing mutual heating
 - There are (generally) no magnetic losses due the steel pipe
 - Extruded-dielectric cables can be directly buried, reducing the thermal resistance to ambient

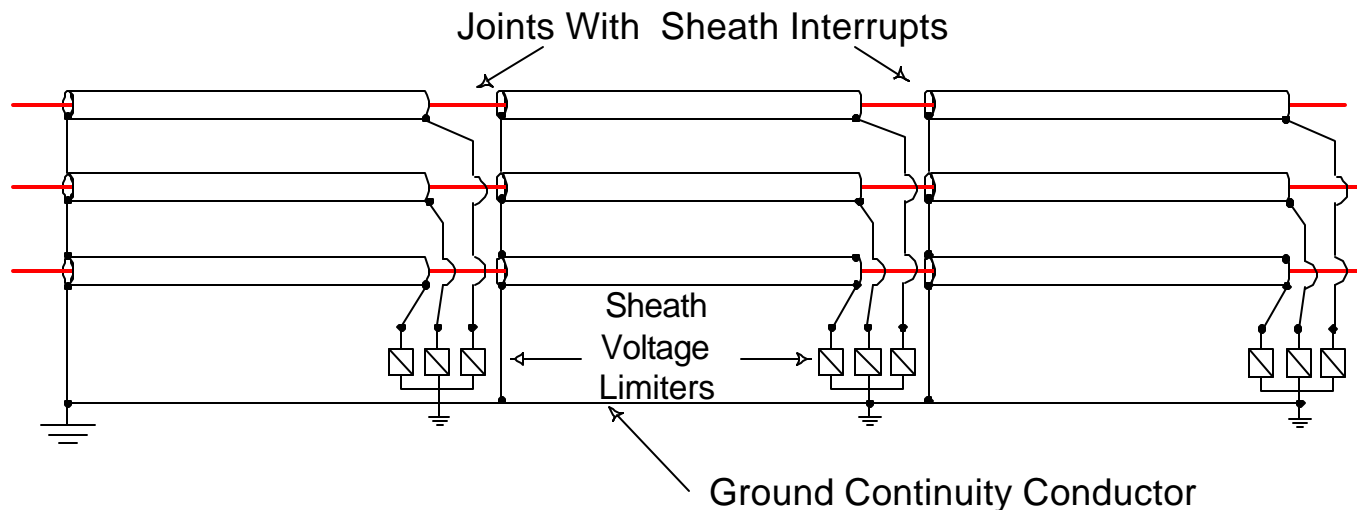


Options for Sheath Bonding

- Multi-point bonding: The three sheaths are bonded to each other and to ground at both ends of the line. Sheath currents reduce ampacity, but the sheath voltage with respect to ground is negligible
- Single-point bonding: The sheaths are grounded at one location, interrupting the current path, but giving potentially high sheath voltages. Sheath voltage limiters (SVL's) are placed at the open end, and a ground continuity conductor is required end-to-end.

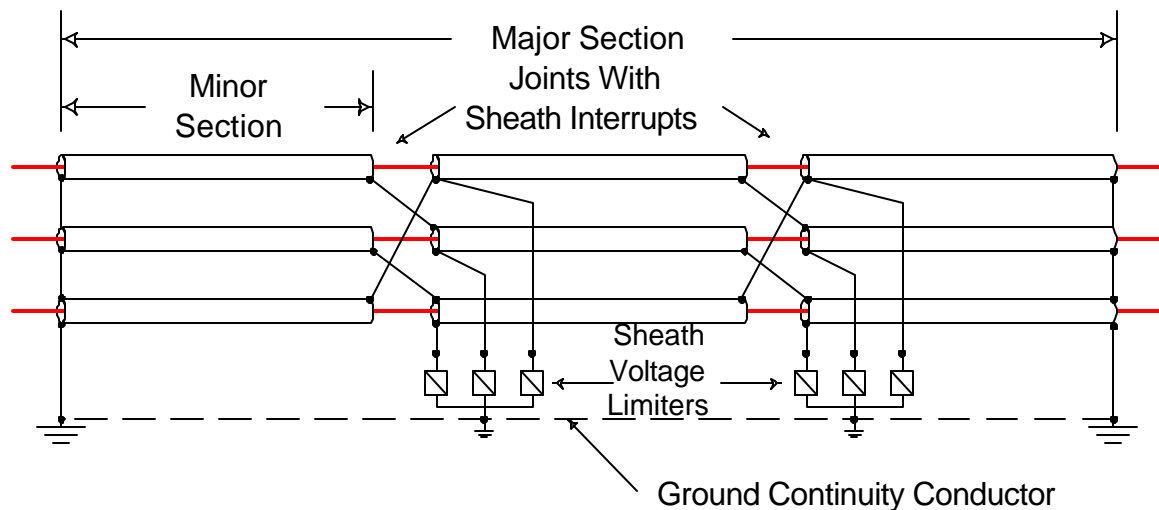
Sheath Bonding Options (Cont'd)

- Multiple single-point bonding: The sheaths are bonded together and to a ground continuity conductor at one end of a section, and connected to SVL's at the other end



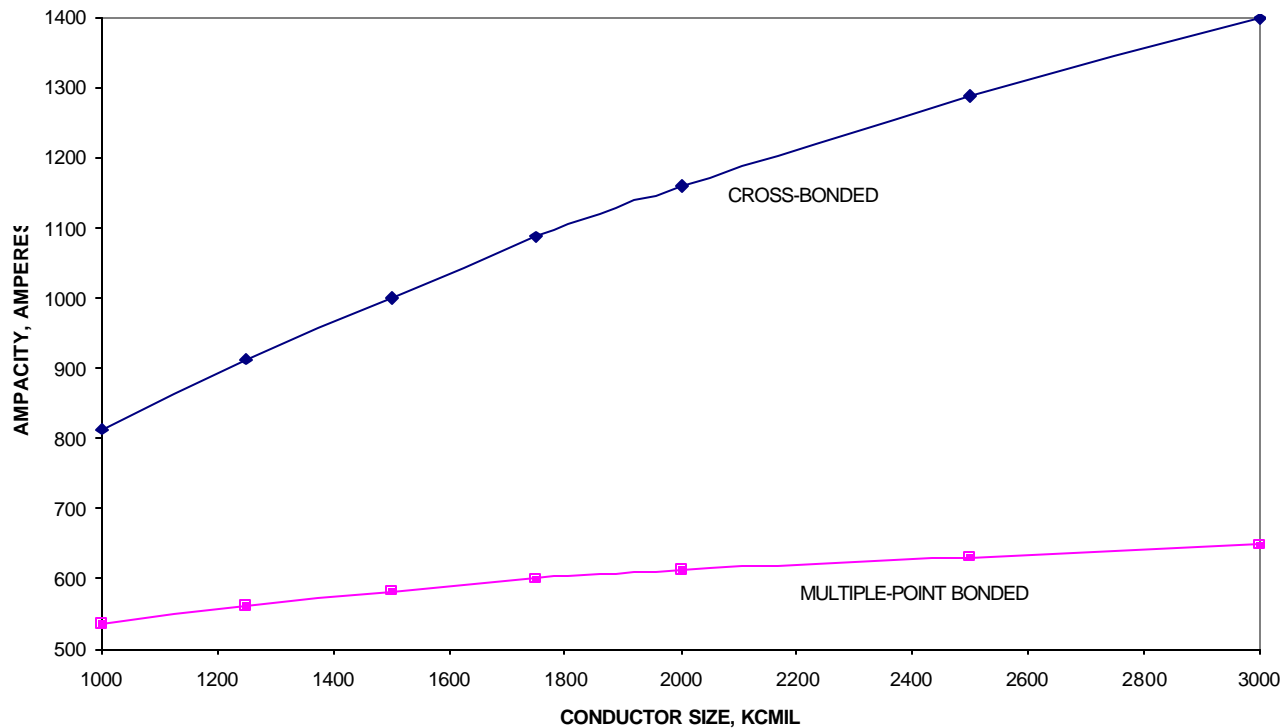
Sheath Bonding Options (Cont'd)

- Cross-bonding: The sheaths are electrically transposed at every splice, reducing both currents and voltages. SVL's are needed at 2 out of 3 joint locations, and a ground continuity conductor is often installed (but not mandatory).



Effect on Ampacity

- Single-circuit, ampacity vs conductor size for multi-point bonded vs. single-point bonded sheaths





Steady-State Sheath Voltages

- Cross-bonded and single-point bonded sheaths will have sheath voltages induced at approximately 50V/1000A/1000ft – therefore sheath voltages of 100V or higher are easily possible.
- There are no U.S. standards or guides for allowable sheath voltages for normal operating conditions
- 125V is a common limit, although some US utilities permit as high as 200V
- Overseas some utilities have standing voltage limits as high as 400V



Transient Sheath Voltages

- SVL's must be selected so that they do not conduct appreciable currents during fault conditions
- SVL's must have an energy dissipation capability higher than that produced by the worst case switching and lightning transients
- The trend to longer distances between manholes (i.e. Horizontal Directional Drilling, etc) results in higher energy dissipation in SVL's
- EMTP analysis is performed for higher system voltages and long distances between manholes



Effects on Parallel Conductors

- Voltages are induced on pipelines, communications circuits, and fences that are parallel to OH/UG transmission lines due to normal operating currents and fault currents
- The grounding system design can have a significant impact on the amount of voltage induced in “proximate” facilities
- IEEE Std 776 and NACE Standard RP0177 concerning inductive coordination should be considered when underground cable alignment is parallel to metallic communications lines and pipelines

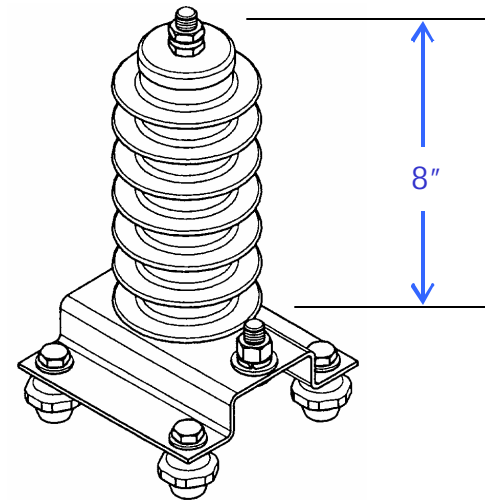
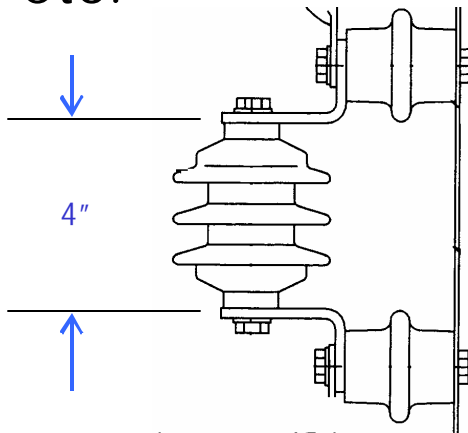


Effects on Parallel Conductors (Cont.)

- Multi-point Bonding: Lowest voltage induction on parallel lines. Most of Zero Sequence (i.e. L-G fault) current returns in cable shield/sheaths
- Cross-Bonding: Low voltage induction on parallel lines. Most of Zero Sequence currents return in cable shield/sheaths and ground conductor
- Single-point Bonding: Results in higher voltage induction on parallel lines. L-G fault current for through-faults must return to source on ground continuity conductor.

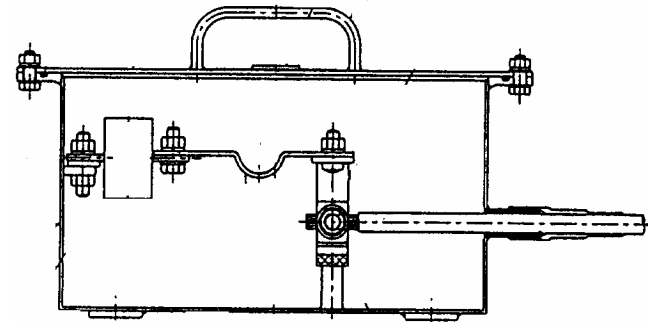
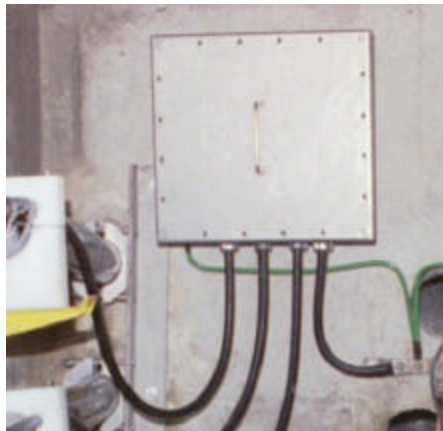
Sheath Bonding Equipment

- For all bonding systems other than multi-point bonded, Sheath Voltage Limiters should be used to limit voltages to acceptable levels during transients. These resemble distribution-class surge arresters, etc.



Sheath Bonding Equipment (Cont'd)

- Link boxes are provided to effect the cross-bonding, give the ability to isolate the sheaths from ground for jacket integrity tests, and to house the SVL's.





Trends To Increase Transmission Cable Ampacity

- Use of special, low thermal resistivity, backfill materials (such as Fluidized Thermal Backfill, thermal sand, limestone screenings) is almost universal
- Cables with integral optical fibers for distributed temperature measurements
- Distributed temperature measurements to accurately determine as-built ratings



Summary

- Ampacities of extruded-dielectric cables can be significantly greater than those of pipe-type cables, especially for directly buried systems without multi-point bonded sheaths.
- However, the sheath bonding methods can be complex and they require careful analysis – and they require careful attention to accessories to provide a reliable system
- Voltage induction on proximate facilities is an important consideration in design of cable system bonding