Strategic Design Alternatives for Underground Medium Voltage Traction Power Cables

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Key Presentation Take-Aways

- Pros and cons of medium voltage cable types based on electrical characteristics, reliability, and life cycle cost
- Cable technology, composition and installation methods
- Cable failure modes

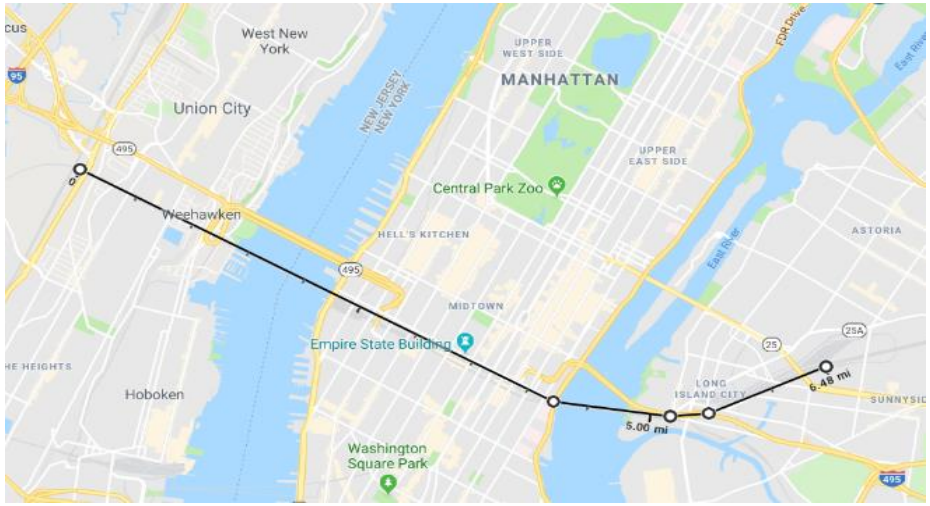
Background: Amtrak 12kV Distribution

- Researched initiated by: the replacement of Amtrak's 12kV PILC traction power cables
- Cables are critical to Amtrak and its partner transit agencies in New York: they provide power to the Hudson and East River Tunnels, Penn Station Complex and Sunnyside Yard
- Cables are approaching almost **90** years in operation

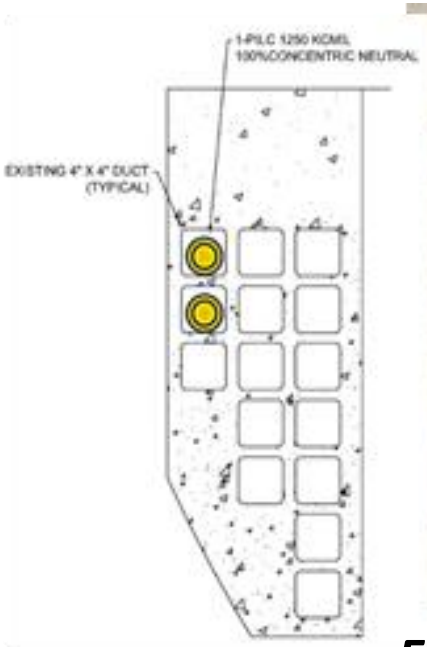
Background: Amtrak 12kV Distribution

- Amtrak's PILC cables span about 6.5 miles (approx. 125,000 feet of total cable length)
- Cables traverse the Hudson and East River using concrete duct banks within the Amtrak tunnels, between Amtrak Substations in North Bergen, NJ and Sunnyside Yards, Queens, NY through New York Penn Station

Background: Amtrak 12kV Distribution



Amtrak MV Cable System



Existing Square Duct Configuration

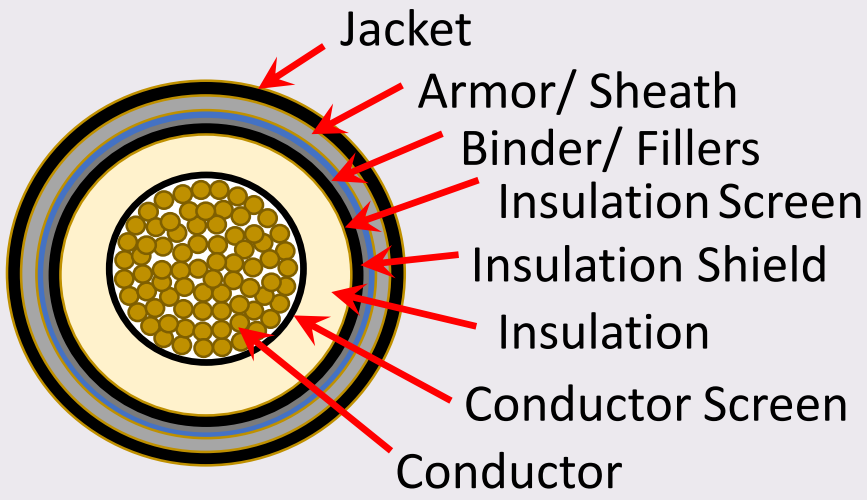
Types of Underground Medium Voltage Traction Power Cables

- Paper Insulated Lead Covered (PILC)
- Ethylene propylene-rubber (EPR)
- Cross-linked polyethylene (XLPE)
  - Tree-retardant XLPE (TR-XLPE)

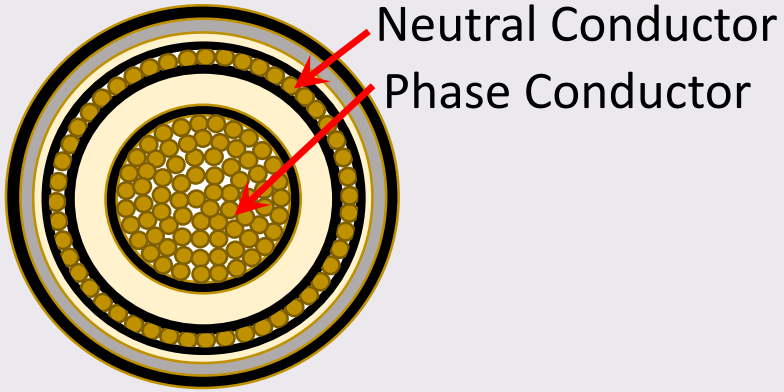
Typical Construction of a Medium Voltage Cable

- Examples of two cable constructions:
  - concentric neutral cable is relevant to the application being considered

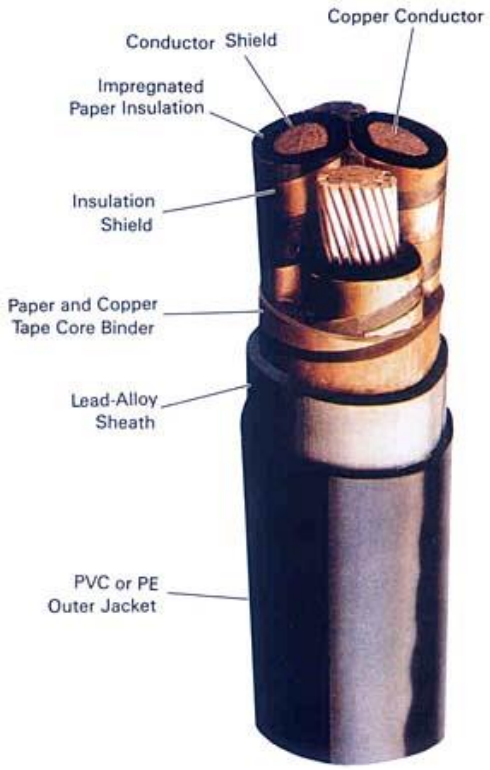
TYPICAL CONSTRUCTION



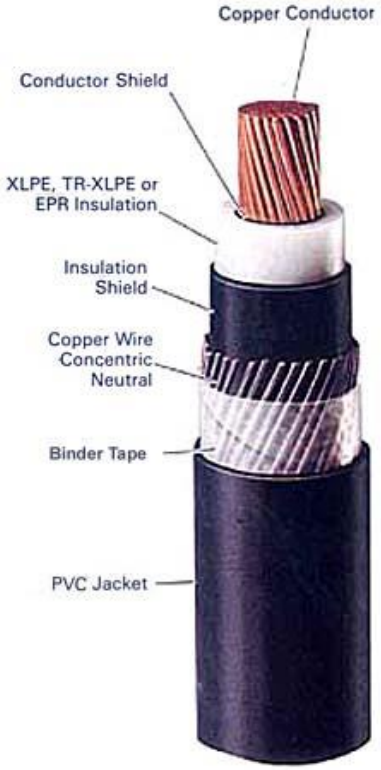
CONCENTRIC NEUTRAL CABLE



Examples of PILC and EPR/XLPE Cables



PILC Cable



XLPE/ EPR Cable

Picture Credit: Open Electrical Wiki Page: https://wiki.openelectrical.org/index.php?title=Cable_Construction

Performance Criteria

- Electrical characteristics
- Thermal performance
- Resistance to water ingression and moisture

Performance Criteria: Electrical Characteristics

- PILCs are considered to have the highest dielectric strength, lowest dissipation factor and lowest dielectric loss compared to both XLPE and EPR
- XLPE performs better than EPR

Performance Criteria: Thermal Performance

- PILC do not suffer from thermal expansion like EPR and XLPE
- EPR has better overload tolerance than XLPE

Performance Criteria: Resistance to Water Ingression and Moisture

- PILC Lead Sheath is completely impermeable
- Moisture ingress can occur at rapid rate if PILC sheath damaged
- EPR has better moisture resistance properties compared to XLPE

Practical Considerations

- Industry trends
- Cable life
- Cable failure modes
- Installation considerations
- Environmental issues
- Manufacturability
- Cost

Practical Consideration: Industry Trends

- PILC cables have been used since late 1800s
- Amtrak PILC cables have been used for nearly 90 years
- PILC concerns: lack of splicer skills, difficult to maintain
- Underground cable design has evolved

Practical Considerations: Cable Life

- PILC cables are resilient
- Aging increases probability of failure
- PILC cable life is 44 years typically
  - Oldest installations are 70-90 years old; (mean age is 80 years)
- Current design life of EPR cables is 40 years (per study by EPRI)

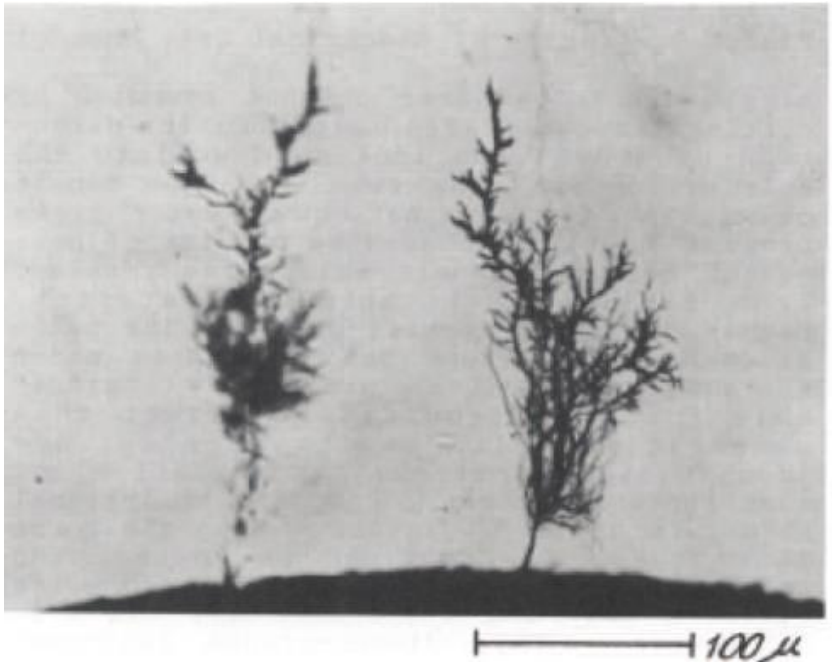
Practical Considerations: Cable Failure Modes

Faulted PILC Cable

- PILC cable primary failure mechanisms:
  - Thermal failure, mostly due to moisture ingress, which tends to increase insulation conductivity *(approx. 40% of failure incidences)*
  - Electrical phenomenon known as partial discharge *(approx. 60% of failure incidences)*

Practical Considerations: Cable Failure Modes

- Water treeing:



Picture Credit: Teyssedre, Gilbert & Laurent, Christian. (2013). Advances in High-Field Insulating Polymeric Materials Over the Past 50 Years. Electrical Insulation Magazine, IEEE. 29. 26-36. 10.1109/MEI.2013.6585854.

Practical Considerations: Installation Considerations

- Cable Pulling
- Cable Weight
- Duct Fill Ratio
- Ampacity
- Splicing

Practical Considerations: Environmental Issues

- Lead leakage from PILC cables is main the concern
  - Released through corrosion or during splicing work
- No regulations restricting use of PILC cable or requiring its removal

Practical Considerations: Manufacturability

- Most manufacturers produce cables with EPR and XLPE insulation for medium voltage applications
- PILC is only produced at select factories

Practical Considerations: Cost Considerations

- Concentric 1250 kcmil PILC cable is significantly more expensive than a concentric EPR cable (approx. 50% higher)
- Installation costs of PILC are significantly higher than other cable types
- XLPE and EPR non-concentric neutral cable are similar in cost

Cable Comparison Table – 1 of 2

CABLE PROPERTY	PILC CABLE	EPR CABLE	XLPE CABLE
HISTORY	PILC cable has longer usage history and more information on reliability than EPR and XLPE cables. The first PILC cables were installed by Ferranti in 1890 and some of them were still in use after more than 70 years.	The development of EPR cable only began in 1960. The EPR cable has the smallest share of underground cables in operation.	XLPE gained popularity during the 1960s. It was the material of choice due to its ease of processing and handling. The share of XLPE is higher than EPR in underground cable operation.
ELECTRICAL CHARACTERISTICS	Impregnated paper insulation of PILC cable has excellent electrical properties, such as high dielectric strength, low dissipation factor, and lower dielectric loss than EPR and XLPE.	EPR cable has lower dielectric strength, higher dissipation factor, and higher dielectric loss than PILC cable.	Dielectric strength of XLPE is much higher than that of EPR. The dissipation factor and dielectric loss of XLPE are also significantly lower than those of EPR
RESISTANCE TO WATER INGRESSION	Among all the water-blocking sheaths, including the polymeric sheath in EPR, lead sheath is completely impermeable to water ingression and humidity diffusion.	EPR cable has reduced resistance to water ingression relative to PILC cable.	XLPE cable is prone to water-tree degradation at a much more rapid rate than EPR.
THERMAL PERFORMANCE	Impregnated paper insulation has no thermal expansion during heating, unlike any polymeric insulation, including EPR.	EPR cable has lower thermal performance than PILC cable and higher thermal performance than XLPE in terms of overload capability and longevity.	Like the EPR, XLPE applications are limited by thermal constraints. But it has increased thermal expansion relative to EPR
COSTS	The initial and maintenance costs of PILC cable are higher than EPR cable.	EPR cable has much lower initial and maintenance costs than PILC cable.	Non-concentric XLPE is more expensive than non-concentric EPR. Cost of Concentric XLPE cable is not available.

Cable Comparison Table 2 of 2

CABLE PROPERTY	PILC CABLE	EPR CABLE	XLPE CABLE
FLEXIBILITY	The PILC cable is more rigid than the EPR and XLPE cables, especially in larger sizes (kcmil-sizes).	The superior flexibility of the EPR cables is a great benefit in larger sizes as those cables must be trained and coiled in vaults and other enclosures.	XLPE cable is less flexible than EPR cable of the same size.
RESISTANCE TO MOISTURE	The impregnated paper insulation of PILC cable can be highly susceptible to deterioration if the lead sheath gets damaged and water gets past the sheath.	EPR is a solid dielectric insulation and it is highly resistant to deterioration.	XLPE has a higher degree of susceptibility to moisture-related degradation than EPR.
INSTALLATION, REPAIR AND MAINTENANCE	Installation, repair and maintenance of PILC cable is more intensive, complicated and time-consuming than both EPR and XLPE cables. Also, a high degree of skill is required for both splicing and termination.	EPR cable is easier to install, repair and maintain than PILC cable. EPR cable is lighter than PILC and uses commercially available splicing and terminating components. EPR cable accessories are not as complicated as PILC cable accessories.	Installation, splicing, repair, and maintenance methods of XLPE and EPR cables are comparable.
ENVIRONMENTAL CONCERNS	PILC cable contains a dielectric fluid (usually a mineral oil) and a lead sheath that are potential environmental contaminants.	EPR cable has excellent environmental stability. No concern of lead or fluid leaks in EPR insulation, unlike PILC cable.	Like EPR cable, XLPE cable does not contain lead or fluid so the environmental effects of leaks are not a problem. Fluid system maintenance is not required.

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