Underground System Design
TADP 547

EPR Insulated Cables
Presentation 2.3

Instructor: George R. Matto
EPR INSULATED CABLES
1) *What is EPR?*
2) *Cable Types and Shield Design*
3) *Comparison of EPR and XLP*
4) *Cable Components and Extrusions*
5) *Thermal Set and Thermal Plastic*
6) *Temperature Rating*
7) *Insulation Level*
8) *Cable Performance*
9) *Cable Memory*
# EPR - Ethylene Propylene Rubber

## Formulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>dielectric</td>
</tr>
<tr>
<td>Clay</td>
<td>filler</td>
</tr>
<tr>
<td>Plasticizers</td>
<td>viscosity modifiers</td>
</tr>
<tr>
<td>Metal Oxides</td>
<td>heat/moisture stabilizers</td>
</tr>
<tr>
<td>Antioxidant</td>
<td>aging characteristics</td>
</tr>
<tr>
<td>Co-Agent</td>
<td>co-curing agent</td>
</tr>
<tr>
<td>Organic Peroxide</td>
<td>curing agent</td>
</tr>
</tbody>
</table>
Some - EPR Cable Constructions
Solid Dielectric Insulation (EPR or XLP)

EPR RUBBER INSULATION: Ethylene Propylene Rubber Compound

Cable manufacturer responsible for and formulates own compound and is responsible for entire process. Or, an independent compounder provides commercial product.

PE, XLPE, TR-XLPE: Family of Polyethylene; thermoplastic, thermo set and tree retardant thermo set polyethylene.

Independent chemical company provides pelletized, ready to extrude, product. Performance guarantee could be questionable.
Okoguard provides the best balance of electrical and physical properties. Okoguard is highly tree retardant, flexible and remains electrically stable at elevated operating temperatures.

Crystalline Effects on Properties

Tree Growth vs. Crystallinity

Source: Fujkura Technical Review #18, Jan. 1989
RETENTION OF PHYSICAL PROPERTIES
100% HOT MODULUS

Tensile Strength PSI

Temperature °C

EPR
XLPE
Electrochemical and Water Trees in XLPE and TR-XLPE

Requirements to Initiate Growth:

- Water vapor
- Electrical stress (approx. 50 volts/mil)
- Time typically 10 to 15 years

Note: EPR is not affected by treeing.
Insulation – Typical Materials

Thermo-Set

- Ethylene Propylene Rubber (EPR)
- Cross linked Polyethylene (XLPE)
- Tree Retardant Cross linked Polyethylene (TR-XLPE)

Thermoplastic

- Polyethylene (PE)
- Polyvinyl Chloride (PVC)
- PVC/Nylon
Cable Design - Components

- Conductor
- Semiconducting Strand Screen
- Insulation
- Semiconducting Insulation Screen
- Metallic Shield
- Protective Covering
  - Jacket/Aarmor
Preferred - all EPR System

- Inner SC – SC-EPR
- Insulation – EPR
- Outer SC – SC-EPR

- No risk of chemical compatibility or rates of expansion and contraction
- Design provides “sameness” vs. “relative compatibility” of EVA or polyolefin semi-cons.
All EPR Insulation System
Conductor Screen

Cables rated 2.4 kV and above

Purpose: To reduce voltage stress at interface between conducting and insulating components

A cylindrical, smooth surface between conductor and insulation

Semiconducting: Not conducting/not insulating
Conductor Screen

For cables rated 5 kV and above. A cylindrical, smooth surface between the conductor and insulation.

**Purpose:** To reduce voltage stress at the interface between the conducting and insulating components.

Typical conductor screen thicknesses run from 0.020” to 0.045 depending on the conductor size. Smaller 69 kV conductor sizes may have thicker conductor screens to reduce the stress.
Insulation – Chief Purpose

- To withstand electrical field applied to cable for its design life in intended installed environment.
- Normal and emergency voltage and current
- Also needs to be bonded to conductor screen, air pockets promote corona.
Insulation Screen:

Purpose: To reduce voltage stress at the interface between the conducting and insulating component.

To provide a symmetrical distribution of voltage stress

A cylindrical, smooth surface between the insulation and shield.
Insulation:

Typical Insulation thickness for 69 kV – 650 mils
Thermoplastic

Thermo set

Over Cooked Spaghetti Analogy
Thermoplastic

Thermo set (Cross linked)
Thermoset vs. Thermoplastic

After one minute in Air oven at 130°C
(weight 85 grams or 29 psi)
TRIPLE TANDEM EXTRUSION

- Okoguard Cables are manufactured on a continuous vulcanization machine (CV) with three tandem extruders
- A closed system that applies all three EPR components in one process
- Damage of critical interfaces and contamination are eliminated
- Employs laser micrometers to measure and control dimensions
- Triple Tandem is superior to the common head process which is limited to the measurement of the combined insulation and insulation shields

1st extruder applies the conductor shield, a black semiconducting, EPR thermosetting compound

2nd extruder immediately applies red Okoguard EPR insulation

3rd extruder applies the insulation shield, a black semiconducting, EPR thermosetting compound
* Insulation System all EPR

- Jacket
- SC
- Strand Screen
- Shield
- * Insulation
- * Conductor
- ALL EPR MATERIALS*
Shielding Types
Listed from High Resistance to Low

- Flat copper tape (High R)
- Concentric cu wires and copper tape
- Longitudinally corrugated tape (LCS) copper or bronze tape
- Concentric copper wires
- Lead sheath
- Flat Straps
- 1/C Al. Armor-CLX (Low R)

Shielding Resistance dictates the amount of circulating current flowing in the shield!
SHIELDING TYPES

POWER CABLE SHIELDING
Shielding
Hybrid, Concentric Neutral EPR Insulated Compact Copper Conductor, Cu Neutrals
JACKET REQUIREMENTS

- PHYSICAL
- CHEMICAL
- TEMPERATURE

- MOISTURE
- AGING
- FLAME
ADVANTAGES of 105°C RATING

• Higher Ampacity:
  • Underground Installation - 7%
  • Air Installation - 12%

• Installation in Higher Ambient Environment
  (Terminations not usually installed at point of highest circuit temp.)

• Assurance of Higher System Reliability
# Insulation – Thicknesses

<table>
<thead>
<tr>
<th>Voltage Rating (shielded)</th>
<th>100 %</th>
<th>133 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 kV</td>
<td>90 mils</td>
<td>115 mils</td>
</tr>
<tr>
<td>15 kV</td>
<td>175 mils</td>
<td>220 mils</td>
</tr>
<tr>
<td>25 kV</td>
<td>260 mils</td>
<td>345 mils</td>
</tr>
<tr>
<td>35 kV</td>
<td>345 mils</td>
<td>420 mils</td>
</tr>
</tbody>
</table>

0.001” = 1 mil or 1” = 1000 mils
## Insulation – Thicknesses

<table>
<thead>
<tr>
<th></th>
<th>100%</th>
<th>133%</th>
<th>173%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relay Clears</td>
<td>Relay Clears</td>
<td>Relay Clears</td>
<td>Indefinite</td>
</tr>
<tr>
<td></td>
<td>&lt; 1min.</td>
<td>&lt; 1hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>For 3 phase systems</td>
<td>For 3 phase systems</td>
<td>For delta systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>where one phase may</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>be indefinitely</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>grounded.</td>
</tr>
</tbody>
</table>
Advantage of ungrounded system is that service may be maintained on entire circuit for indefinite period, even though one phase is grounded.

However, the voltage on two remaining phases will increase to 1.73 X normal phase-to-ground level.
173% Voltage Ratings

Examples

Solid Dielectric (EPR and XLPE)

4.16 kV * 1.73 = 7.2 kV: thus use 8 kV cable
13.3 kV * 1.73 = 23 kV: thus use 25 kV cable

PILC

13.3 kV * 1.73 = 23 kV: use thickness from AEIC Table I that corresponds to 23 kV: 225 mils

Typical installations - generator leads
## Insulation – Thicknesses Current Basis

<table>
<thead>
<tr>
<th>Voltage</th>
<th>100%</th>
<th>133%</th>
<th>173%</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 kV</td>
<td>Occasional</td>
<td>Most Popular</td>
<td>Limited Usage</td>
</tr>
<tr>
<td>25 kV</td>
<td>Most Popular</td>
<td>Occasional</td>
<td>Limited Usage</td>
</tr>
<tr>
<td>35kV</td>
<td>Most Popular</td>
<td>Occasional</td>
<td>Rare</td>
</tr>
</tbody>
</table>
## 15 kV XLPE Thicknesses to Compensate for Treeing

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Fast Tree Growth</th>
<th>Medium Tree Growth</th>
<th>Slow Tree Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>&lt; 10 Years</td>
<td>10 – 15 Years</td>
<td>15 – 20 Years</td>
</tr>
<tr>
<td>133%</td>
<td>175</td>
<td>220</td>
<td>295</td>
</tr>
<tr>
<td>Odd</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ACCELERATED CABLE LIFE TESTS
Per IEEE Paper #81WM115-5
Sample: 1/0 A/175 Wall - unjacketed

- AC Test Voltage - 4X Voltage to Ground
- Water Temperature - 60-70°C
- Conductor Temperature - 90°C
- Water in Strand
- Days to Fail 50% of the Samples*

XLPE................................................................. 46
TR XLPE............................................................ 186
TR XLPE w/Super Smooth Semi-Con...360
XLPE w/Super Smooth Semi-Con...........375

All EPR (No PE) .................................................

*Published Data

TEST TERMINATED AFTER
1415 DAYS
(3.87 YEARS)
Cable Memory

- A failure may occur when a cable rated at the next higher voltage is used for some time, then system voltage is increased to match rating.

- For example, a 25 kV cable operated at 13.8 kV for 15 years, then the voltage is increased to 23 kV.

- Basically the voltage is doubled on a particular tree size.

- This would not be an issue with EPR — no trees
CABLE MEMORY?

Cable Operates at Reduced Voltage

Cable Fails When Raised to Rated Voltage
Topics Covered

1) What is EPR?
2) Cable Types and Shield Designs
3) Research Comparing EPR and XLP
4) Cable Components and Extrusions
5) Thermal Set and Thermal Plastic
6) Temperature Rating
7) Percent Insulation Level
8) Cable Performance
9) Cable Memory