Solid Dielectric Cable Systems

- Solid dielectric insulated cables use polyethylene (PE), cross-linked polyethylene (XLPE) and ethylene-propylene-rubber (EPR).

- Reasons for increased use of solid dielectric insulated cable include the following:
  - Environmental benefits by eliminating the use of dielectric fluids.
  - Lower maintenance costs and requirements - no hydraulic equipment needed.
  - Lower risk of fire during a fault with absence of fluid.
  - Lower capacitance and dielectric losses

- The most common solid dielectric cables used today are XLPE insulated systems.
Solid Dielectric Cable Comparison

- PE and XLPE are known for having very low dielectric losses when compared to paper and EPR insulated cables.

- The dielectric losses stay constant up to emergency operating temperatures on PE and XLPE cables - compared to paper insulated cables where these losses can increase substantially with temperature.

- PE insulated cables are very similar to XLPE cables. However, because of lower melting point and high expansion rate of PE cables at higher temperatures, they are limited to a normal operating temperature of 70°C.

- Because the lower melting temperature of PE insulated cables are easier to extrude, they can be filtered at low temperatures in a liquid state, and can be cross linked to create XLPE.
PE insulated cables are thermoplastic compared to XLPE cables which are thermo-set. A thermo-set material is one that cannot be remolded into a different shape by applying heat.

PE is a lower cost insulation material due to its high purity and absence of fillers compared to other polymers.

XLPE insulated cables have a higher normal operating temperature of 90°C and emergency temperature of 105°C.

This 20°C rise over PE cables equates to an increase ampacity of about 18–20%.

However, since XLPE cables require a cross linking process they are more complicated to manufacture.
Solid Dielectric Cable Comparison (cont.)

- Cross linking is a slow process which reduces the amount of time available for overall production.
- It also requires a synchronized continuous vulcanization process during extrusion.
- A cross linked process is a chemical reaction which requires high standards in material and manufacturing quality control.
- Extruder temperature and pressures are critical during the extrusion process since they control the cross linking process and material flow.
- The start of an extrusion run is typically scrapped since it is used to make adjustments. Likewise, the trailing end is also scrapped since it’s hard to control extruder tube pressure.
After the cable is manufactured a degassing period must take place to remove by-products created during the cross linking process.

Cables are placed in large ovens at temperatures at 60 – 80°C for 5 to 10 days - depending upon cable size and oven temperature.

Cables are degassed since the by-products can mask imperfections which can go undetected during factory high voltage tests.
XLPE Insulated 138 kV Cable
Solid Dielectric Cable Applications

- EPR insulation is a filled cross linked, thermo-set material similar to XLPE.
- EPR cables mostly used at 69 kV level (in some cases up to 138 kV) since the higher dielectric losses in EPR ampacity is reduced compared to XLPE - especially at higher voltages.
- EPR cables, when compared to XLPE, have smaller bending radius, greater emergency temperature (130°C), and greater resistance to moisture.
- EPR cables have increased resistance to moisture and better bending flexibility.
- At lower voltages levels EPR cables are used for underwater installations.
EPR Insulated 69 kV Cable
Cable Construction

- Typical Cable Construction:
  - Conductor
  - Conductor Shield
  - Insulation
  - Insulation Shield
  - Bedding Tapes
  - Sheath
  - Jacket
Cable Conductors

- Typically made of strands of aluminum or copper.
- Conductors are typically round or segmental.
- Segmental conductors used for larger size conductors to reduce skin effect.
- It is more difficult to manufacture perfectly round segmental conductors so binder tapes are wrapped tight around conductors to keep them round.
- In some cases, a water block material is applied to conductor as a powder or sticky paste.
- Typical conductor sizes range from 500 kcmil to 5000 kcmil. However, sizes as large as 7000 kcmil are feasible.
Conductor Shield

- Conductor shields are semi-conductive and used to provide an electrically smooth surface so that any high stresses caused by imperfections around the conductor are eliminated.

- The conductor shields bonds to the insulation and is allowed to expand and contract at the same rate as insulation.

- A shield must be robust in design to avoid penetration of the conductor wires during installation or during thermal cycling under normal operation.

- AEIC and ICEA standards specify recommended thickness.
Cable Insulation

- Insulation material is pure and must be very clean when extruded to avoid impurities in the insulation.
- Insulation thickness is based upon insulation used, extrusion and curing process, accessories being used, and the use of a moisture barrier along with the targeted electrical stress.
- Thicker insulation is not necessarily a more conservative better or choice since it would increase the cable diameter, thus making it more expensive and may require a larger cable duct.
- AEIC and IECA specify recommended insulation thickness and stress levels.
Insulation Shield

- An insulation shield is very similar to the conductor shield. However, it must be able to resist penetration of outer cable layers such as shield wires or metal sheaths during installation or thermal expansion forces during operation.

- AEIC and ICEA standards specify recommended thickness.
Bedding Tapes

- Bedding tapes (also referred to as cushioning tapes) provide a layer of protection for the insulation shield.

- Water swellable tapes are installed to stop moisture and are typically sandwiched between the bedding tapes.

- Bedding tapes contain a super absorbent polymer. Super absorbent polymers have been used in cable designs since the 1980’s.

- Bedding tapes and water swellable tapes must be semi-conductive so they can transmit the capacitive charging current from the XLPE insulation to the shield.
Cable Sheath

- Most extruded dielectric transmission cables contain a metal sheath to provide a radial moisture barrier.

- In addition to providing a moisture barrier, the sheath is designed to handle insulation charging, fault, and surge currents.

- Metallic sheaths used for transmission cables are:
  - Lead
  - Corrugated Aluminum and Copper
  - Smooth welded aluminum
  - Copper and Aluminum Foil laminates
  - Stainless Steel
Cable Jacket

- The jacket is a key layers of cable construction and is used to protect the cable during installation, and ensure longevity during operation.

- Jacket tests are performed after manufacturing and installation to ensure jacket is intact and not damaged.

- A semi-conductive or graphite layer is applied to jacket in order to be able to perform the jacket or spark test.

- Typical jacket material is polyethylene (PE) or PVC.

- AEIC and ICEA standards specify recommended thickness.
XLPE Cable Design

XLPE Insulation

Segmental Copper Conductor

Conductor Binder Tapes

Conductor Shield

Insulation Shield

Bedding Tapes

Copper Shield Wires

Bedding Tapes

Copper Foil Laminate Sheath

PE Jacket
XLPE Cable Design

- Copper Segmental (4) Conductor
- XLPE Insulation
- Extruded Lead Sheath
- PE Jacket
EPR Cable Design

- Round Copper Conductor
- Conductor Shield
- EPR Insulation
- Insulation Shield
- Copper Shield Wires
- PE Jacket
Manufacturing Process

- Three different types of extruders are used to manufacture solid dielectric cables:
  - Vertical Continuous Vulcanization (VCV)
  - Horizontal Continuous Vulcanization (HCV)
  - Cantenary Continuous Vulcanization (CVC)

- VCV lines are predominantly used for transmission cables with large conductors.

- The tower height is based on length of VCV tube required to heat and cool cable.

- Typical tower height is about 300 ft.
Equipment used (extruders, controls, clean rooms, tension rollers, etc.) are the same as other lines.

The advantage to using a VCV line is cable circularity is easier to maintain and production speed is faster.

However, VCV lines are more expensive to construct and in some areas height may be limited due to local regulations.
CCV lines are widely used to manufacture medium (MV) and high voltage (HV) because of low cost and high output rates.

The CV tube on CCV lines are installed almost at ground level with extruder mounted a few stories high.

CCV lines require large tension wheels to keep conductor centered in tube to produce a circular cable.

There are very few CCV lines designed to manufacture large conductor transmission cables which use silicone oil instead of nitrogen.
Manufacturing Process (cont.)

- HCV lines have manufactured a significant amount of transmission cables up to 400 kV level.
- HCV line uses a die to extrude the cable similar to a mold.
- Die tube is 10 to 20 meters long and has to be machined to the specified design diameter of cable.
- HCV lines are low cost to install since they are installed on ground level. However, dies are expensive, the tube is short which limits production output, and limited conductor tension make it difficult to produce a round cable.
- Cable surface temperature is higher which risks the chance for thermal aging.
Vertical Continuous Vulcanization

1 - Pay-off stand
2 - Conductor butt welding machine
3 - Dancer accumulator
4 - Braking unit
5 - Conductor preheating
6 - Extruder group with triple cross head
7 - Diameter/wall thickness measuring device
8 - Granules conveying and drying system
9 - CV tube
10 - Reversing ring
11 - Belt-type caterpillar
12 - Cable saw
13 - Take-up stand
14 - Line operating panel process computer
1 Input Drum
2 Dancer Accumulator
3 Conductor
4 Conductor Capstan
5 Conductor PreHeat
6 Triple Cross Head
7 Conductor Shield Extruder
8 Insulation Extruder
9 Core Shield Extruder
10 X-ray Geometry Check
11 Pressuried Silicon or Gas Curing Zone
12 Water or Gas Cooling Zone
13 Insulated Cable Core
14 Turnaround Capstan
15 Laser Dimensional Check
16 Ultrasonic Inspection
17 Caterpillar
18 Output Drum
Cantenary Continuous Vulcanization Line

1 Pay-off Stands
2 Conductor butt welding machine
3 Accumulator
4 Braking unit
5 Conductor preheating
6 Extruder group with triple cross head
7 Diameter/wall thickness measuring device
8 Granules conveying and drying system
9 CV-tube
10 Tractive unit
11 Helper caterpillar
12 Take-up stands
Horizontal Vulcanization Line

- Insulation Extruder
- Cross-head (triple extrusion)
- Conductor Straightening
- Conductor Screen Extruder
- Insulation Screen Extruder
- Vulcanization tube: Long Land Die (High temperature/high pressure)
- Cooling Section
- Cable Core
Horizontal Vulcanization Line