Crosslinked Polyethylene Jackets for Medium Voltage Cables

Fall 2010 IEEE PES ICC Meeting
Subcommittee C – Cable Systems
October 20, 2010

William S. Temple

General Cable

Medium Voltage Cable Jacket Materials

- Linear Low Density Polyethylene (LLDPE) has been the jacket material of choice for North American Utility MV primary distribution cables because of its good physical properties and relative low cost
- Thermoset crosslinked polyethylene (XLPE) delivers designs that offer benefits that can't be provided by thermoplastic materials

Crosslinked Jackets for MV Cables

- Eco-nomical
  - Through an innovative redesign of the cable's concentric neutrals the amount of high-cost copper can be reduced to cut initial material costs
- Eco-efficient
  - Cross-Linked Polyethylene (XLPE) cable jacketing coupled with reduced concentric neutrals, provides better efficiency over the life of the cable through cooler operation, lower line loss and greater resistance to deformation
- Eco-friendly
  - With its built-in cost benefits and long-term efficiencies, XLPE jacket is the total green solution — allowing you to go green and save green for an overall better return on investment
    - Reduced Copper in Concentric Neutrals
    - Cooler Operation
    - Enhanced Thermal-Mechanical Properties
    - Optimal Efficiency with Lower Line Loss

Crosslinked Jackets for MV Cables

- Approximately 25% reduction in copper in the concentric neutrals
  - Using the ICEA P-45-482-2007 calculations to determine the shield cross-sectional area required for a given fault current, LLDPE jackets are limited to a maximum transient temperature of 200 °C; XLPE jackets allow 350 °C
  - The higher temperature allowance provides a greater amount of fault current capability for a given cross-sectional area, reducing the required copper in the neutrals
  - A smaller circulating current provides a reduced operating temperature, resulting in higher cable ampacities

Further savings can be realized through the EPRI Short2 Program calculation method

Crosslinked Jackets for MV Cables

- Reduced shield losses equate to lower line loss
  - With reduced copper concentric neutrals, the shield resistance will increase, with lower losses due to circulating currents
  - This effect is most easily seen in the larger kcmil sizes but is applicable to all conductor sizes
- Equivalent physical properties to existing LLDPE jacketed construction
  - Test data has shown that XLPE jackets maintain the physical properties, jacket stripping, coefficient of friction and installation characteristics of traditional LLDPE jacket constructions

Jacket Material Physical Properties

	LLDPE Jacket	XLPE Jacket
Unaged Requirements		
Tensile (psi)	2382-3220	2608 -2993
Elongation (%)	635-805	513 – 557
Air oven Aging Requirements	48 hours at 100 °C	168 hours at 136 °C
Tensile (% retained)	75-120	88 - 98
Elongation (% retained)	84-108	71 - 85
Heat distortion (%)	(@100 °C) 1.3-12	(@ 136 °C) 5.2 - 6.9
Cold Bend (-40 °C) 4 hr	No cracks	No cracks
Cold Impact (-40 °C) 4 hr (# failed)	0/10	0/10

Jacket Material – Abuse Resistance Properties

	LLDPE	XLPE Jacket
Sharp Impact Resistance Test		
Pound-Force Inch	9	13
Blunt Impact Resistance Test		
Pound-Force Inch	44	59
Abrasion Resistance Test		
Test Cycles	245	142
Scoring Resistance Test		
Test Cycles	25	49
Crush Resistance Test		
Pounds	877	880
Puncture Resistance Test		
Pounds	51	53

Note: Test Cable – 1/0 AWG, 80 mil Jacket – S-81-570 Standard

Jacket Material – Flexure Properties

Flexure Test		LLDPE	XLPE Jacket
90° Bend @ -16°C	Foot-Pounds	9.0	9.3
180° Bend @ -16°C	Foot-Pounds	10.1	11.0
90° Bend @ 0°C	Foot-Pounds	8.3	8.4
180° Bend @ 0°C	Foot-Pounds	9.4	9.6
90° Bend @ 21°C	Foot-Pounds	7.2	7.7
180° Bend @ 21°C	Foot-Pounds	8.0	8.4

Note: Test Cable – 1/0 AWG, 80 mil Jacket – S-81-570 Standard

Jacket Material – Coefficient of Friction

Duct Type	Jacket Type	Coefficient of Friction	
		Without Lubricant	With Lubricant
PVC	LLDPE	0.22	0.12
	XLPE	0.21	0.06
HDPE	LLDPE	0.26	0.13
	XLPE	0.19	0.11
Fiberglass	LLDPE	0.24	0.13
	XLPE	0.23	0.14

Thermomechanical Testing

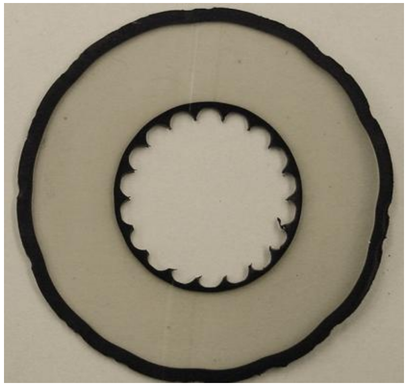
- Cable tested in conduit, 2 straight sections, 1 U-bend
  - 1/C Cable/Conduit testing outlined by Industry Standards
  - Additional 3 x 1/C Cable/Conduit comparative testing also conducted

AEIC / ICEA Thermomechanical Qualification Test Set-up

Thermomechanical Testing

- **14 Current load cycles**
  - Achieve 6 hours of Emergency Overload Temperature during on period
  - Return to within 5 °C of ambient temperature during off period
- **Initial/final dissipation factor & partial discharge**
- **U-Bend sample taken for dimension inspection; cable shield/jacket must not exhibit any cracks or splits**
- **500 kcmil AL, 0.345" TRXLPE, 16/#12 CU CN, Extruded-to-Fill Jacket, 35 kV Cable Design**

Unaged Wafer



Aged Wafer

Standard Single Conductor Cable
AEIC / ICEA 140ºC Thermomechanical Qualification Test
TRXLPE / Round Wire Concentric Neutral / XLPE Jacket Design

Thermomechanical – LLDPE Jackets

- Results of the testing showed that the LLDPE failed 3 x 1/C Cable/Conduit 140 °C testing; it clearly melted and fused together, causing exposed concentric neutrals at some locations

Thermomechanical – XLPE Jackets

- XLPE Jacketed Cables passed 3 x 1/C Cable/Conduit 140 °C testing with no problem areas

Fault Current Capability

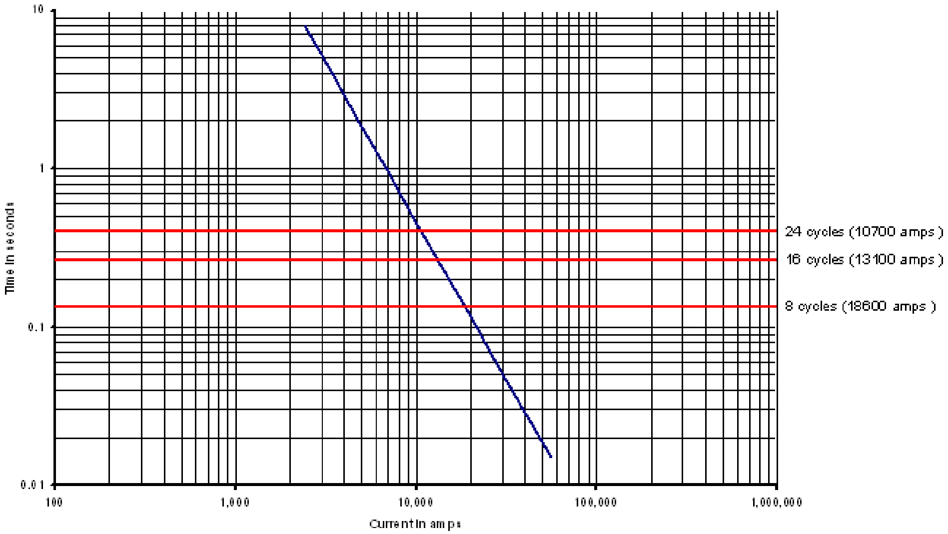
Aluminum Conductor Size	LLDPE		XLPE		Copper Reduction (%)
	NEUTRALS	FAULT CAPABILITY (Amps @ 6 Cycles)	REVISED NEUTRALS	FAULT CAPABILITY (Amps @ 6 Cycles)	
1/0 AWG	11 X #14	9052	**13 X #16**	**9226**	**26**
4/0 AWG	16 X #14	13166	**12 X #14**	**13840**	**25**
500 KCMIL	16 X #12	20920	**12 X #12**	**21990**	**25**
1000 KCMIL	16 X #12	20920	**12 X #12**	**21990**	**25**
1250 KCMIL	20 X #12	26150	**15 X #12**	**27488**	**25**

Short Circuit calculations based on **ICEA P-45-482-2007** methodology.

Fault Current Capability - Side by Side Comparison

1000 kcmil Al, 0.345" TRXLPE, 16 / 12 AWG Cu LLDPE

MAXIMUM FAULT CURRENT OPERATING LIMITS
FOR A 104458 cmil COPPER METALLIC SHIELD AT 60 Hz



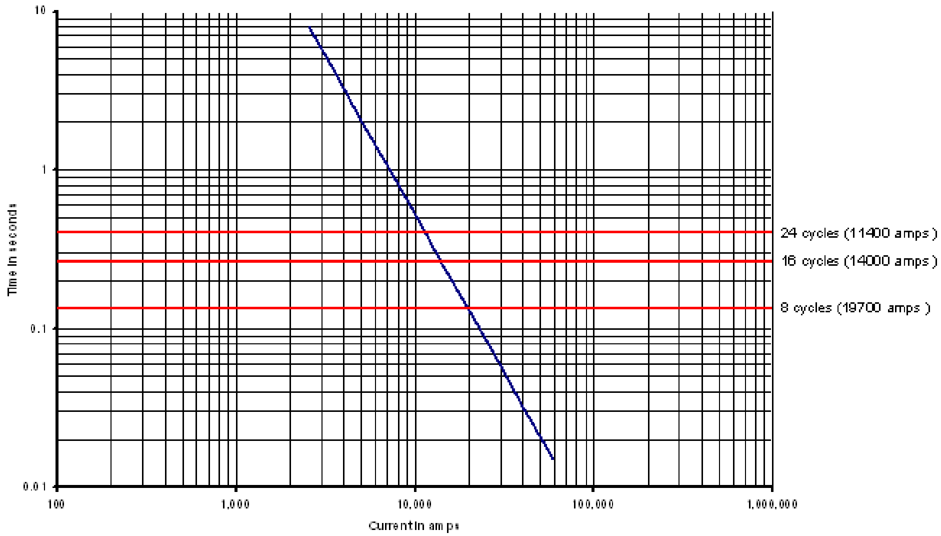
16 x #12AWG Copper Concentric Neutral

Number of Cycles	Time (s)	Current (amps)
8	0.13	18600
16	0.27	13100
24	0.40	10700

Notes -
The curves assume that all heat generated remains in the metal.
The time shown is that calculated for a given RMS fault current to bring the metallic shield to a temperature that will not cause damage to the insulation shield or cable jacket.
The calculations are as per ICEA P-45-482 using an "M factor" of 0.065 corresponding to a 35-46 kV rated cable, with a conductor temperature of 90 and a metallic shield starting temperature of 80 C and a metallic shield ending temperature of 200

1000 kcmil Al, 0.345" TRXLPE, 12 / 12 AWG Cu XLPE

MAXIMUM FAULT CURRENT OPERATING LIMITS
FOR A 78344 cmil COPPER METALLIC SHIELD AT 60 Hz



12 x #12AWG Copper Concentric Neutral

Number of Cycles	Time (s)	Current (amps)
8	0.13	19700
16	0.27	14000
24	0.40	11400

Notes -
The curves assume that all heat generated remains in the metal.
The time shown is that calculated for a given RMS fault current to bring the metallic shield to a temperature that will not cause damage to the insulation shield or cable jacket.
The calculations are as per ICEA P-45-482 using an "M factor" of 0.092 corresponding to a 35-46 kV rated cable, with a conductor temperature of 90 and a metallic shield starting temperature of 80 C and a metallic shield ending temperature of 350

Crosslinked Jackets for MV Cables

Wind Farm Comparative Study LLDPE Jacket Versus XLPE Jacket		
PRODUCT DESIGN	**DESCRIPTION -** 1000 kcmil Aluminum, TRXLPE, 1/3 CN, 35kV	
	LLDPE JACKET	**XLPE JACKET**
Concentric Neutrals	20 x 10 AWG	23 x 12 AWG
Concentric Neutrals - CU WGT	660 lbs/kft (982 kg/km)	478 lbs/kft (711 kg/km)
Shield Fault Capacity - Currents @ 6 Cycles (AMPS)	42645 A	42695 A
Ampacity(1) - Direct Buried @ 90°C – Flat	645 A	660 A
Cost of Shield Losses(2)	**$82,700**	**$75,300**
Calculated Savings(3)		**$976,800**

(1) Based on 3 conductor, flat, 7.5" spacing, 36" burial depth, 20° C ambient, 75% load factor, soil Rho 0.9 °C-m/W
(2) Based on 3 conductor, flat, 7.5" spacing, 645 A, avg. energy cost $0.06/kWh, 1 circuit mile, 1 year time frame
(3) Based on 3 conductor, flat, 7.5" spacing, 645 A, avg. energy cost $0.06/kWh, 20 circuit miles, 20-year life of a wind farm, 1/3 production time

XLPE Jacket Material Cure

- Moisture Cure Monosil Process
  - One step process where polyethylene resin is fed into the extruder and a solution of silane, initiator and catalyst is injected into the barrel
- Moisture Cure Pre-grafted Resin/Catalyst Process
  - Two step process that utilizes pre-grafted resin (vinyl silane grafted onto polyethylene backbone) mixed with a catalyst master-batch just prior to the extruder
- In both moisture cure processes the material curing is initiated during extrusion
  - Cure can be accelerated by post treating with steam or hot water
  - Cure will also complete in an ambient environment, but at a slower rate
  - Cure is quicker in the Monosil process

XLPE Jacket Material Cure

- Since moisture cure materials do not cure immediately in the cable extrusion process, it will be necessary to develop an accelerated production test procedure to establish the material is grafted and will crosslink
  - A preconditioning step with elevated temperature and moisture applied to the specimens for the hot creep / set test will allow cure to be established in a timely manner during cable production

- The ambient cure rate is a function of temperature, humidity and wall thickness
  - Pre-grafted Resin/Catalyst process material cures in Eastern Canada winter months in approximately 60 days
  - Pre-grafted Resin/Catalyst process material cures in Southwestern USA summer months in approximately 7 days
  - Ambient cure materials are utilized commonly in Europe, Asia and South America

Industry Standards & XLPE Jackets

- XLPE jackets are recognized by UL 1072 Standard
- Proposal submitted for inclusion of XLPE jackets in MV Utility Cable Standards
  - ANSI/ICEA S-94-649 & ANSI/ICEA S-97-682 Standards
  - CSA C68.5 Standard
- ICEA Working Group has been initiated to establish the physical requirements for XLPE jacket materials

Industry Standards Proposal

Crosslinked Polyethylene, Black (XLPE)

Physical Requirements	Values	
Unaged Requirements		
Tensile Strength, Minimum psi (MPa)	1500 (10.3)	
Elongation at Rupture Minimum Percent	150	
Aging Requirements After Air Oven Aging at 121 °C ± 1 °C for 168 hours		
Tensile Strength, Minimum Percentage of Unaged Value	70	
Elongation, Minimum Percentage of Unaged Value	70	
Heat Distortion at 121 °C ± 1 °C, maximum percent	50	
Hot Creep Test at 150 °C ± 2 °C		
*Precondition samples	Unfilled	Filled
Elongation, Maximum Percent	175	100
Set, Maximum Percent	10	5
Carbon Black Minimum Percent	2.0	

***** Moisture cured XLPE jackets only

Crosslinked Jackets for MV Cables

Your Best Choice

Utilities have historically used Linear Low Density Polyethylene (LLDPE) thermoplastic jackets for the beneficial balance of cost and physical protection it provides. The future of utility power cable jacketing is thermoset XLPE jackets that provide a lower-total-cost solution

- Eco-nomical
- Eco-efficient
- Eco-friendly

Thank you!

Questions?