SPECIFYING QUALITY CABLES

Presented at
RMEL Distribution Engineers Workshop
Denver, CO

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System of Specifications

Utilities
Association of Edison Illuminating Companies (AEIC)

Cable Manufacturers
Insulated Cable Engineers Association (ICEA)

Cable Accessories
IEEE 404 (joints), IEEE 48 (terminations), IEEE 386 (separable connectors)

IEEE, IEC, ASTM, NEMA, ANSI, UL, etc.
Main Standards for Utility Distribution Cables

• AEIC CS8-13 Specification for Extruded Dielectric, Shielded Power Cables Rated 5 Through 46 kV (a new issue is being prepared)

• ANSI/ICEA S-94-649-2013 Standard for Concentric Neutral Cables Rated 5 Through 46 kV

• ANSI/ICEA S-97-682-2013 Standard for Utility Shielded Power Cables Rated 5 Through 46 kV
Supporting Documents

• AEIC CG10-10 Guide for Developing Specifications for Extruded Power Cables Rated 5 Through 46 kV

• AEIC CG8-10 Guide for Electric Utility Quality Assurance Program for Extruded Dielectric Power Cables
What Cable Users Should Be Aware of?

Just a Few Examples
EXTRUDED DIELECTRIC CABLES
MANUFACTURING IMPERFECTIONS

At the Conductor Shield:
Protrusions
Voids
Protruded Strand(s)
Skip in the Shield
Shield Fall-in

At the Insulation Shield:
Loose Shield
Protrusions
Voids
Excessively Thin Shield

In the Insulation Wall:
Contaminants
Voids (Spherical/Irregular)
Microporosity (halo)
Poorly Dispersed Ingredients
Skip in the conductor shield
Protrusion from the conductor shield
Voids
Void in EPR
Contaminants
Water blocking compound protruded into the insulation
Ambers
A quiz for volunteers:
How would you call it?
What these features may cause:

a) Enhanced electric stress
b) Water treeing
c) Partial Discharge
d) Accelerated degradation causing development of electrical trees and premature failures
**VOLTAGE STRESS CONCENTRATION AT AN HYPERBOLOIDAL PROTRUSION**

<table>
<thead>
<tr>
<th>D/R</th>
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<th>4</th>
<th>6</th>
<th>10</th>
<th>30</th>
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<tbody>
<tr>
<td>EF=$\frac{E_{\text{MAX}}}{E_{\text{AVG}}}$</td>
<td>8.7</td>
<td>22</td>
<td>38</td>
<td>74</td>
<td>74</td>
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<tr>
<td>EF at $E_{\text{AVG}} = 75$ V/MIL</td>
<td>652</td>
<td>1,650</td>
<td>2,850</td>
<td>5,550</td>
<td>21,525</td>
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</table>

![Diagram of voltage stress concentration at an hyperboloidal protrusion](image)
Table 1
Stress concentration at an ellipsoidal projection

<table>
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<tr>
<th>c/a</th>
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<th>6</th>
<th>10</th>
<th>30</th>
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<tbody>
<tr>
<td>$E_{\text{max.}}/E_{\text{avg.}}$</td>
<td>5.9</td>
<td>13.3</td>
<td>22.7</td>
<td>49.2</td>
<td>289.0</td>
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</table>
Water tree vented at the conductor shield
Vented water tree extending protrusion at the insulation shield
Bow tie
water
tree
Breakdown channel and electrical tree initiated at water trees
Modern tree retardant compounds: small bow tie trees originating at less than 1 mil contaminants
Design of Cable Components

This subject is not discussed in the presentation.

Most Utilities have a long and well established history of cable designs and each alternative deserves a separate analysis and discussion.

Quality Assurance

Follows
Most Significant Factors for Cable Quality
(to be considered in cable specifications)

- Cleanliness of compounds and processes
- Triple extrusion: all three layers are extruded in the same process, without exposure to environment and contamination
- Dry curing vs. steam curing conducive to much lower porosity and moisture content
- Tree retardant compounds with improved characteristics
- Super Smooth shields, etc.
First Line of Defense

Specifications Must Require Proof of Qualification Tests

A) Core Material Qualification
B) Thermo-Mechanical Qualification (optional)
C) CV Extrusion Line Qualification
D) Other Qualifications
Core Material Qualification Tests

Every Manufacturer must have these tests performed on each combination of materials used: conductor shield – insulation – insulation shield.
AC Breakdown Strength – TR-XLPE Compounds

Reference only
AC Breakdown Strength – Super Smooth vs. Not Super Smooth

Reference only
CV Extrusion Qualification

• **Mandatory Monthly Tests** on a randomly selected cable produced **On Each Extrusion Line** used during a particular month.

• **When specifying cables, availability of these reports should be required.** It also makes sense to read these reports, at least from time to time 😊.
Second Line of Defense

Audit of Manufacturer’s Plant(s)

• Highly Recommended, especially when qualifying a new supplier (what you see is what you get)

• Subcontracting industry experts, proficient in cable manufacturing and testing, is usually beneficial and helpful
Third Line of Defense

Reinforcing Required Production Tests

• Witnessing these tests
• Understanding the test performance
• Knowing as to how to read these reports
• READ the reports!
# Summary of Production Tests and Sampling Frequency Requirements

<table>
<thead>
<tr>
<th>TEST</th>
<th>STANDARD REFERENCE</th>
<th>TEST METHOD REFERENCE</th>
<th>MINIMUM FREQUENCY</th>
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<tr>
<td><strong>Conductor</strong></td>
<td></td>
<td></td>
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<tr>
<td>dc Resistance</td>
<td>Part 2</td>
<td>9.3.1 and ICEA T-27-581</td>
<td>100%</td>
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<tr>
<td>Diameter</td>
<td>Part 2</td>
<td>ICEA T-27-581</td>
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<td>Elongation After Aging</td>
<td>Part 3</td>
<td>9.4.15</td>
<td>Plan H</td>
</tr>
<tr>
<td>Volume Resistivity</td>
<td>Part 3</td>
<td>9.8.1</td>
<td>Plan H</td>
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<tr>
<td>Thickness</td>
<td>Part 3</td>
<td>9.4.2</td>
<td>Plan E</td>
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<td>Voids, Protrusions and Irregularities</td>
<td>Part 3</td>
<td>9.4.13</td>
<td>Plan A</td>
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<td>Wafer Brittleness</td>
<td>Part 3</td>
<td>9.4.12</td>
<td>Plan B</td>
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<td>Spark Test (Non-conducting Layer Only)</td>
<td>Part 3</td>
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<td><strong>Insulation</strong></td>
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<td>Unaged and Aged Tensile and Elongation</td>
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<td>Shrinkback Test (XLPE/TRXLPE Only)</td>
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<td>Voids and Protrusions</td>
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<td>Dimensional Measurements</td>
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<td>Jackets (if required)</td>
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<td>Unaged and Aged Tensile and Elongation</td>
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Forth Line of Defense

Quality Assurance Programs with Third Party Involvement

• Different level of programs can be designed considering particular circumstances, both short term (mitigating a known shortcoming) and long term and.

• Selected EXAMPLES follow
Tests at an Independent Laboratory

a) Verifying cable quality by:
   Physical tests and examinations
   High Voltage tests on individual samples

b) Witnessing final in-factory tests
Acceptance Tests

On Short Samples
a) Dimensional Analysis
b) Microscopic Examination for Voids, Contaminants and Protrusions
c) Stripping test (bond strength and field stripping)
d) Hot Creep
e) Shrink-back
f) Check to see if jacket is loose over core (for EPR)
Acceptance Tests

On 50 ft. Samples

a) High voltage time test – breakdown

b) Establish origin and direction of breakdown

c) Longitudinal water penetration resistance (for blocked conductors)

d) Structural stability test
   Partial Discharge Dissipation Factor
High Voltage
Comparative Results
Reference only

Voltage Breakdown Stress

Boring
Voltage Breakdown Stress

OOPS!
Voltage Breakdown Stress

WHOOPS!
Cable Shipping Reel
Witness Testing

a) Partial Discharge

b) High Voltage Withstand
CABLE QUALITY ASSURANCE PROGRAM

WITNESSED FACTORY TESTS (100%)

LABORATORY TESTING OF RANDOMLY SELECTED CABLE SECTIONS (100 FT FROM EACH PRODUCTION RUN OR PER 100,000 FT)

INVESTIGATION OF DETECTED PROBLEMS

IMPLEMENTATION OF CORRECTIONS
Example of an Outcome (data from 2012 through 2014)

<table>
<thead>
<tr>
<th>Cable Supplier Since</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>Percentile rejected during factory tests*</td>
<td>?</td>
<td>15 kV – 0% 35 kV – 0.3%</td>
<td>15 kV – 0.8% 35 kV – 1.6%</td>
<td>-</td>
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<tr>
<td>Number of problems identified by laboratory testing*</td>
<td>1 MAJOR 5 MINOR</td>
<td>2 MAJOR</td>
<td>3 MAJOR</td>
<td>-</td>
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<tr>
<td>Outcome</td>
<td>Continues</td>
<td>Continues</td>
<td>Purchases Stopped</td>
<td>Just started</td>
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Reference only
Last but not Least

COMPARATIVE EVALUATION OF CABLE ACCESSORIES

ALL MAJOR TYPES EVALUATED:
- HAND TAPED
- PREMOLDED
- HEAT SHRINK
- COLD SHRINK
- STRAIGHT AND BRANCHED

EVALUATION OF MATERIALS AND COMPONENTS, INCLUDING SOLDER, CRIMP AND SHEAR BOLT CONNECTORS AND LUGS

IDENTIFIED PROBLEMS AND FINDINGS:
- CONNECTOR OVERHEATING
- EFFECT OF STRAND FILLING TECHNIQUES
- PARTIAL DISCHARGE IN HAND TAPED ACCESSORIES
- MOST OF COLD SHRINK JOINTS CANNOT SUPPORT INTERNAL PRESSURE, TYPICAL OF CABLES WITH CORRODING ALUMINUM CONDUCTORS
- HAND TAPED ACCESSORIES ALLOW FOR VENTING INTERNAL PRESSURE WITHOUT HARMFUL EFFECT
CONCLUSIONS

• When developing cable purchase specifications, quality assurance measures are of prime importance.
• Different program levels should be considered and specified, depending on Utility experience with a particular supplier, failure rate, etc.
• Cable accessories should not be forgotten in the specifications.