Perspective on Connector Tests to ANSI C119.4 & IEEE 404

Presented by:
Thomas J. Parker
Introduction

• Results previously reported at ICC have indicated there may be a problem with connectors installed on filled strand conductors.

• The NEETRAC membership is sponsoring work to investigate the effect(s) that filled strand conductor has on connector performance.

• Test methods applied:
  — IEEE 404 in-air heat rise and cyclic aging of medium voltage joints at different temperatures
  — ANSI C119.4 current cycle submersion tests of connectors

• Test samples included:
  — Conductor with non-filled and different types of filled strand materials
  — Different connectors and joints
  — Wire-brushed and not wire-brushed connections
# Project Advisors

<table>
<thead>
<tr>
<th>Company</th>
<th>Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M</td>
<td>Bill Taylor</td>
</tr>
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<td>Ameren</td>
<td>Harry Hayes</td>
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<td>American Electric Power</td>
<td>Doug Fitchett, Carol Liu, Austin McMillion</td>
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<tr>
<td>Baltimore Gas &amp; Electric</td>
<td>John Spence</td>
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<td>Borealis Compounds LLC</td>
<td>Dominic Kung</td>
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<td>Cooper Power Systems</td>
<td>Andy Lemminger</td>
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<tr>
<td>Dominion-Virginia Power</td>
<td>Steve Boles</td>
</tr>
<tr>
<td>Dow Chemical Company</td>
<td>Yimsan Gau</td>
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<tr>
<td>Duke-Energy</td>
<td>Jon Carter, Chris Fletcher</td>
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<tr>
<td>Exelon</td>
<td>Jim Crane, John Hans, Dan Zoladz</td>
</tr>
<tr>
<td>NSTAR Electric and Gas</td>
<td>Vanessa Dube, Ruvani Nagage</td>
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<tr>
<td>Oncor Electric Delivery</td>
<td>Richie Harp</td>
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<tr>
<td>Prysmian Cables and Systems</td>
<td>Chris Amick</td>
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<tr>
<td>South Carolina Electric &amp; Gas</td>
<td>Mark Furtick</td>
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<tr>
<td>Southern Company</td>
<td>Tim Wall</td>
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<tr>
<td>Southwire</td>
<td>Kim Knuckles, Joe McAuliffe, Nick Ware</td>
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<tr>
<td>Thomas &amp; Betts</td>
<td>Matt Cawood, Jim Zahnen</td>
</tr>
<tr>
<td>Tyco / Raychem</td>
<td>Alexander Bulza, Miguel Contreras</td>
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</tbody>
</table>
ANSI C119.4 Test Samples

• Conductor: 1/0 AWG Class B Compressed 1350 Al 3/4 HD
  — Without Filled Strand Material, Non-filled
  — Filled Strand Material, Fill-1
  — Filled Strand Material, Fill-2

• Connectors: Two different 1/0 AWG Compression Sleeve Connectors (crimped using recommended die with three crimps per side according to manufacturer instructions)
  — Small: ≈ 2.15 inches long and 0.65 inch diameter
  — Large: ≈ 3 inches long and 0.90 inch diameter
ANSI C119.4 CCST
(Current Cycle Submersion Test)

• 18 Samples in Test Loop A
  — Three replicates per condition – conductor wire brushed
• 12 Samples in Test Loop B
  — Two replicates per condition – conductor not wire brushed
• Samples all properly installed
• 100 cycles – 1 hour current ON, ½ hour current OFF
ANSI C119.4 CCST Results

Connector Temp Relative to Control Conductor Temp at ~ 120 °C

ANSI C119.4 at 100 Cycles (Bare)
ANSI C119.4 CCST Results

Connector Temp Relative to Control Conductor Temp at ~ 120 °C

ANSI C119.4 at 100 Cycles (Bare)
# ANSI C119.4 CCST Results

Analysis of Variance (ANOVA)
Relative Connector Temperature

<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector</td>
<td>2</td>
<td>Small, Large</td>
</tr>
<tr>
<td>Brushed Conductor</td>
<td>2</td>
<td>No, Yes</td>
</tr>
<tr>
<td>Stand Filled Conductor</td>
<td>3</td>
<td>Non-filled, Fill-1, Fill-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>$P$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector</td>
<td>0.000</td>
<td>$&gt;99.9%$</td>
</tr>
<tr>
<td>Brushed Conductor</td>
<td>0.000</td>
<td>$&gt;99.9%$</td>
</tr>
<tr>
<td>Strand Filled Conductor</td>
<td>0.072</td>
<td>92.8%</td>
</tr>
</tbody>
</table>
ANSI C119.4 CCST Results

Main Effects Plot for Relative Connector Temp - BARE
Temperature Means at ~ 120 °C Conductor Temp

1. Connector
2. Brushed Conductor
3. Filled Strand Conductor
IEEE 404 Test Samples

• Cable: 25 kV, 260 mil TRXLPE, 16 - #14 AWG Concentric Neutrals, Encapsulating LLDPE Jacket
  — Without Filled Strand Material, Non-filled
  — Filled Strand Material, Fill-1
  — Filled Strand Material, Fill-2

• Joints: Two different 1/0 AWG, 25 kV rated joints (joint kits came with the same connectors previously described)
  — Joint A: Cold-shrink, small connector
  — Joint B: Molded, large connector
IEEE 404 In-Air Cyclic Aging

• 18 samples in one loop
  – Conductor WAS wire brushed before connector installation on two replicates per condition
  – Conductor WAS NOT wire brushed before connector installation on one replicate per condition

• 37 cycles have been completed – 8 hours current on / 16 hours current off
IEEE 404 In-Air Cyclic Aging
## IEEE 404 In-Air Cyclic Aging

### Load Cycle History

<table>
<thead>
<tr>
<th>Cycles</th>
<th>Target Conductor Temperature (°C)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-24</td>
<td>90</td>
<td>IEEE Std. 404 load cycles (in air) with voltage applied</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Thermocouples installed on joint connector through hole drilled in joint housing. No test voltage applied for remainder of testing.</td>
</tr>
<tr>
<td>25-30</td>
<td>90</td>
<td>Seven samples found to be exceeding the control conductor temperature at cycle 25. One was removed after 29 cycles because it was exceeding 130 °C.</td>
</tr>
<tr>
<td>31-37</td>
<td>105</td>
<td>Ten samples now found to be exceeding the control conductor temperature at cycle 31 after increasing control conductor temperature to 105 °C.</td>
</tr>
</tbody>
</table>
IEEE 404 In-Air Cyclic Aging Results

Connector Temp Relative to Control Conductor Temp of 90 °C
IEEE 404 at 30 Cycles (Insulated)
IEEE 404 In-Air Cyclic Aging Results

Connector Temp Relative to Control Conductor Temp of 90 °C
IEEE 404 at 30 Cycles (Insulated)

Relative Connector Temp

Conductor Strandfill
Fill-1
Fill-2
Non-filled

Joint
A
B
A
B
A
B
0
-10
10
20
30
IEEE 404 In-Air Cyclic Aging Results

Connector Temp Relative to Conductor Temp of 105 °C
IEEE 404 at 31 Cycles (Insulated)
IEEE 404 In-Air Cyclic Aging Results
Analysis of Variance (ANOVA) for 90 °C Control Conductor Temperature

<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint / Connector</td>
<td>2</td>
<td>A, B</td>
</tr>
<tr>
<td>Brushed Conductor</td>
<td>2</td>
<td>No, Yes</td>
</tr>
<tr>
<td>Filled Strand Conductor</td>
<td>3</td>
<td>Non-filled, Fill-1, Fill-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>P</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint / Connector</td>
<td>0.110</td>
<td>89%</td>
</tr>
<tr>
<td>Brushed Conductor</td>
<td>0.834</td>
<td>16.6%</td>
</tr>
<tr>
<td>Filled Strand Conductor</td>
<td>0.061</td>
<td>93.9%</td>
</tr>
</tbody>
</table>
IEEE 404 In-Air Cyclic Aging Results

Main Effects Plot for Relative Connector Temp of Joint
Temperature Means at 90 °C Conductor Temp

1. Filled Strand Conductor
2. Joint / Connector
3. Brushed Conductor
## Main Effects for Connector Temperature

<table>
<thead>
<tr>
<th>Significance of Effect</th>
<th>ANSI C119.4 CCS Bare Conductor and Connectors</th>
<th>IEEE 404 In-Air Cyclic Aging of Medium Voltage Insulated Cable and Joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Most)</td>
<td>Connector</td>
<td>Filled Stand Conductor</td>
</tr>
<tr>
<td>2</td>
<td>Brushed Conductor</td>
<td>Joint / Connector</td>
</tr>
<tr>
<td>3 (Least)</td>
<td>Filled Strand Conductor</td>
<td>Brushed Conductor</td>
</tr>
</tbody>
</table>
Temperature Results

- ANSI C119.4 CCST: 1 out of 30 exceeded conductor temperature (3.3%)*
- IEEE 404 at 90 °C: 7 out of 18 exceeded conductor temperature (38.9%)
- IEEE 404 at 105 °C: 10 out of 18 exceeded conductor temperature (55.6%)

NOTE: * Two failures based on resistance criteria.
What did we learn?

• Filled Strand *always* affects connector temperatures to some extent, but the impact is different depending on the circumstances.

• The impact of filled strand is
  — Third in significance for the ANSI C119.4 CCS test (bare connectors), but
  — Most significant for IEEE 404 Cyclic Aging style tests (insulated connectors).

• Filled Strand appears to hurt performance with bare connectors, but may sometimes help performance with insulated connectors.
What did we learn?

- Connectors run hotter in insulated tests than in bare tests for the combinations tested.

- Other factors affect connector performance, such as:
  - The choice of connector used
  - Wire brushing the conductor before installing connectors

- Tests on bare connectors and conductor may not necessarily be sufficient to qualify connectors for use in medium voltage (insulated) systems.
What do we not know?

• We do not know about other:
  — Connectors or joints
  — Filled Strand compounds
  — Long Term vs. Short Term Performance

• We have not looked at the effect of:
  — Different connectors with the same joint
  — Incorrect installation of connectors
Additional Food for Thought

• Tests in existing Standards may not be sufficient to make an informed choice of the best connector for a given application (existing requirements are pass / fail only)
ANSI C119 Pass / Fail vs. Margin

Connector Temp Relative to Control Conductor Temp

Connector

Relative Connector Temp (°C)

Fail
Pass

Increasing Margin

Connector-A
Connector-B
Questions ?