IEEE Std 592™ Test Program using Current Cable Accessories and Installation Practices

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Joint Jacket Restoration – Phase I

• During revision of IEEE Std 592-2007, concern arose over the impact of jacket restoration practices on the ability of the semiconductive exterior of joint housings to initiate faults.

• 25 kV rated cable joints, with and without jacket restoration, were fault-tested according to the Standard to determine if the covering adversely affected the device’s ability to meet the minimum requirement for initiating faults.
Fault Tests – Phase I
Conducted at Power Laboratory A

Four Samples Each of Four Sample Types
• Bare Joint
• Hand Taped Re-jacketed Joint
• Cold Shrink Re-jacketed Joint
• Heat Shrink Re-jacketed Joint

Samples assembled using premolded joints, 25 kV MV cable with 1/0 AWG conductor and a PE jacket, and various jacket restoration materials

IEEE 592 Section 4.3, *Fault Current Initiation Test*
10 kA for 10 cycles, 2 operations
Typical Jacket Restoration Samples – Phase I

Hand Taped

Heat Shrink

Cold Shrink

None
Fault Test – Phase I

Typical Non-Jacketed Sample – After Fault 1

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Fault Test – Phase I

Typical Hand Taped Sample – After Fault 2

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Results – Phase I

- All test samples successfully initiated two consecutive fault current arcs as required by the Standard.

- The application of jacket restoration may have improved performance.
Fault Rod Selection

• Limited information provided in Standard:
  – “erosion resistant metal, such as copper-tungsten, 3/8-inch in diameter, and threaded at one end to engage the accessory connector through a drilled hole not to exceed 3/8-inch in diameter”
  – copper-tungsten alloys are available that vary from 55 % tungsten / 45 % copper to 80 % tungsten / 20 % copper in various ratios

• An alloy consisting of 56% tungsten and 44 % copper was chosen for this test program

• Same alloy used for Phase II
Connector Selection

No information provided in Standard

- **9/16 die size (top)**
  - 11/16 inch O.D.
  - 3/8 inch I.D. – same as outside diameter of rod
  - limited engagement of rod threads

- **840 die size (bottom) used in samples tested**

- Same connector used for Phase II
Additional Construction Issues

• Fault rod location on joint
  – Illustration in standard shows fault rod installed in center of the joint on the side opposite the attachment eyes for the shield drain wires
  – For the premolded joints initially supplied, that location put the fault rods through the injection molding port

• Joint body stretched when installed opening up the diameter of the hole drilled for the fault rod leaving gaps around the rod
• Test samples remade using an available different premolded joint housing design to assure tight fit on the fault rod and relocating the fault rod to not pass through the injection port.
Areas of Investigation – Phase II

• **Semiconductive Shield Resistance Measurements:** IEEE 592 contains a test procedure and minimum requirements for the semiconductive shield resistance of cable accessories. How do the samples we are testing measure up? Does the test seem adequate?

• **4 kV systems:** IEEE 592 fault initiation tests on 15 kV\textsubscript{rms} φ−φ rated system components are tested according to their intended use voltage. **However,** these systems are also often operated in service at \( \approx 4 \text{ kV}_{\text{rms}} \phi−\phi \). Does fault initiation still occur on these lower voltage systems?

• **Elbows:** The installation of a Faulted Circuit Indicator (FCI) increases the gap between an elbow and the cable metallic shield. Does this increased gap affect the initiation of a fault when an elbow failure occurs?
Resistance Measurements on Semiconductive Shields

All measurements made according to requirements in the IEEE 592 Standard using four-wire resistance measurements with silver paint and/or copper braid electrodes.
# Resistance Measurements on Semiconductive Shields

## Summary

<table>
<thead>
<tr>
<th>Samples</th>
<th>Average Resistance (Ω)</th>
<th>Before Aging</th>
<th>After 21 Days Aging @ 121 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>@ 20 °C</td>
<td>@ 90 °C</td>
</tr>
<tr>
<td>Joints</td>
<td></td>
<td>378</td>
<td>169</td>
</tr>
<tr>
<td>Elbows</td>
<td></td>
<td>186</td>
<td>162</td>
</tr>
<tr>
<td>Cable IS</td>
<td></td>
<td>378</td>
<td>1257</td>
</tr>
</tbody>
</table>

All measurements made according to requirements in the IEEE 592 Standard using silver paint and / or copper braid electrodes.

- Both joints and elbows met the requirement in the Standard that the resistance be \( \leq 5000 \, \Omega \).
- Cable Insulation Shield (IS) measurements reported for information only.
Fault Tests Phase II at High Power Lab B

Four Sample Types

1. Bare Joint
2. Re-jacketed Joint
3. Standard Elbow
4. FCI Elbow (3-inch jacket and neutral cutback below elbow cable entrance for FCI installation)
Cable Joint Configurations Tested

Exposed Semi-conductive Shield

Jacket Material Installed Over Semi-conductive Shield

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Separable Insulated Connector Test Configurations

Standard Elbow Test Configuration

FCI Elbow Test Configuration
Fault Test Plan

• Use first sample of each sample type to determine voltage needed for repeated faults
  – Apply \(1.8 \text{kV}_{\text{rms}} \phi–G\) for first attempted fault
  – If necessary, increase applied voltage in 0.5 \(\text{kV}_{\text{rms}}\) steps until sample faults each time voltage is applied

• Use that test voltage for testing remaining two samples (target is three faults each of 10 \(\text{kA}_{\text{rms}}\) for 10 cycles)
Bare Joint Fault Test Setup

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Did Not Try to Initiate Third Fault

Bare Joint Sample (JB2) After Fault 2
Sample JB2 Dissection

Removal of joint body reveals no damage inside joint (neutral bent back in place)
## Joint Fault Test Summary

### BARE JOINTS

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fault</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>JBD (Dummy)</td>
<td>1</td>
<td>Took 4.3 kV&lt;sub&gt;rms&lt;/sub&gt; $\phi$-G to get second fault – Seven shots on sample by 2&lt;sup&gt;nd&lt;/sup&gt; fault – last shot with much higher current than 10 kA – Did not try 3&lt;sup&gt;rd&lt;/sup&gt; shot</td>
</tr>
</tbody>
</table>
| JB2        | 1     | Cable conductor connection destroyed and neutral partially destroyed on sample source end during 2<sup>nd</sup> fault  
**All faults at 4.3 kV<sub>rms</sub> $\phi$-G** – Could not try 3<sup>rd</sup> shot |
| JB3        | 1     | Cable conductor connection and neutral connection on source end destroyed during 2<sup>nd</sup> fault  
**All faults at 4.3 kV<sub>rms</sub> $\phi$-G** – Could not try 3<sup>rd</sup> shot |
| JB6        | 1     | Cable conductor connection destroyed and neutral partially destroyed on sample source end during 1<sup>st</sup> fault  
**All faults at 4.3 kV<sub>rms</sub> $\phi$-G** – Could not try 2<sup>nd</sup> shot |
Re-jacketed Joint Fault Test Setup

Re-jacketed joint sample (JC7) ready for test
Re-jacketed Joint Fault Test

HS Video for JC7, Fault 1
4.3 kV\textsubscript{rms} $\phi$-G

Tried but Did Not Initiate Second Fault
Sample JC7 Dissection

Removal of joint housing reveals severe damage inside joint / no fault rod

Source Connection
## Joint Fault Test Summary

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fault</th>
<th>Comments</th>
</tr>
</thead>
</table>
| JC1    | 1 2   | Cable semicon damage present at source end of joint  
         |       | All faults at 4.3 kV\(_{\text{rms}}\) \(\Phi\)-G – No fault initiated on 3\(^{rd}\) shot |
| JC6    | 1 2 3 | All faults at 4.3 kV\(_{\text{rms}}\) \(\Phi\)-G |
| JC7    | 1     | Fault rod, cable, conductor, and connector severely damaged inside joint during 1\(^{st}\) shot  
         |       | All faults at 4.3 kV\(_{\text{rms}}\) \(\Phi\)-G – No fault initiated on 2\(^{nd}\) shot |
Summary – All Joint Tests

• 4.3 kV $\Phi$-G required for multiple fault initiation
• Some faults did not initiate until many cycles into the three seconds of voltage application.
• Some faults self-extinguished before the required 10 cycles were complete. Some restrikes did occur resulting in a second fault within the allotted three-second voltage application.
• Third fault on bare samples occurred on zero of four tested. Arc destroyed source sample connections on three of four samples.
• Third fault on jacket restoration samples occurred on one of three samples tested.
Elbow Fault Test Setup

Typical Elbow Sample Ready for Test

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Standard Elbow Fault Test (1 of 2)

HD Video for END (Dummy Sample), Fault 1
1.8 kV_{rms} \phi-G
14-225 Videos\14-225 Sample END TRC025.mp4

Sample Damaged
Too Much to Continue Using It for Testing

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Standard Elbow Fault Test (2 of 2)

HS Video for EN6, Fault 3

3.4 kV_{rms} \phi-G

[14-225 Videos\16906_A99_030.mp4]
## Elbow Fault Test Summary

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fault</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>END</strong></td>
<td>1</td>
<td>No fault at 1.8 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G / sample caught fire and had</td>
</tr>
<tr>
<td>(Dummy)</td>
<td></td>
<td>to be put out with extinguisher – No further testing possible</td>
</tr>
<tr>
<td><strong>EN6</strong></td>
<td>1 2  3</td>
<td>Required 3.4 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G to get 1&lt;sup&gt;st&lt;/sup&gt; fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Remaining faults also at 3.4 kV φ-G</td>
</tr>
<tr>
<td><strong>EN7</strong></td>
<td>1 2  3</td>
<td>All faults at 3.4 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G</td>
</tr>
<tr>
<td><strong>EN1</strong></td>
<td>1 2  3</td>
<td>All faults at 3.4 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G</td>
</tr>
</tbody>
</table>

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FCI Elbow Fault Test Setup

FCI Elbow Sample Ready for Test (Sample EF3)

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FCI Elbow Fault Test

HD Video for EF3, Fault 1 [With Restrike]

3.8 kV$_{\text{rms}}$ $\phi$-$G$

14-225 Videos\14-225 Sample EF3 TRC043.mp4
FCI Elbow Fault Test

FCI Elbow Sample (EF3) Fault 1 Waveforms
Sample EF3 Examination / Dissection

Severe cable semicon damage below elbow. Did not try additional faults

Neutral connection below elbow and exposed cable neutrals destroyed
Elbow Fault Test Summary

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fault</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF6</td>
<td>1</td>
<td>First fault occurred at 3.3 kV φ-G</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Took 3.8 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G to get 2&lt;sup&gt;nd&lt;/sup&gt; fault</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Remaining fault at 3.8 kV φ-G</td>
</tr>
<tr>
<td>EF2</td>
<td>1</td>
<td>All faults at 3.8 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Elbow blown off of cable on 2&lt;sup&gt;nd&lt;/sup&gt; fault</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Could not try 3&lt;sup&gt;rd&lt;/sup&gt; shot</td>
</tr>
<tr>
<td>EF3</td>
<td>1</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Fault at 3.8 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground below elbow destroyed by 1&lt;sup&gt;st&lt;/sup&gt; fault and cable semicon severely damaged – Did not try 2&lt;sup&gt;nd&lt;/sup&gt; shot</td>
</tr>
<tr>
<td>EF8</td>
<td>1</td>
<td>All faults at 3.8 kV&lt;sub&gt;rms&lt;/sub&gt; φ-G</td>
</tr>
</tbody>
</table>
Summary – All Elbow Tests

• Fault rod NOT in location shown in the Standard which likely *lowered* the required fault initiation voltage.
• Too low voltage (1.8 kV_{rms} φ-G) caused the one sample tested at that voltage to catch on fire.
• 3.4 kV_{rms} φ-G required for multiple faults on “standard” samples
• 3.8 kV_{rms} φ-G required for multiple faults on “FCI” samples
• Some faults self-extinguished before the required 10 cycles were complete.
• Three faults achieved on “standard” samples.
• Three faults on “FCI” samples achieved on two of four samples tested. Remaining samples were damaged during testing so that tests could not be continued.
Overall Summary / Conclusions (1 of 2)

4 kV System Operation:
• Joints tested required $4.3 \text{kV}_{\text{rms}} \phi-G$ minimum to initiate multiple faults.
• Elbows tested required $3.4 \text{kV}_{\text{rms}} \phi-G$ minimum to initiate multiple faults. (Note that this may be a lower required fault initiation voltage due to the change in the fault rod location over that of the location identified in the Standard.)
• IEEE Std 592 specifies testing these accessories at $7.0 \text{kV}_{\text{rms}} \phi-G$.

The semiconductive shields of the accessories tested would not initiate faults on a $4.2 \text{kV}_{\text{rms}} \phi-\phi$ system.
Cable Jacket and Metallic Shield Cutback for FCI Use:

- *FCI cutbacks below elbows increase the voltage required to initiate a fault over that of a standard elbow installation.*
- Considerable damage is done to the cable in this area when a fault occurs.
Additional Issues

• **Fault Rod** – Do we need to provide more information regarding the selection of fault rods? Where should the fault rod be located in elbows?

• **Connector Selection** – Do we need to provide information on the selection of connectors to use in joint test samples?

• **Joint Body Stretching/Fault Rod Contact with Accessory Body** – What, if anything do we need to include in the standard about this topic?

• **Sample Construction Neutrals** – Should the neutral be overlapped onto the accessory under test as shown in the diagrams in IEEE 592 or should the accessory be installed per manufacturer instructions?
**Additional Issues**

- **X/R Ratio** – What should the X/R ratio of the test circuit be since it is currently not defined? (These tests used an X/R of 17)
  
  – IEEE 386-2006 uses an X/R of 6 for 200 A rated connectors and an X/R of 20 for 600 A rated connectors for the short-time current tests.

  – IEEE 404-2012 does not specify an X/R ratio for the short-time current tests.

- **Acceptable Fault** – What defines an acceptable 10-cycle fault as required by IEEE 592? (Some faults will self-extinguish after a few cycles and then *may* reform.)
Questions?