Oconee Nuclear Station

Technical Discussion on Cable Testing and Proposed Modifications

December 15, 2015

DUKE ENERGY®

Duke Energy Participants

- Ed Burchfield, Engineering General Manager
- Todd Grant, Assistant Operations Manager
- Vance Bowman, Engineering Director
- Bert Spear, Lead Electrical Engineer
- Ryan Greco, Electrical Engineer
- Chris Wasik, Regulatory Affairs Manager
- Chris Nolan, Director, Fleet Regulatory Affairs
- Art Zaremba, Licensing Manager, Fleet Regulatory Affairs

Agenda

▪ Opening Remarks	Ed Burchfield
▪ Modification Schedule	Todd Grant
▪ Cable Fault Testing	Bert Spear
▪ Modification Scope	Todd Grant
▪ Scope of 10 CFR 50.55a Submittal	Chris Wasik
▪ Closing Remarks	Ed Burchfield

Ed Burchfield

Engineering General Manager

Background

- November 18, 2015 public meeting – Oconee discussed a pending 10 CFR 50.55a submittal
- Oconee is taking action to address the NRC's concerns
- Submittal seeks to amend the Oconee licensing basis with respect to the cables of concern
  - Demonstrates an acceptable level of quality and safety for the proposed alternatives
  - No changes in Manholes 1 through 5
  - Enclosures being added in Keowee Equipment Gallery, Manhole 6 and PSW Cable Spreading Area
- Test results will be used to:
  - Support acceptability of proposed alternatives in the submittal
  - Validate previous engineering evaluations regarding postulated fault propagation
- Testing parameters and set-up established to bound plant conditions
- Proposed modifications improve margin for the cables in question

Todd Grant

Assistant Operations Manager

Modification Locations

- Keowee Underground Power Path (Trench 3)
  - Removing all low voltage control cables from the UG trench
  - All KHU1 and all Tech Spec (TS) related KHU2 cables scheduled to be removed by 12/18/15
  - Remaining three non-TS related cables to be removed by 12/31/15
- Keowee Mechanical Equipment Gallery
  - 1st cable enclosure modification approved; implementation to begin first quarter of 2016
  - 2nd cable enclosure modification being designed
- PSW Ductbank Manhole 6 (MH-6) & PSW Cable Spreading Area
  - Cable enclosure modifications are being designed
- Cable Enclosure modifications to be completed Summer 2016
- Submittal to include request for temporary acceptance of the as-is condition until cable enclosure modifications are completed

Bert Spear

Lead Electrical Engineer

General Overview of Cable Testing

- The purpose of the cable testing was to confirm Duke's previous evaluations that an assumed single failure on a circuit consisting of single conductor medium voltage cables would be confined to a line-to-neutral (L-N) fault and would not propagate to a three-phase (L-L) fault.
- Testing was performed November 2 - 6, 2015 at KEMA Labs in Chalfont, PA.
- Four cable types – two medium voltage power cables and two Instrumentation and Control cables:
  1. Okonite 250 kcmil single conductor 5 kV nominal insulation (173% insulation level),
  2. Okonite 750 kcmil single conductor 15 kV nominal insulation (173% insulation level),
  3. Rockbestos eight #9 AWG conductor 1kV XLPE insulation, polyester and copper tapes over cable core, galvanized steel interlocked armor jacket,
  4. Rockbestos sixteen (16) shielded pairs with drain wire, 300 V XLPE insulation aluminum and polyester tapes, galvanized steel interlocked armor jacket.

Note: Cable types 3 and 4 were installed adjacent to the power cables to collect additional data on the effects of cable faults.

General Overview of Cable Testing (cont'd)

- Four circuit configurations:
  - CT4 - 13.8 kV circuit from Keowee hydro to transformer CT4 (two conductors per phase)
  - KPF - 13.8 kV circuit from Keowee hydro to Protected Service Water (PSW) switchgear (one conductor per phase)
  - Fant - 13.8 kV circuit from offsite Fant substation to PSW switchgear (one conductor per phase)
  - CX - 4.16 kV circuit from switchgear 1TC to Keowee station service transformer CX (one conductor per phase)

General Overview of Cable Testing (cont'd)

- Three power source neutral grounding configurations:
  1. Keowee hydro generators are resistance grounded (small magnitude L-N fault current)
  2. Offsite Fant substation is solidly grounded (large magnitude L-N fault current)
  3. Plant switchgear 1TC is solidly grounded (large magnitude L-N fault current)
- Five tests for each circuit type
- For each circuit type, KEMA configured the power source to provide the specified voltage and symmetrical fault currents and durations for L-N and L-L faults
- The required minimum voltage and current were increased 3% to account for instrument uncertainty
- Recorded parameters included duration, voltage (power and control cables), phase current, shield currents on faulted conductor, calorimeters and high speed video
- Testing was done with continuous Duke oversight and attended by NRC and Okonite staff

Description of Okonite Medium Voltage Single Conductor Cables

Cable nominal voltage
L-L = 4.16 kV; L-N = 2.4 kV

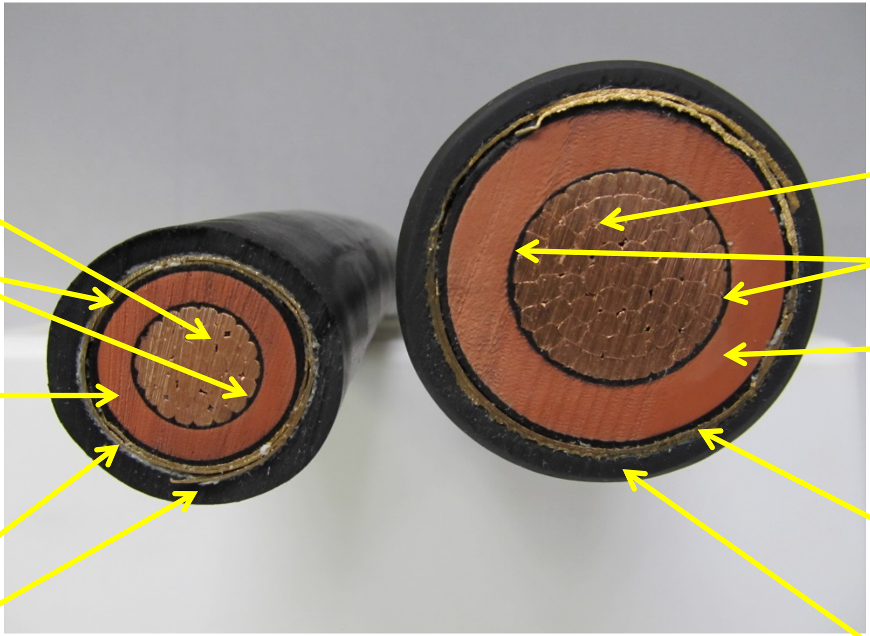
250 kcmil copper conductor

Semiconducting strand and insulation shields

140 mils EPR insulation
5 kV nominal at 173% insulation level (8 kV)

Two 10 mil layers bronze tape shield

80 mils CSPE jacket



Cable nominal voltage
L-L = 13.8 kV; L-N = 8 kV

750 kcmil copper conductor

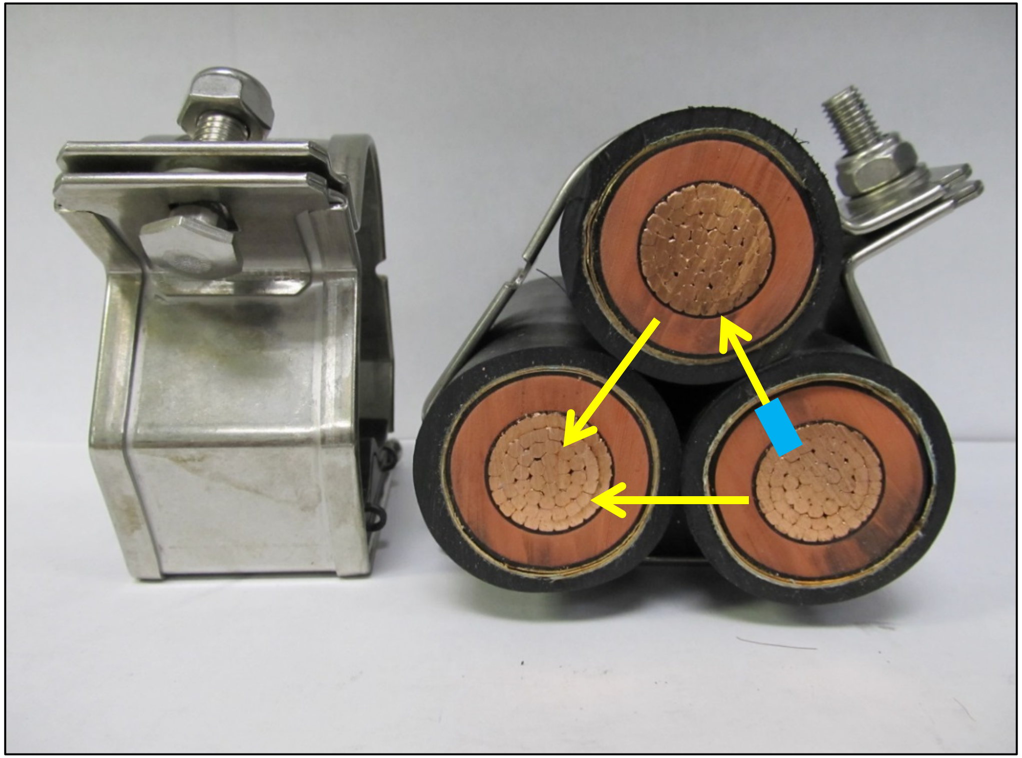
Semiconducting strand and insulation shields

260 mils EPR insulation
15 kV nominal at 173% insulation level (25 kV)

Two 10 mil layers bronze tape shield

110 mils CSPE or TS-CPE jacket

Cable Cleat With 750 kcmil Cables and Diagram of Postulated Fault Paths



L-N Fault Path L-L Fault Paths

Initial fault path created by cutting and folding back jacket, drilling hole through bronze tapes and insulation. Copper wire was inserted to create bolted L-N fault and jacket taped back into place. Cable cleats and fault orientation ensure worst-case for direct impingement of fault on adjacent cables.

Sequence of Events for Three-Phase L-L Fault:

1. Purposely induced L-N fault penetrates cable jackets.
2. Fault penetrates both layers of grounded bronze tapes on adjacent cables.
3. Fault penetrates insulation to conductor on adjacent cables.
4. Three-phase L-L fault occurs prior to protective relaying and breaker detecting and clearing the fault (0.0717 – 1.18 seconds)

Fault initiation method developed with assistance from Okonite.

Cable jacket flap cut back to allow hole to be drilled through bronze tape and insulation to conductor.

Copper wire inserted through hole to create L-N fault path from conductor to bronze tape shield. #18 AWG wire used for low current L-N faults; #12 AWG wire used for high current L-N faults.

Jacket folded back and taped with Scotch 88 vinyl tape and Scotch 69 glass cloth tape.

Circuit Electrical Parameters

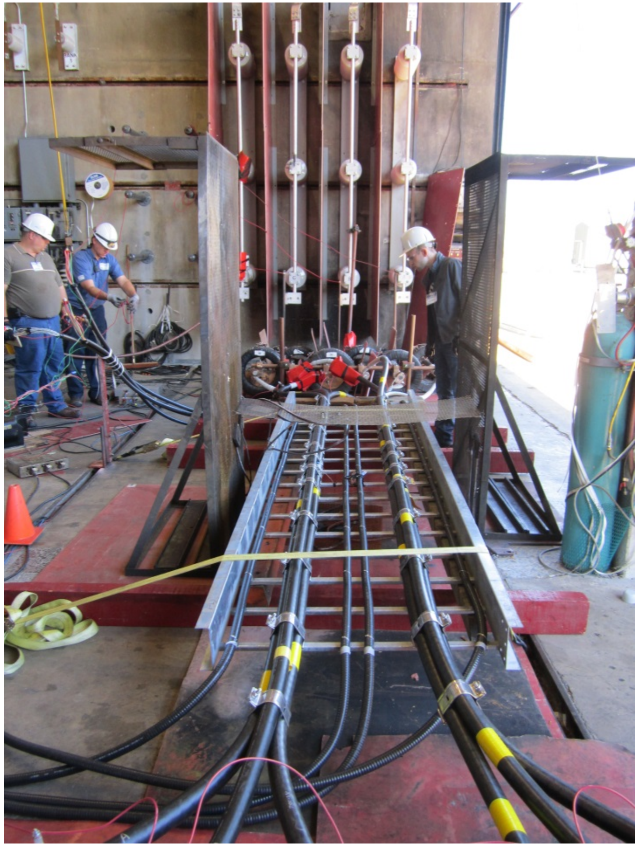
Test Type	Minimum Phase Voltage	Fault Current Ranges	Minimum Fault Duration
CT4 (Resistance Grounded)	14.9 kV (15.0)	* L-N: 18.1 A – 19.9 A (19.3) L-L: 16.8 kA – 18.5 kA (N/A)	L-N: 1.18 seconds (2.13) L-L: 0.183 seconds (N/A)
KPF (Resistance Grounded)	14.9 kV (15.9)	* L-N: 18.1 A – 19.9 A (24.2) L-L: 18.0 kA – 19.8 kA (N/A)	L-N: 1.18 seconds (2.13) L-L: 0.183 seconds (N/A)
Fant (Solidly Grounded)	14.9 kV (15.0)	** L-N: 4.57 kA – 4.71 kA (4.83) L-L: 4.87 kA – 5.01 kA (N/A)	L-N: 0.0717 seconds (0.0786) L-L: 0.0717 seconds (N/A)
CX (Solidly Grounded)	4.54 kV (4.60)	** L-N: 6.50 kA – 6.69 kA (6.78) L-L: 9.63 kA – 9.92 kA (N/A)	L-N: 0.183 seconds (187) L-L: 0.117 seconds (N/A)

Maximum tested values in parentheses

* # 18 AWG wire used to initiate fault for low L-N fault current

** # 12 AWG wire used to initiate fault for large L-N fault current

CT4 Circuit Configuration



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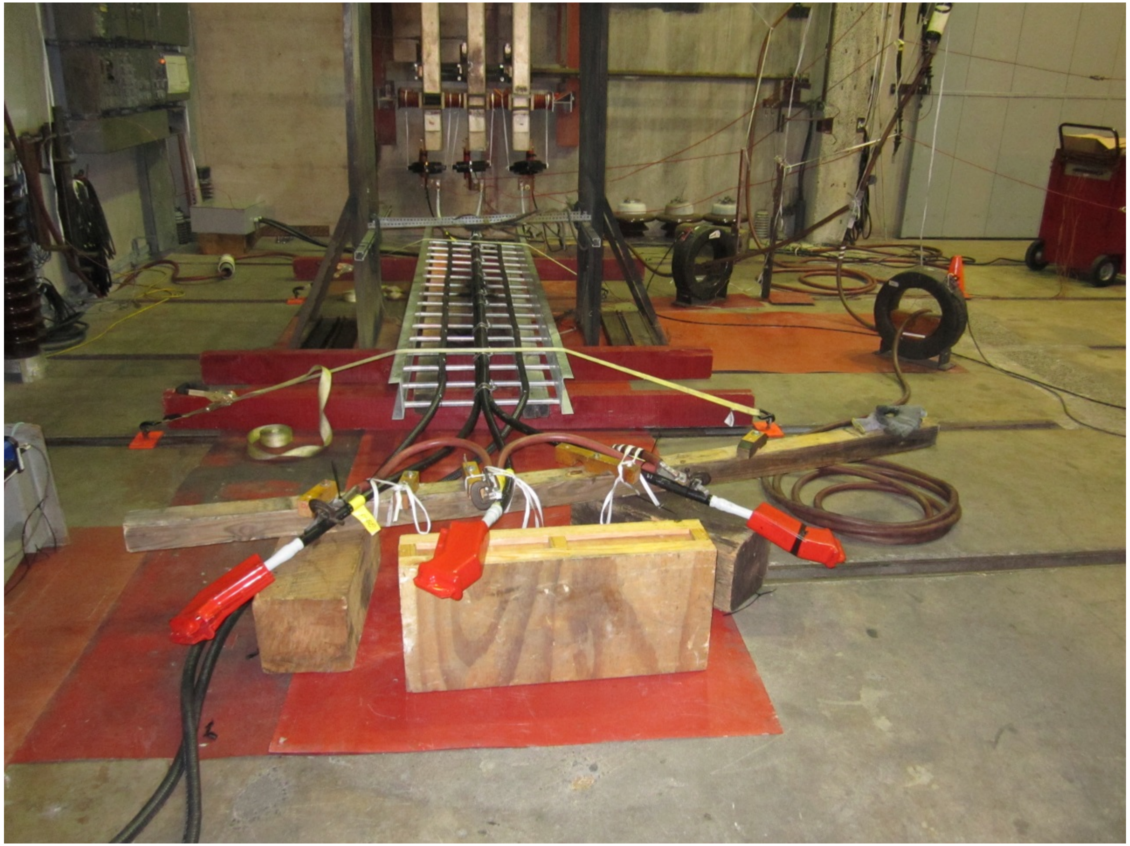
KPF and Fant Circuit Configurations

CX Circuit Configuration



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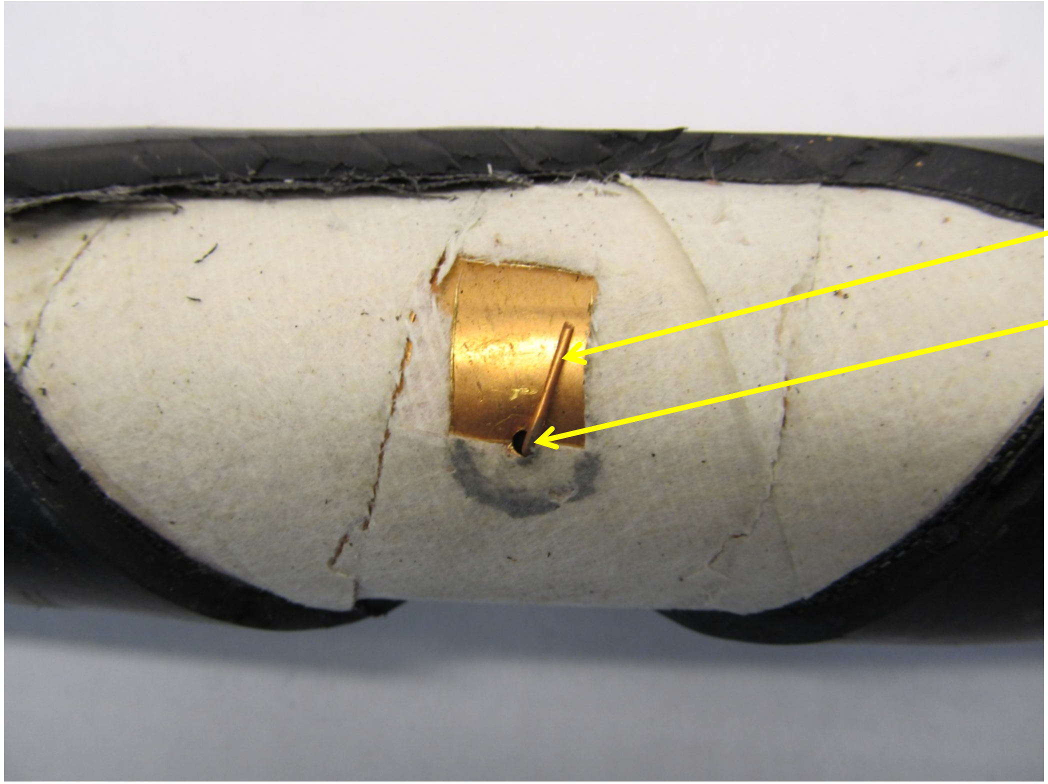
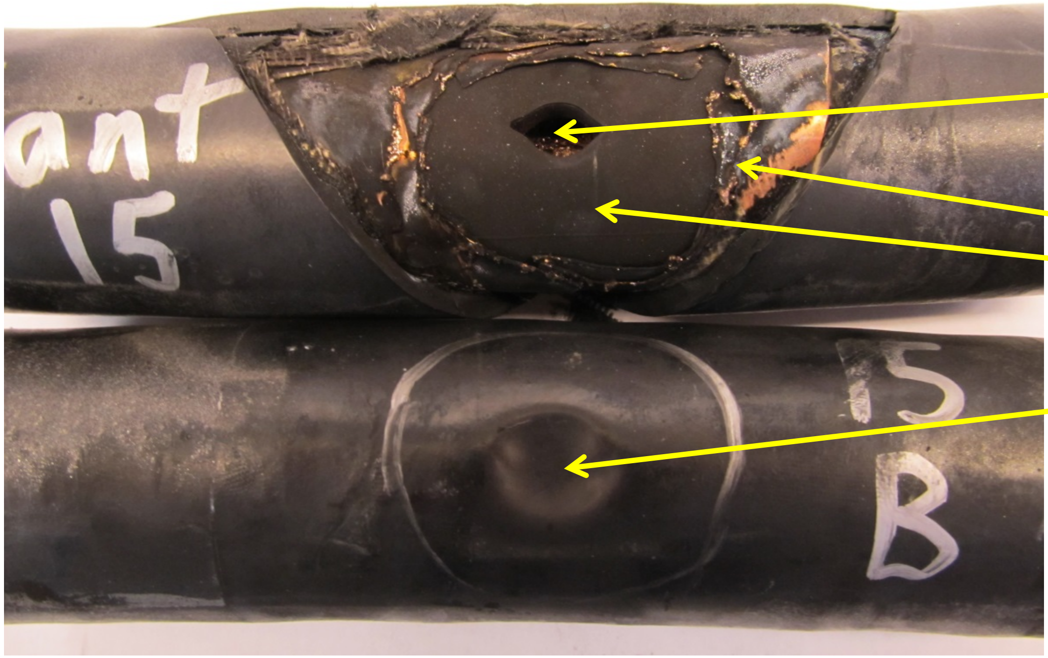
Typical Post-Fault Cable From CT4 and KPF Tests



Faulted Cable From Test 5 (CT4)

- Keowee power source parameters with neutral resistance grounding (limited L-N fault current)
- #18 AWG wire provided bolted fault path from conductor to bronze tape shield
- Hole drilled through both layers of bronze tape and insulation to conductor
- No evidence of overheating
- Conclusion: Power sources with neutral grounding resistors limit equipment damage.

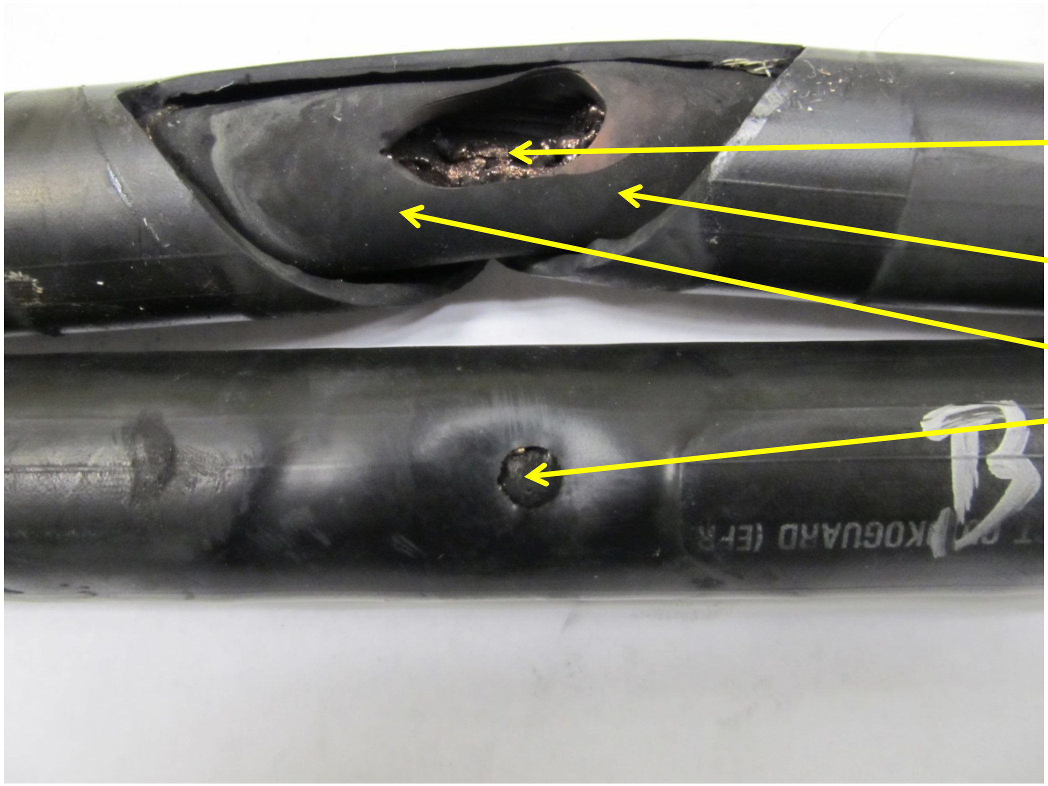
Typical Post Fault Cable From Fant Tests



Faulted Cable From Test 15 (Fant)

- Fant power source with solid grounding (large L-N fault current)
- Fault enlarged drill hole and vaporized #12 AWG wire. Partially melted 750 kcmil conductor is visible beneath hole.
- Bronze tape has been melted or vaporized
- Semiconducting layer
- Adjacent cable directly over fault has been dented. The jacket was not breached.
- L-N faults on solidly grounded power systems result in greater damage compared to resistance grounded systems.

Post Fault Cable From CX Tests



Faulted Cable From Test 18 (CX)

- Switchgear 1TC power source with solid grounding (large L-N fault current)
- Fault significantly enlarged drill hole and vaporized #12 AWG wire. Partially melted 250 kcmil conductor visible beneath hole.
- Bronze tape has been melted or vaporized around entire cable circumference.
- Semiconducting layer
- Adjacent cable directly over fault has 0.25 inch hole through jacket and bronze tapes.
- Most significant damage to adjacent cable of all 21 tests, but did not result in a L-L fault.
- Adjacent cable passed a post-test VLF/Tan Delta withstand of 7.0 kV for 30 minutes.
- CX test parameters had largest L-N fault current for longest duration compared to the other three tests configurations.

Review of Test Results

- Total of 21 tests conducted
- Test configurations CT4 and KPF using electrical parameters of the Keowee-fed resistance grounded power source resulted in no visible damage or overheating to the fault area beneath the faulted cable jacket. The faulted cable jacket was not breached and there was no damage to adjacent cables.
- Test configurations Fant and CX using electrical parameters for solidly-grounded power sources resulted in significant damage to faulted cable. Affects on faulted and adjacent cables included:
  - Faulted conductor was partially melted or fully melted,
  - Faulted cable bronze tape was completely melted or vaporized around the fault area to the semicon layer,
  - Taped jacket on faulted cable was partially or fully opened with a visible and audible arc flash,
  - Some cable jackets over the fault had thinning, splitting, or punctures,
  - Soot deposits on faulted and adjacent cables,
  - Some adjacent cable jackets were indented but the jacket was not breached, except for one test,
  - For Test 18 (CX), one adjacent cable had a 0.25 inch circular hole through the jacket and both layers of bronze tape. Despite the damage, this cable successfully passed a 7.0 kV VLF withstand test for 30 minutes, demonstrating significant margin in Duke cable design.

Review of Test Results

- For all test configurations and power sources, the purposely induced single L-N fault did not result in propagation to a three-phase fault
- Previous evaluations by Duke that a single phase-ground fault does not propagate to a three-phase fault has been confirmed based on 21 successful tests

Questions

1. In accordance with 10 CFR 50.54(jj) (2015), what quality standards were used to design the testing plan and to analyze the testing data?

2. Did the design of these tests meet the requirements of IEEE 279-1971? How?

3. How were the worst-case tested ground faults determined? What quality standards were used for this determination?

Questions (cont'd)

4. Why were three-phase faults not considered for testing?
   [previously covered]
5. Why did the testing not address cascading failures (i.e. circuit breaker failures that may result from the short circuit conditions)?
6. What analysis was done to ensure that each configuration bounded the worst case asymmetrical and symmetrical fault conditions for [each of the four configurations]?
7. What analysis was done to ensure that each configuration bounded the worst case arc flash duration for [each of the four configurations]?

Questions (cont'd)

8. The "as installed" cable clamping configuration differs from that at the test laboratory. The test laboratory employed metal cable cleats designed for the forces encountered during electrical faults in accordance with IEC 61914 "Cable Cleats for Electrical Installations." The cleats were spaced at ~1 ft. intervals and secured to a cable tray in an open environment. The installed condition used metal zip ties to strap the cables to Unistrut pegs approximately every 4 ft. in an enclosed cable raceway. How does this difference address the impact of magnetic forces resulting from a worst-case fault condition as discussed in industry standards?

9. How does the use of new cables compare to the "as installed" cables, which can be in a more degraded condition due to variations in ambient conditions (temperature, moisture etc.), electrical transients, and variations in current flow?
   - Is the assumption for a limiting condition single phase to ground fault appropriate for cables? What quality standards addressed this?

Questions (cont'd)

10. How were the configuration differences ("as-tested" vs "as installed") analyzed? What quality standards were used for this analysis?

    [previously covered]

11. What effects did the test configuration have on the test results? (i.e. the power cables were open-circuited and no operating loads were used for AC or DC)

12. How would the inductive and capacitive coupling effects be influenced when current is present on all phases of the power cables and the DC cables are energized? What quality standards were used to address this aspect?
    a. Were the concerns presented in Annex B of IEEE 603 investigated in relation to this question?
    b. Has the impact of increased cable length been investigated (i.e., as installed (4000 ft.) vs. as-tested (12 ft.))?

<u>Questions</u> (cont'd)

13. In some of the cable tests observed, the bronze tape shield melted partially. Has Duke evaluated the impact of such melting, if a worst-case fault is postulated?

14. Did Duke calculate the maximum magnetic force that would be exerted in the raceway system to CT4, which has approximately 4,000 feet of cable? The NRC staff's review of industry guidance indicates that cables in the concrete trench could be exposed to a substantial amount of force. It did not appear that these effects were simulated in the cable testing. If these magnetic forces were not modeled in the tests, how did the testing performed demonstrate that the existing cable configuration meets the ONS licensing basis and applicable ANSI standards?

Follow-up Questions

These three follow-up questions refer to Oconee feedback on the "Background" section of the NRC Questions.

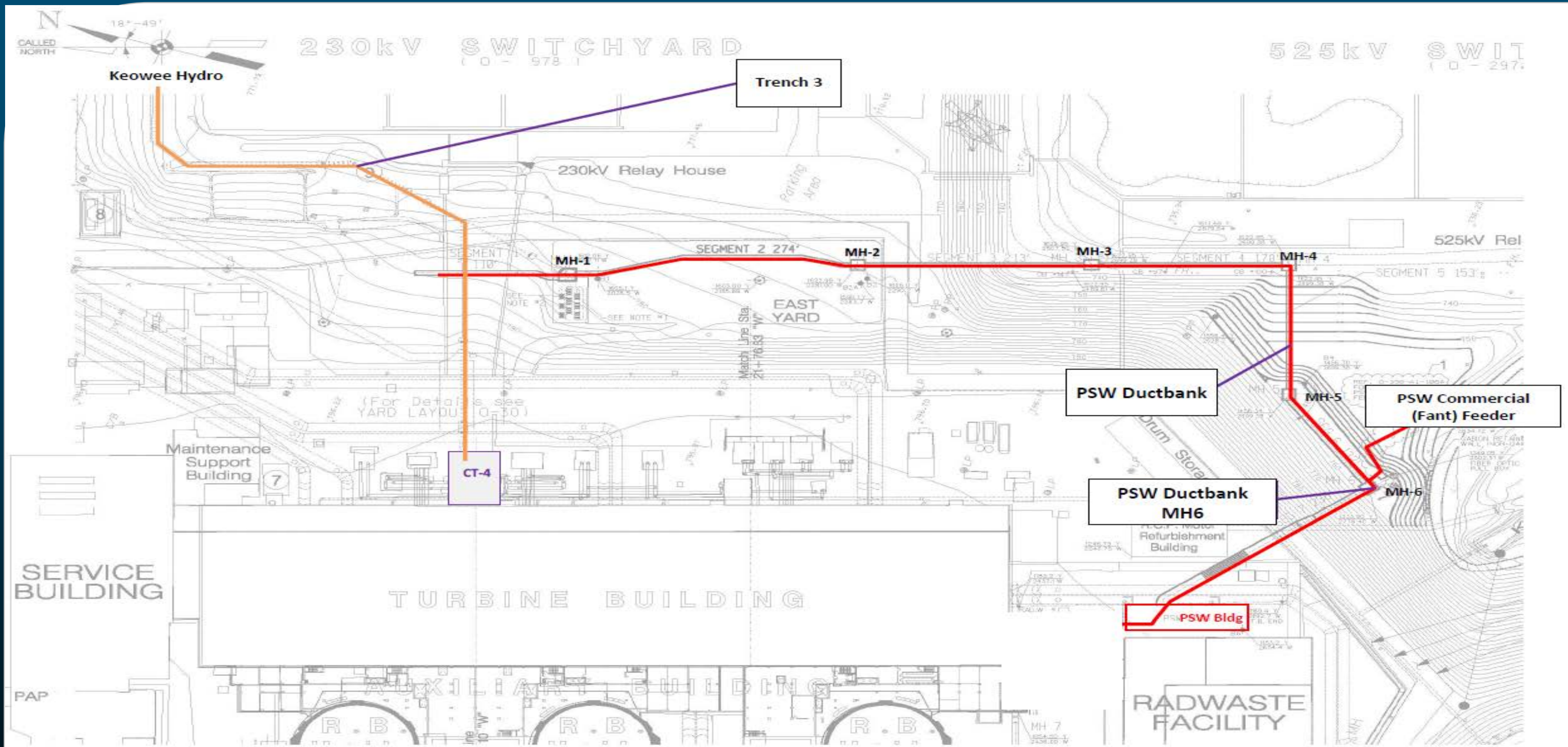
1. Why was 12 gauge wire used in tests 3 & 4?
   [previously covered]

2. Demonstrate why the current was not split [between the three cables]?

3. What quality standards were used to determine this?

Todd Grant

Assistant Operations Manager



Trench 3 and PSW Ductbank Layout

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Keowee Underground Power Path (Trench 3)

- Removing all low voltage control cables’ circuits from Trench 3
- Functions and circuits returned to original direct buried trench cables
- Medium voltage cables remain in Trench 3

Underground Trenches

Trench 1 (2)
Original Sand Filled

Trench 3
Gray & Yellow Control Cable
Functions Eliminated

Keeowee Mech. Equipment Gallery, PSW Ductbank MH-6, PSW Cable Spreading Area

- Proposed modifications designed to meet the separation requirements for a Limited Hazard Area as noted by IEEE 384-1992, Paragraph 6.1.4
- IEEE 384-1992 is endorsed by NRC RG 1.75, Criteria for Independence of Electrical Systems

  "Conformance with the requirements of IEEE Std. 384-1992, "Standard Criteria for Independence of Class 1E Equipment and Circuits," provides a method that the NRC staff considers acceptable for satisfying the agency's regulatory requirements concerning physical independence of the circuits and electrical equipment that comprise or are associated with safety systems…"

- Limited Hazard Area – hazards limited to failures or faults internal to the electrical equipment or cables.
- Enclosed to enclosed configuration – identifiable housing such as enclosed raceway used for cables.

Enclosed Raceway

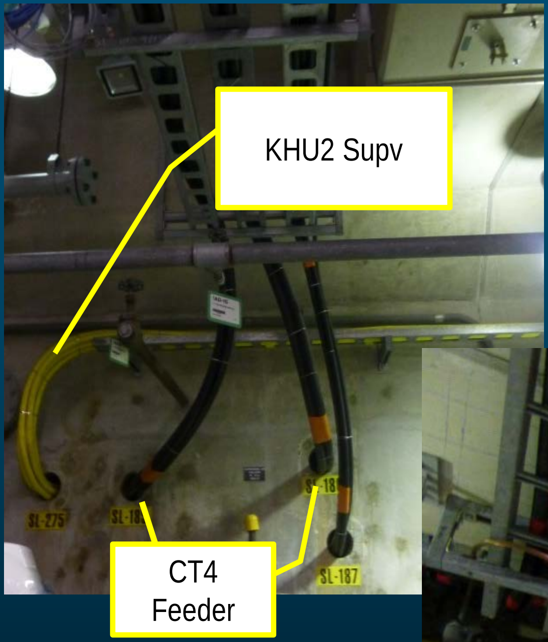
New covers will not be louvered.

New cable enclosures will have solid top and bottom covers.

Keowee Mechanical Equipment Gallery

- KUG control cable functions will be removed / eliminated.
- Keowee U/G power & CX Power cables will be enclosed where it is within 3’ horizontally and 5’ vertically of cables of a mutually redundant function or PSW controls.
- Control cables within 3’ horizontally and 5’ vertically of the CX & Keowee U/G power or PSW cable bus cables will be enclosed unless control cable function is not mutually redundant.
- Existing vented covers (top and bottom) on the PSW cable bus will be replaced with solid covers. Replacement is not required where cable bus is of the same KHU as the adjacent control cables.

Keewee Mechanical Equipment Gallery



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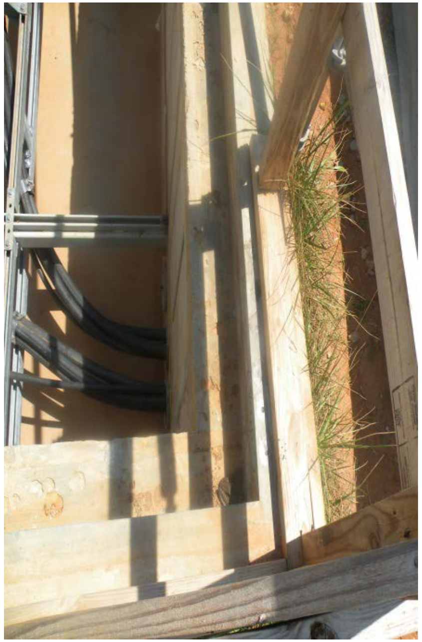
PSW Ductbank Manhole 6 (MH-6) & PSW Cable Spreading Area

- Enclosed to enclosed raceway for the gray control cables, yellow control cables and Fant Line cables



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Chris Wasik

Regulatory Affairs Manager

Submittal Scope Change

- Scope is reduced from that discussed on November 18th
  - No longer includes Keowee Underground Power Path (Trench 3)
    - Modifications to be completed in December 2015
    - Eliminates concerns for Trench 3 medium voltage and low voltage control cable interaction
- Scope to include as described today and November 18th:
  - PSW Ductbank Manholes 1-5
  - PSW Ductbank Manhole 6
  - PSW Cable Spreading Area
  - Keowee Mechanical Equipment Gallery

PRA Insights

- Submittal will include risk insights

Location	CDF
Trench 3	2E-10
PSW Ductbank Manholes 1 through 5	< 1E-13
PSW Ductbank Manhole 6, and PSW Cable Spreading Area	2E-11
Keowee Equipment Gallery	5E-12
Total	3E-10

Ed Burchfield

Engineering General Manager