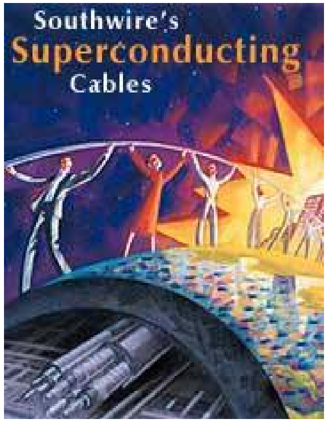
High Temperature Superconducting Cable



2005 Annual Peer Review

Southwire
WE DELIVER POWER

AEP

Ultera™
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PRAXAIR

nkt cables

American Superconductor™

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Superconductivity Program for Electric Systems
U.S. Department of Energy

August 2-4, 2005
Washington, DC

Presentation Outline

- Introduction (David Lindsay, Southwire)
  - Overall SPI Goals & Objectives
  - Design Approach
  - Review FY 2005 Milestones
- FY 2005 Results
  - 30-m Cable Operation and Testing (David Lindsay, Southwire)
  - AEP project
    - Overview
    - HTS Tape Status, Cryogenics Status
    - Mechanical verification tests of cable & cryostat for pulling
    - Worst-case fault current tests
  - Cable/Term. Research & Testing at ORNL (Jonathan Demko, ORNL)
    - Qualification tests for Triax cable + terminations
  - Cryogenic Dielectrics Research (Isidor Sauers, ORNL)
- FY 2005 Performance
- Planned FY 2006 & FY 2007 Milestones
- Program risk mitigation strategy
- Research Integration
- Summary

AEP Project Partners

Partner		***Area of Responsibility/Expertise***
Southwire/nktc/Ultera		**Cable design, manufacturing, termination design, installation, cryo system design, systems integration, O&M, project management**
AEP		**Installation site engineering, site civil & electrical construction, Commissioning, Monitoring, O&M**
ORNL		**Cable research, termination research, testing, cryo design**
Praxair		**Cryogenics system design, construction, operations & service**
AMSC		**HTS tape supplier**

Project Participants

- **Southwire/Ultera**
  - John Armstrong
  - Zack Butterworth
  - Randy Denmon
  - Terry Dyer
  - Gary Hyatt
  - Kim Knuckles
  - David Lindsay
  - Sammy Pollard
  - David Reece
  - Mark Roden
  - Jerry Tolbert
  - Nick Ware
  - Dag Willen
  - Chresten Traeholt
- **AEP**
  - Doug Fitchett
  - Albert Keri
  - Dale Krummen
  - John Schneider
  - Ben Mehraban
  - Harry Tumageanian
- **Oak Ridge National Laboratory**
  - Jonathan Demko
  - Robert Duckworth
  - Alvin Ellis
  - Paul Fisher
  - Mike Gouge
  - Randy James
  - Winston Lue
  - Marshall Pace
  - Isidor Sauers
  - Bill Schwenterly
  - Dennis Sparks
  - Marcus Young
  - Chris Rey
- **Praxair**
  - John Royal
  - Rick Fitzgerald
  - Nancy Lynch
  - Barry Minbiole
  - Jeff Kingsley
- **AMSC**
  - Larry Masur
  - Angelo Santamaria

SPI Project Goals & Objectives:

- SPI-1: 30-m Installation, Carrollton, GA
  - The cable system will continue to be operated and studied. Optimizations will be made to improve operating efficiencies and reliabilities.

- SPI-2: Bixby Substation, AEP, Columbus, OH
  - **To complete a 200m cable demonstration with AEP**
    - **Install 13.2 kV, 3.0 kA (69 MVA) HTS cable system in Bixby substation, about 2 times the power of the Carrollton, GA demonstration**
    - **Highest current cable project**
    - **Length would be on the order of 7 times the Carrollton, GA demonstration**
    - **Design and install a simplified and reliable cryogenic system based on prior experiences**
    - **Demonstrate pre-commercial feasibility of an underground installation.**

Basic SPI Project Approach

An integrated team from Ultera, ORNL, PX, AMSC and other industry partners will design, build and install a reliable cable system.

- Cables, terminations and other component sub-systems will be *proto-typed and fully tested* in the lab prior to implementation
  - Designs evaluated by use of computer modeling
  - Design verification and proto-type testing is facilitated through the use of the 5-m test-bed at ORNL

- Where needed, expertise will be brought to the team through the use of outside contractors/consultants

- Ultera & ORNL will work with electric utilities to identify market applications and guide technology development to achieve a commercially viable product which meets industry needs.

Southwire/ORNL FY 2005 Plans
Oct. 1, 2004 to Sept. 30, 2005

- **SPI-1: 30-m Installation, Carrollton, GA**
  - SPI contract expires 9/30/2004. Final technical report due to DOE.
    - EXTENDED TO 6/30/05 – Final tech report submitted. Other close-out docs pending.
  - Disposition of system – Southwire will continue operation.
- **SPI-2: Bixby Substation, AEP, Columbus, OH**
  - 1Q,FY2005 (Oct-Dec 2004)
    - Assemble and test full scale terminations for 3 kA 5-meter cable prototype. – Cmplt.
    - Fault current and bend testing of 3-meter triaxial cable. - COMPLETE
    - Finalize design of cryogenic system. - COMPLETE
  - 2Q,FY2005 (Jan-Mar 2005)
    - Bend test of 5-meter triaxial cable. - COMPLETE
    - Splice test of 5-meter triaxial cable. – Design COMPLETE, Build/Test PENDING
    - Mechanical verification test of cryostat/cable assembly. - COMPLETE
  - 3Q,FY2005 (Apr-Jun 2005)
    - Begin construction of triaxial cables for AEP project. - COMPLETE
    - Begin civil/electrical work at Bixby site. – Dsgn ONGOING, Constr. will start 8/05
  - 4Q,FY2005 (Jul-Sept 2005)
    - Ongoing system construction. – Under Way
    - Complete construction of triaxial cable. - PENDING
  - 1Q, FY2006 (Oct-Dec 2005)
    - Begin on-site installation of equipment.

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As of Aug 1, 2005, the HTS cables have provided 100% of the customer load for over 30,000 hours

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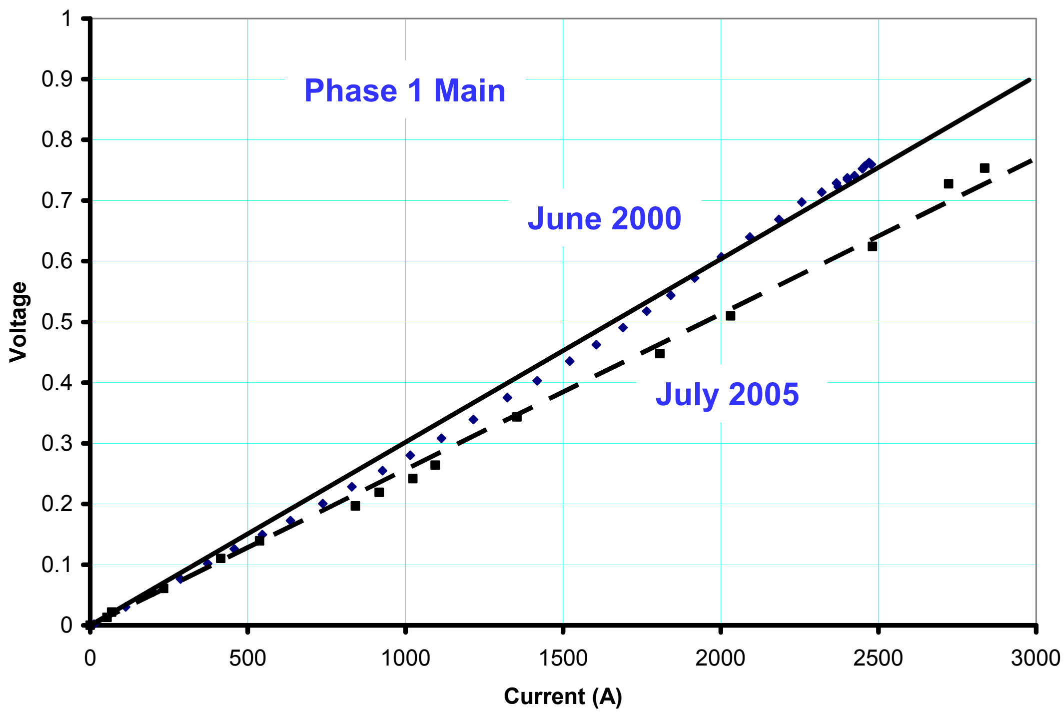
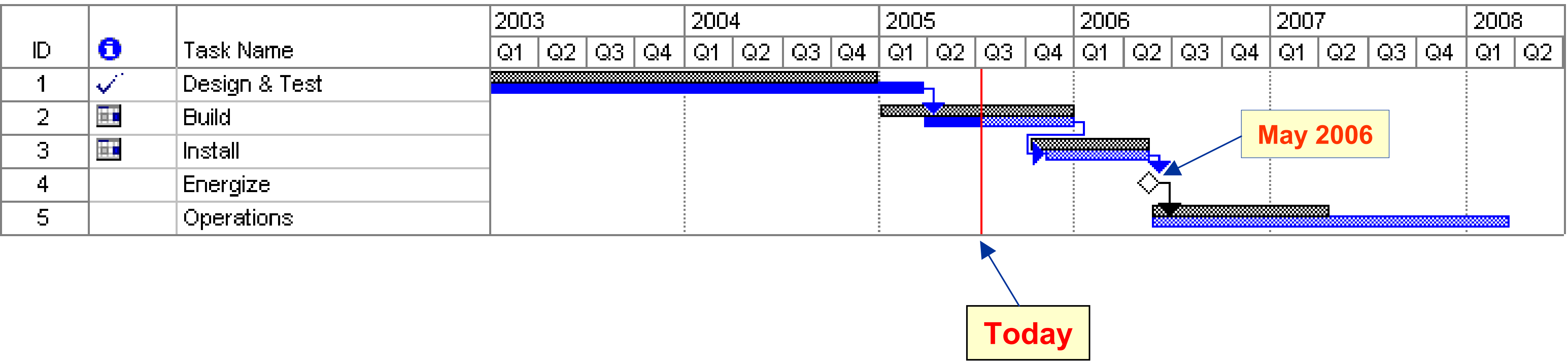
DC-VI results of 30-m cables show no change in conductor performance.

- Voltages are measured from bus, so there is a normal resistive component.
  - The voltage taps and connecting bus was different for the two measurements.
- Three phase conductors' I_c above 3 kA limit of power supply.
- The shield I_c remained unchanged above 2 kA.



AEP-Southwire Project Timeline

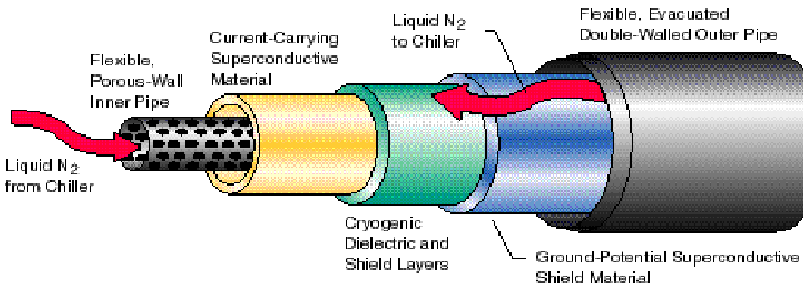


Project Status:

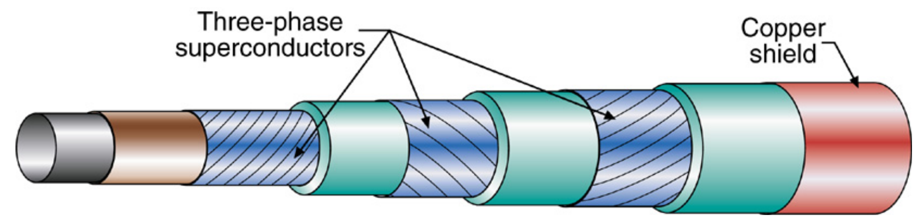
- Design & Qualification tests ran longer than expected
- Overall – project still on schedule to energize as planned
- On Budget

Comparison of HTS Cable Designs

30-m System
Single-Phase, Co-axial Design



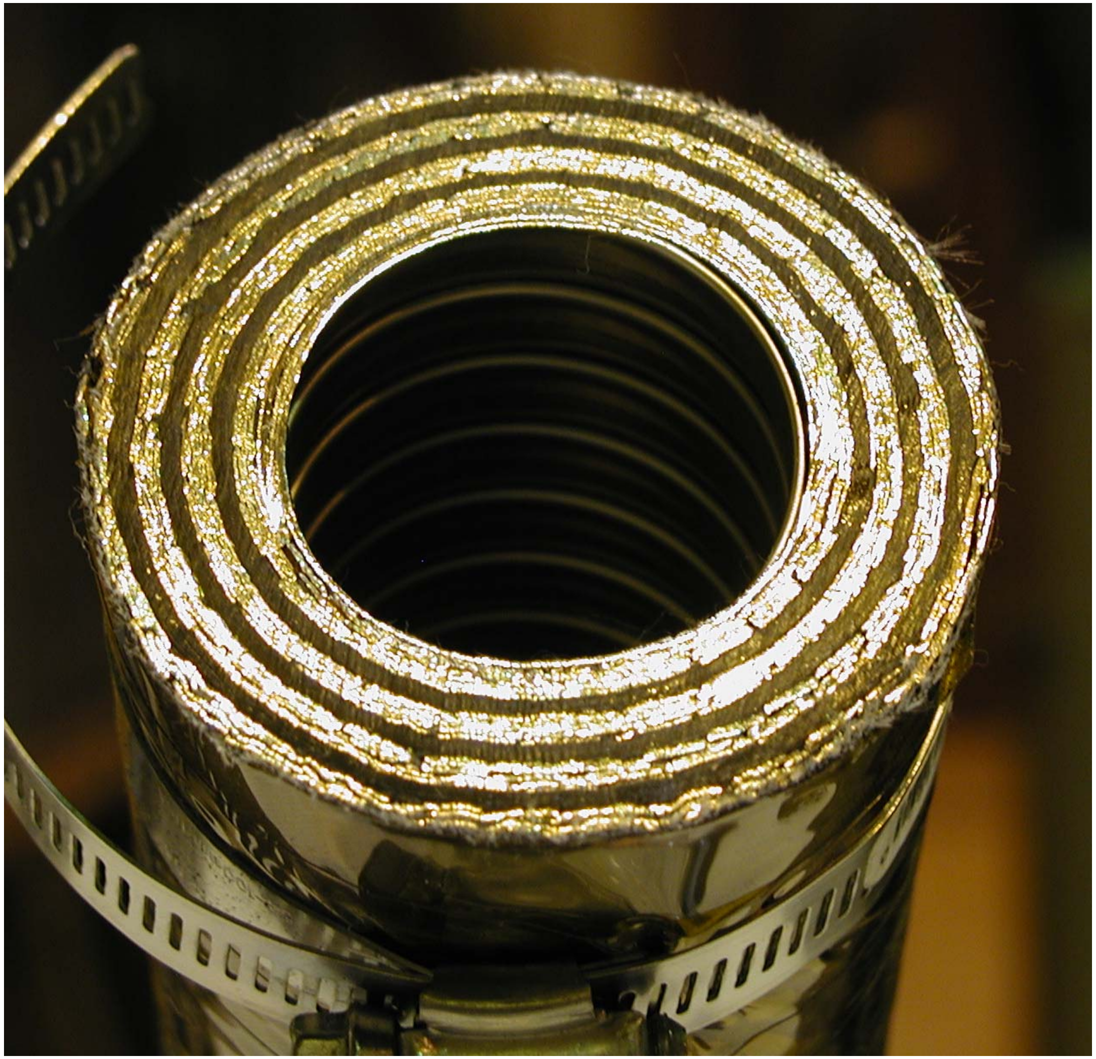
Bixby System
3-Phase, Triax Design



- **Features of the Co-axial HTS cable**
  - Magnetic field shielded.
  - Both conductor and dielectric are wrapped from tapes.
  - Cryogenic dielectric reduces size and increases current carrying capacity.
  - Flexible cable to allow reeling

- **Features of the tri-axial cold dielectric HTS cable**
  - Highest current density design
  - Potential to reduce the required HTS tape by ~1/2
  - Potential to reduce heat loads by ~1/2
  - Flexible cable to allow reeling.
  - Cable + Termination designed for 3000 A_{rms} to meet AEP project requirement.

HTS Triax Cable Capable of Carrying 3000 A was Manufactured by Ultera



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‘AEP Project’

U.S. Department of Energy
SPI Phase-III

- Utility Partner = American Electric Power
- Location = Bixby Substation, Columbus, OH
- Length = 200 meters
- Voltage = 13.2 kV
- Load Rating = 3.0 kA_{rms} AC / 69 MVA
- Fault Current Peak = ~56 kA asymmetric
- Cable Design = Triax
- Other Features = Splice
  Underground
  Multiple 90° Bends
- Energize mid-2006

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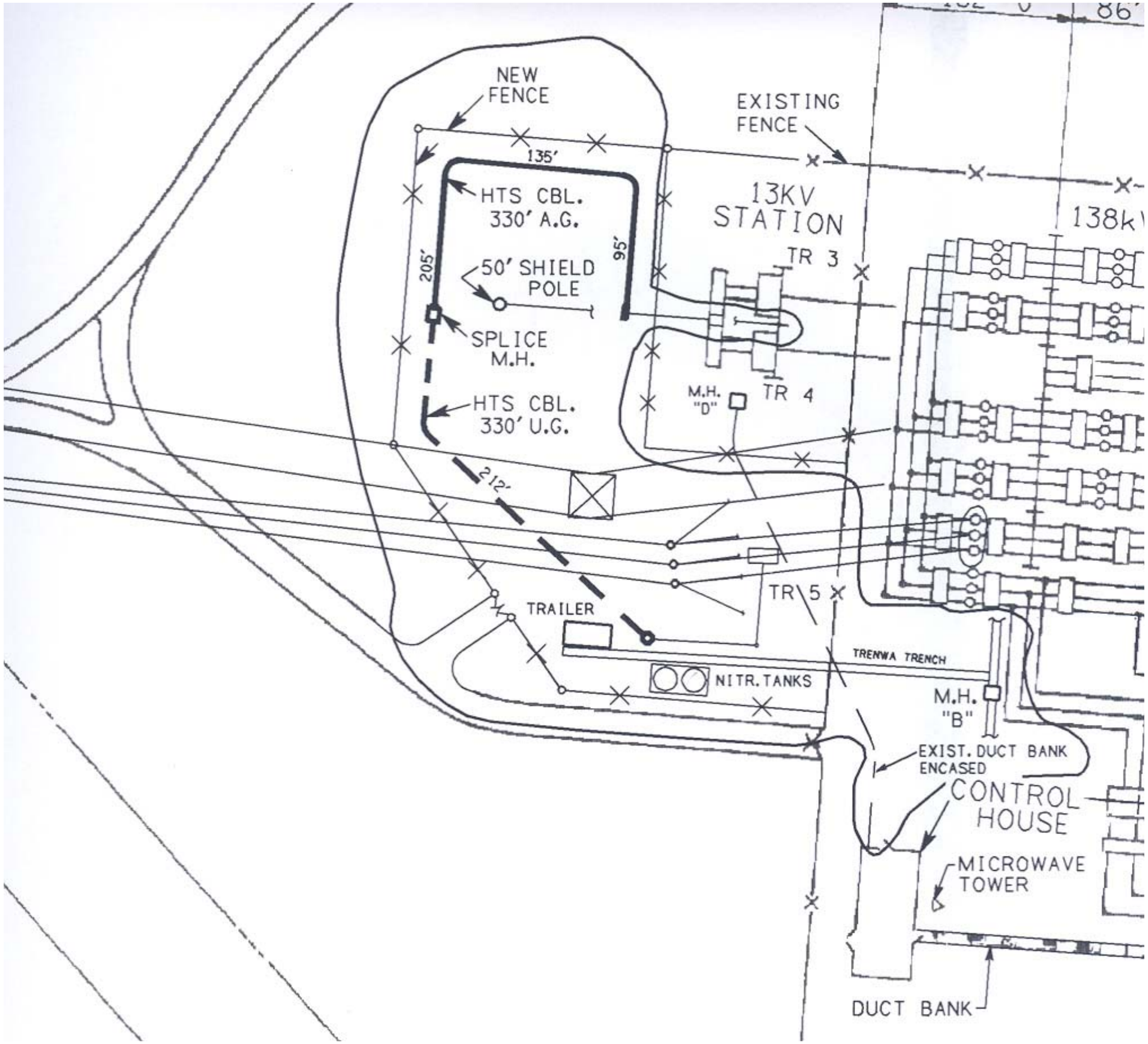
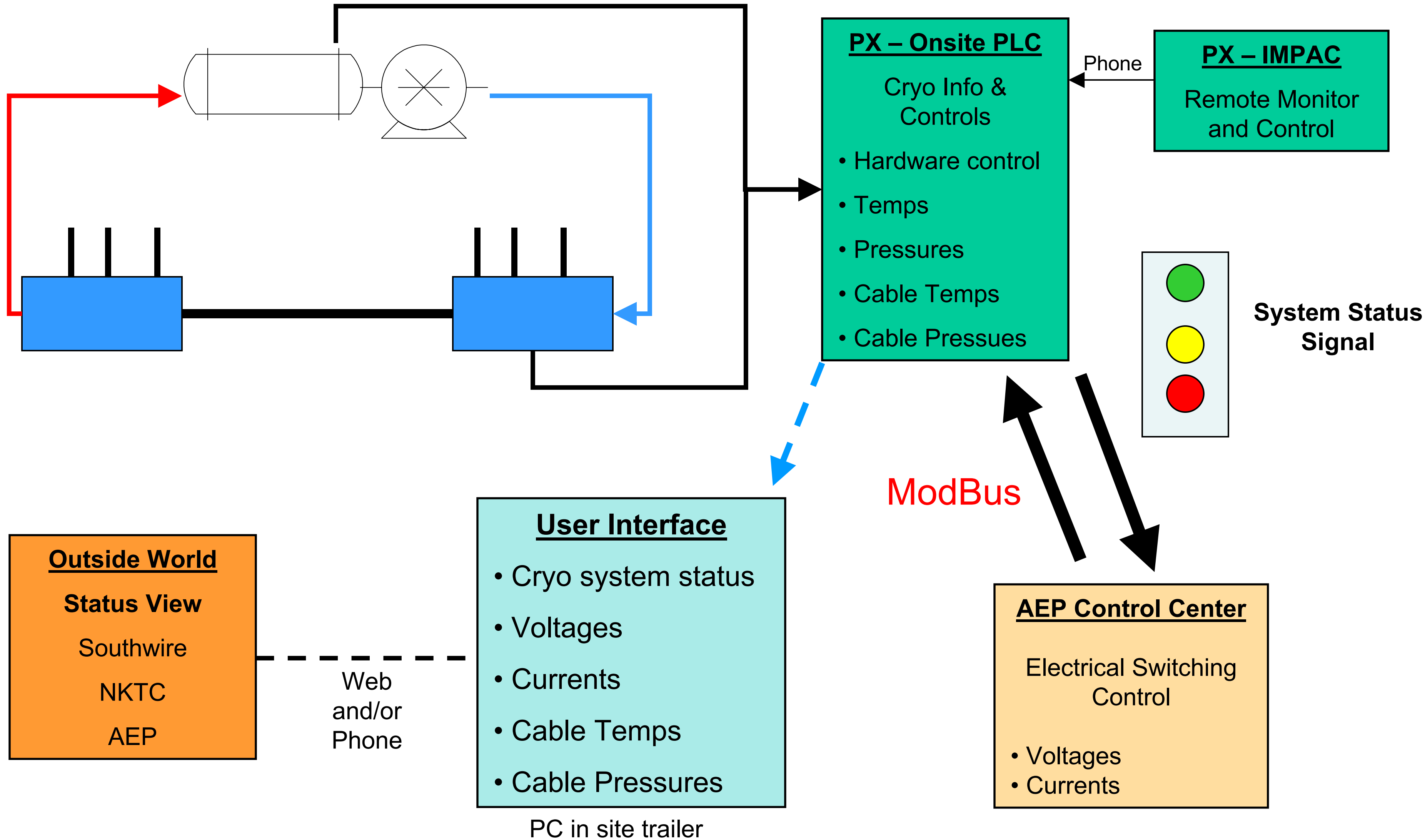
AEP Site Layout



System Operational Monitoring and Controls



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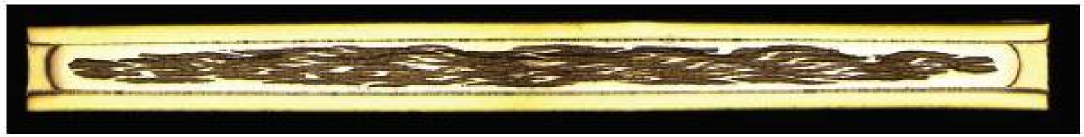
AMSC HTS Hermetic Wire

American Superconductor

Bismuth based, multi-filamentary high temperature superconductor wire encased in a silver matrix and laminated with brass to increase mechanical strength and provide a hermetic seal.



Specifications:	
Average thickness:	0.36-0.44 mm
Minimum width:	4.0 mm
Maximum width:	4.45 mm
Min. double bend diameter (RT):	70 mm[i]
Max. Rated tensile stress (RT):	175 MPa[i]
Max. Rated wire tension (RT):	20 kg[i]
Max. Rated tensile stress (77K):	200 MPa[i, ii]
Max. Rated tensile strain (77K):	0.30%[i, ii]
Hermeticity	30 atm LN2 for 16 hours[iv]

Customer Options:

Minimum amperage (Ic)	Average engineering current density (Je)[iii]
115 A[ii]	6,700 A/cm^2[ii]
125 A[ii]	7,300 A/cm^2[ii]
135 A[ii]	7,900 A/cm^2[ii]
145 A[ii]	8,500 A/cm^2[ii]
Continuous piece length	Up to 800 m
Insulation options	PTFE or Kapton wrap
Splice options	Spliced wire is available in longer lengths

[i] Greater than 95% Ic retention
[ii] 77K, self-field, 1μV/cm
[iii] Je is a calculated value based upon average thickness and width
[iv] Thickness inspection after pressurized LN2 test

Designed for use in applications where the wire is exposed to pressurized liquid cryogens

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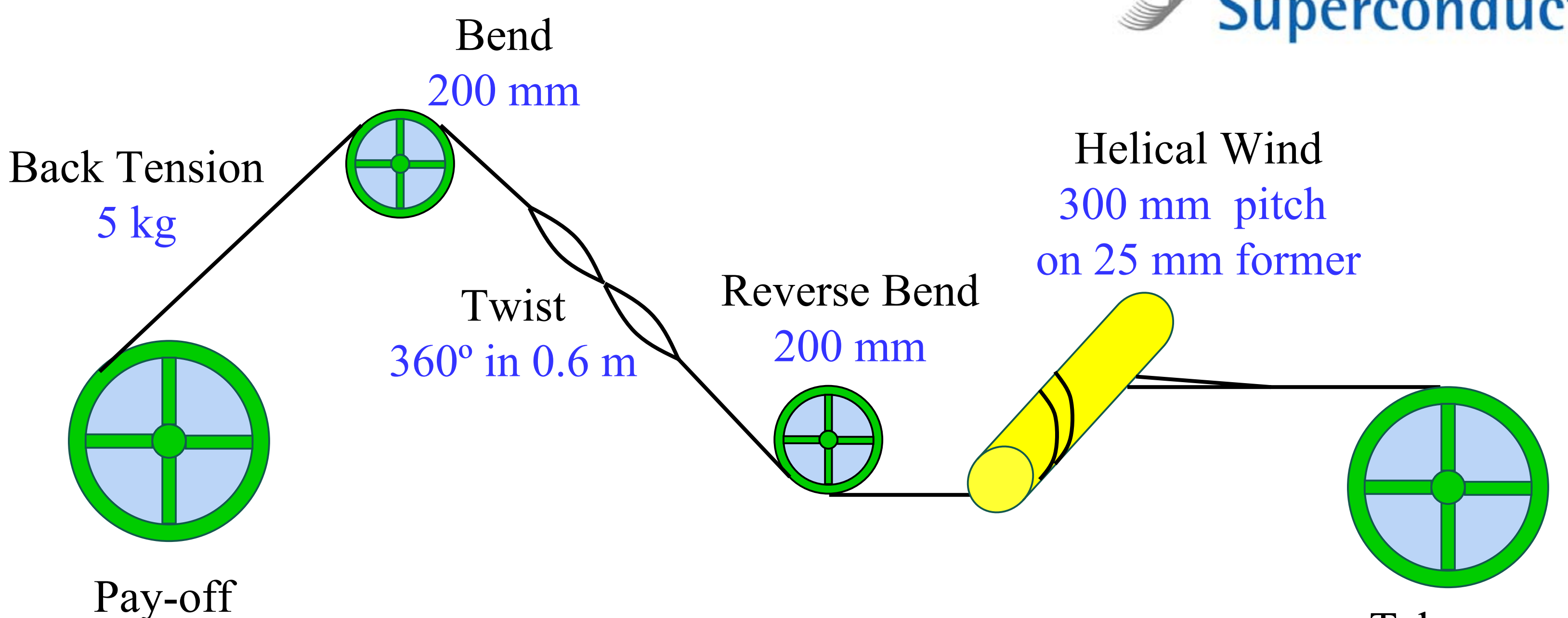
Tape Reliability Testing: Mechanical Aging Test

Wire and splices designed to be hermetic and survive bending & twisting



Test parameters in blue

Tested to meet or exceed conditions of cable stranding processes

HTS Tape Production Status

- **Length Requirements:**
  - **184 pieces x 265 meters each = 48,760 meters**
- **Ic Requirement (77K, 1μV/cm) > 115 amps**
- **Status as of July 31, 2005**
  - **All wire manufacturing complete at AMSC**
  - **All wire shipped from AMSC to Ultera**

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AMSC commercial HTS wire manufacturing meets large volume cable requirements

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Cryogenic Cooling

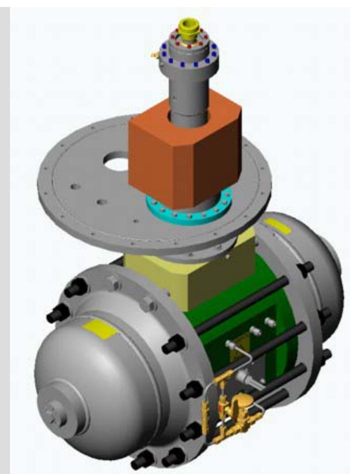
Experience 1: Stirling coolers
2 years operation at AMK

Experience 2: Open system
4+ years operation at Carrollton

AEP

Hybrid System
Vacuum
+
Pulse-Tubes

New: Q-drive + pulse tube
- low vibration
- low maintenance



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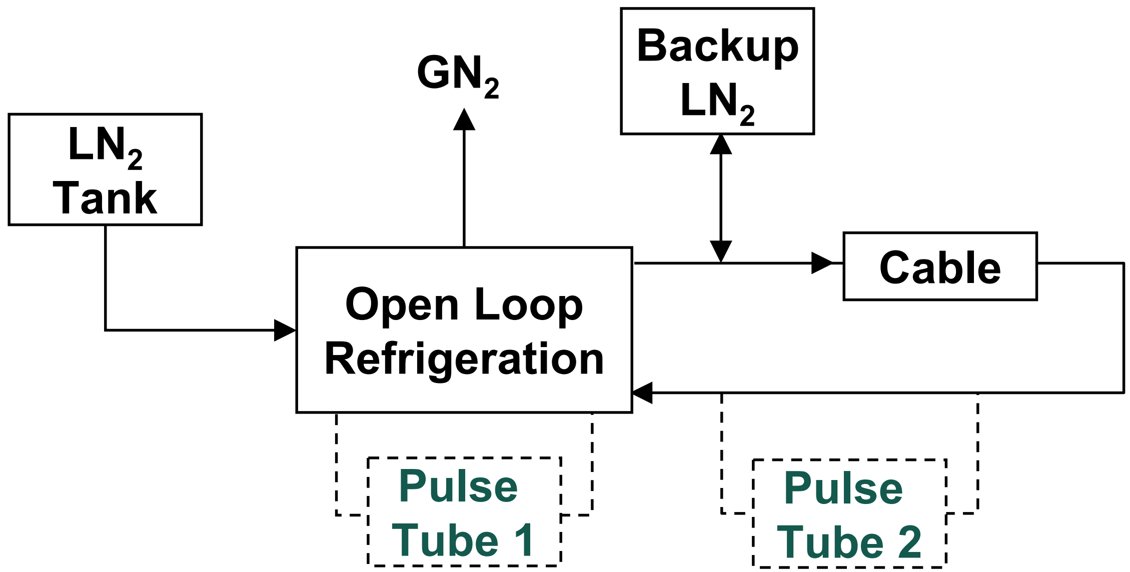
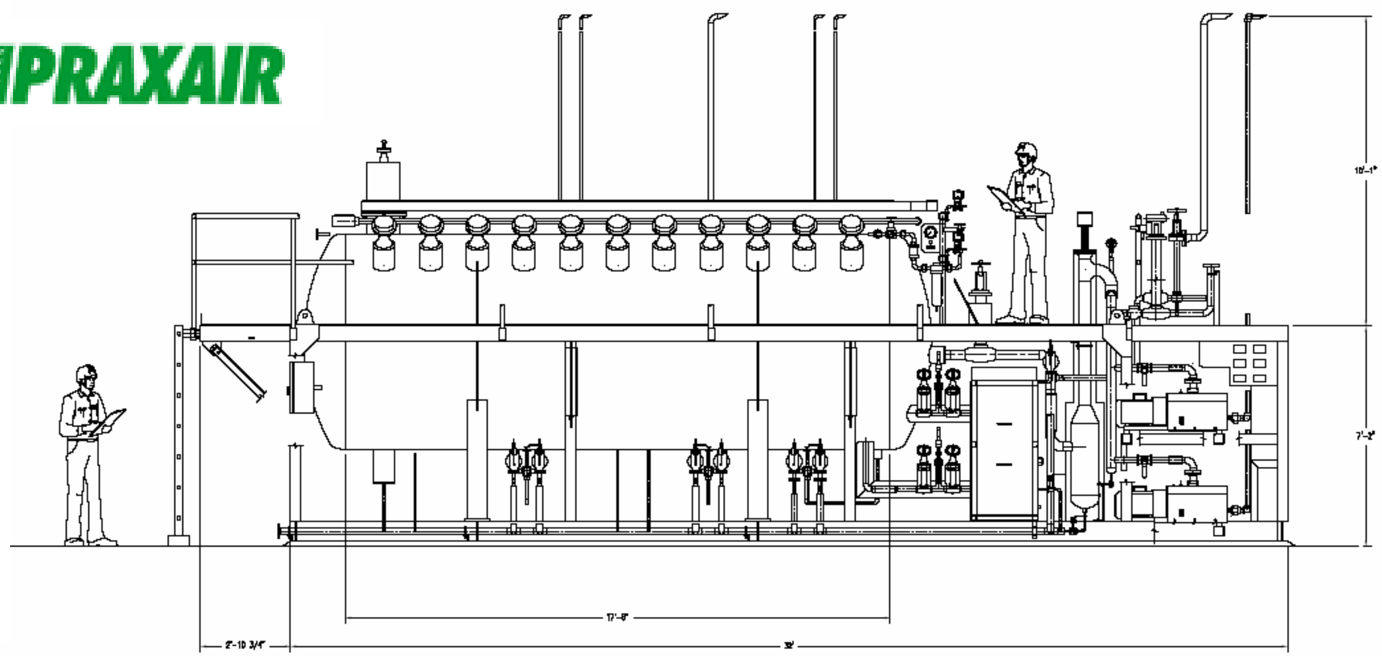
HTS Cable Demonstration
Cryogenic System Overview Integration



HTS Cable Demonstration
Open Loop Refrigeration System and Equipment

- **Vacuum system skid detail design underway**
- **Major equipment on order/received; vacuum skid fabrication awarded (PHPK)**
- **Overall layout completed**
- **Installation scheduled for December 2005**



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HTS Cable Demonstration
Large Cryocooler Development

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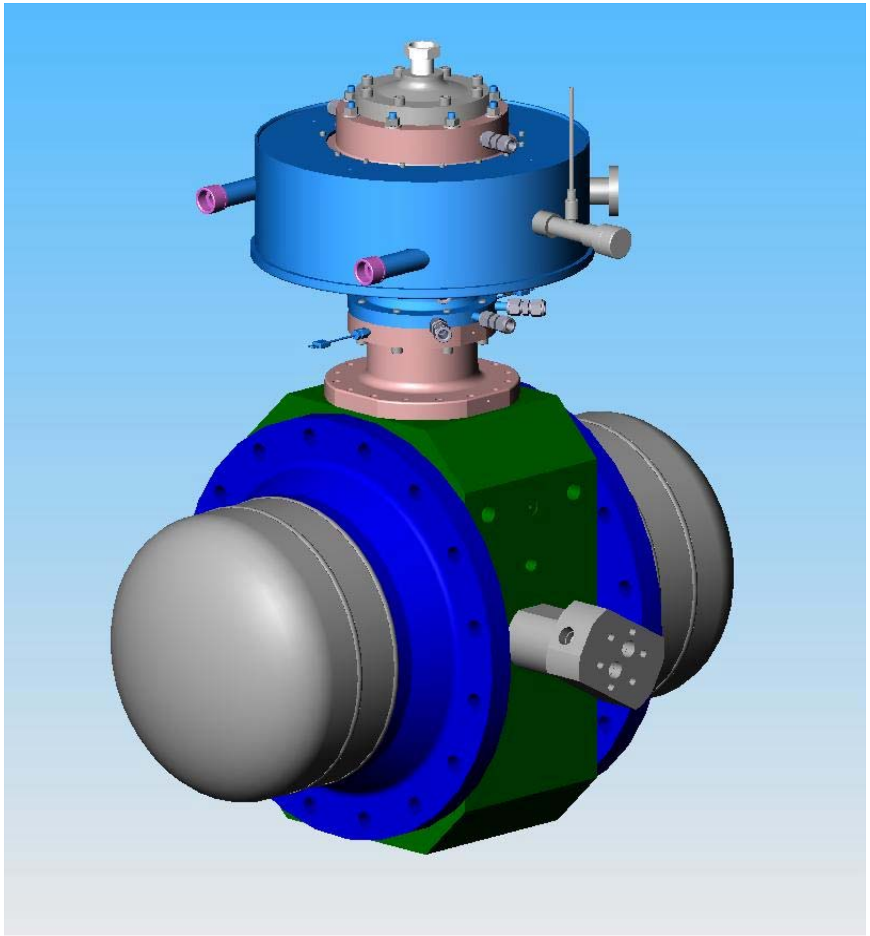
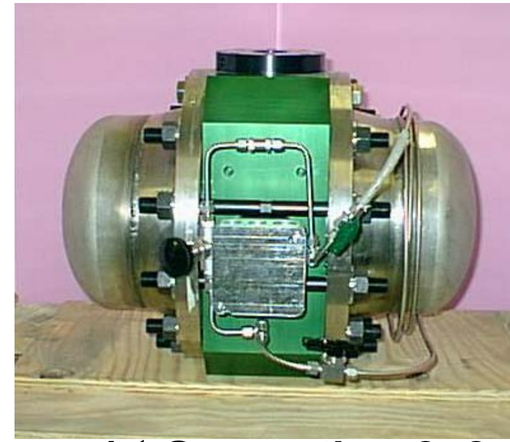
- Design Target: 1kW at 70K
- Modular unit designed and fabricated
- No Load Temperature: 57K
- Testing, modification and development ongoing

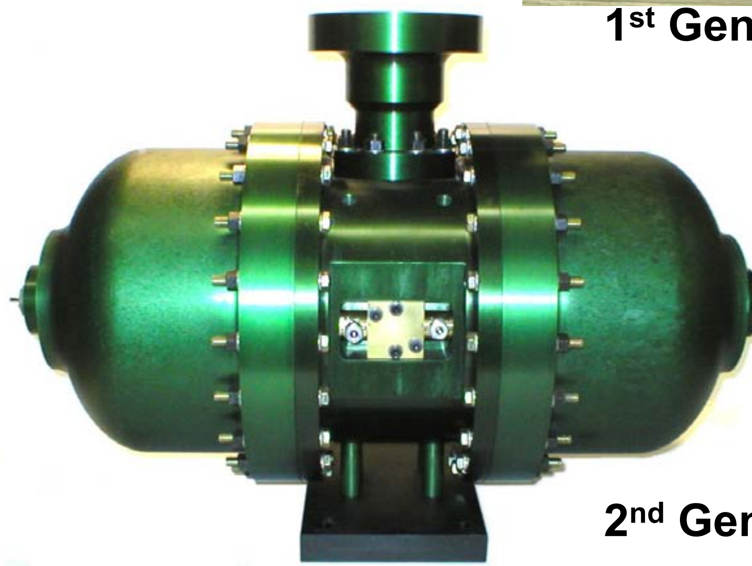


HTS Cable Demonstration
Large Cryocooler Development

- **Second generation PWG in development (CFIC)**
  - Lower cost
  - Lower weight
  - Improved efficiency
- **Suspension re-design**
  - Current design passed initial hurdle (10^8 cycles at 100% of stroke
  - Overstroke testing underway
- **Design complete, components in fabrication**



1st Generation 2x2



2nd Generation 2x2

Pressure Wave Generator (PWG)

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Cable Stranding – Manufacturing Commissioned

HTS Stranding

Dielectric Lapping

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Pulling & Mechanical Verifications

No damage or degradation to cable or cryostat from pulling

Cryostat Pulling

Cable Pulling

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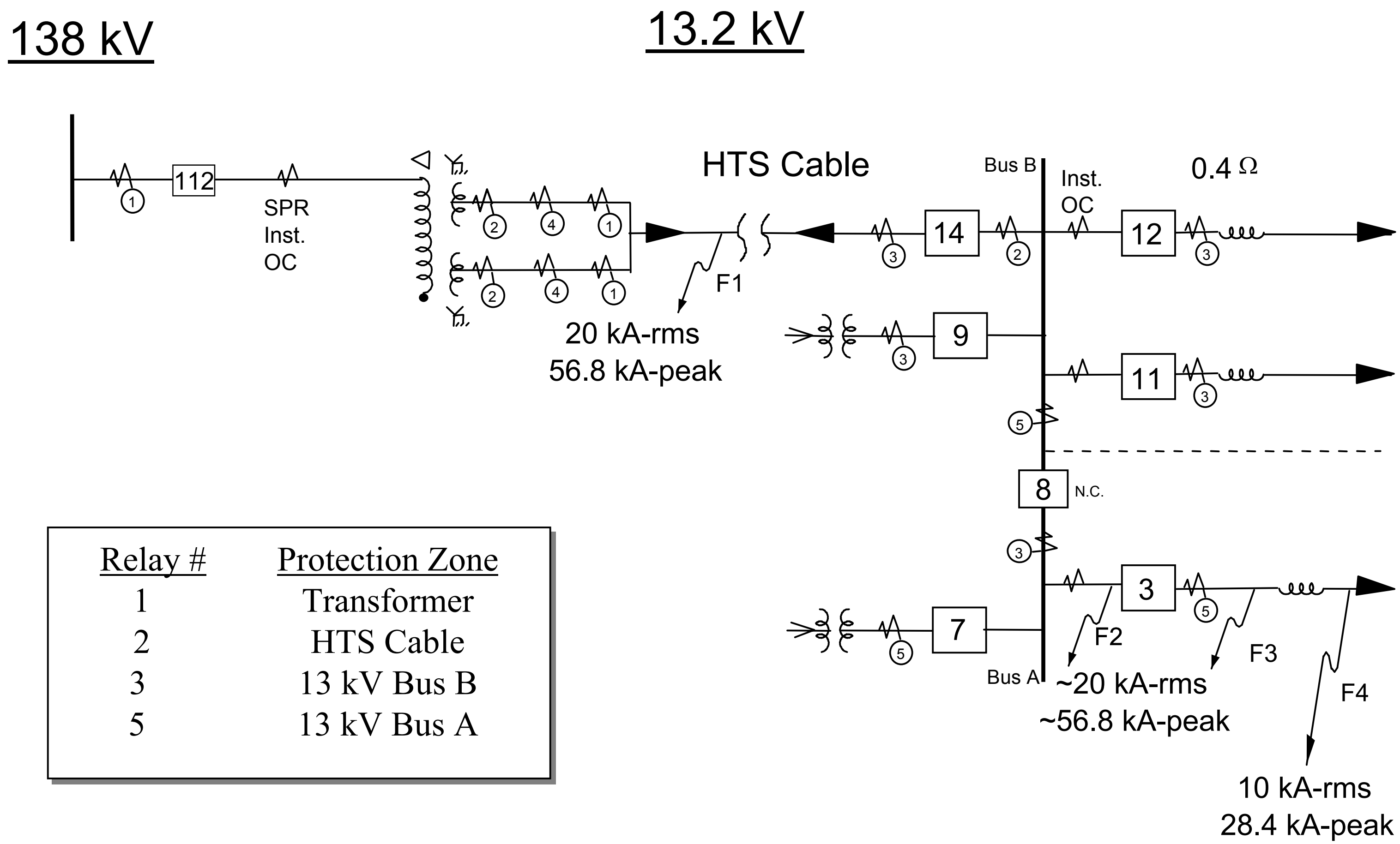
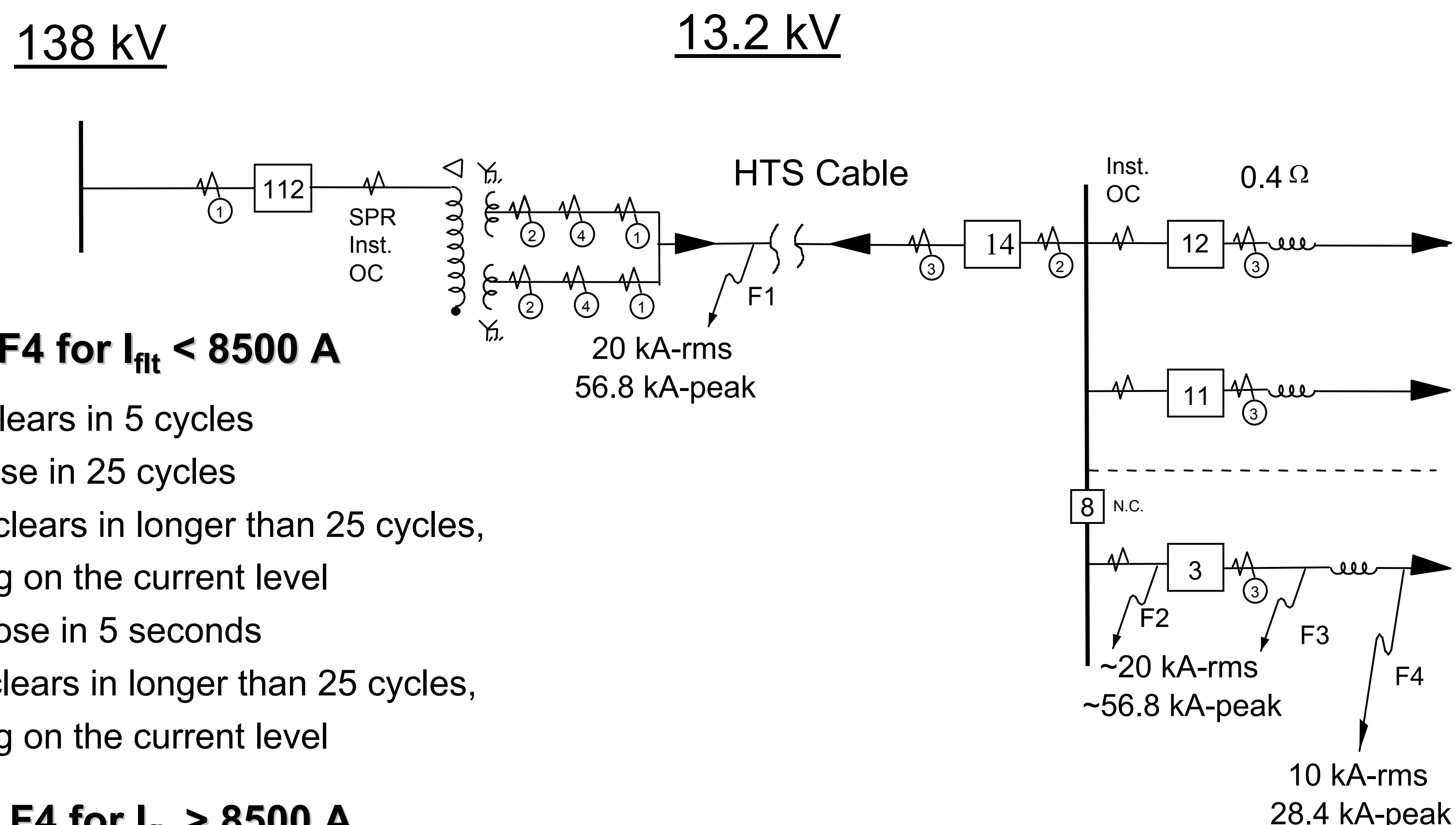
Fault current / protection at Bixby 13.2 kV



Relay #	Protection Zone
1	Transformer
2	HTS Cable
3	13 kV Bus B
5	13 kV Bus A

Faults on Distribution Lines



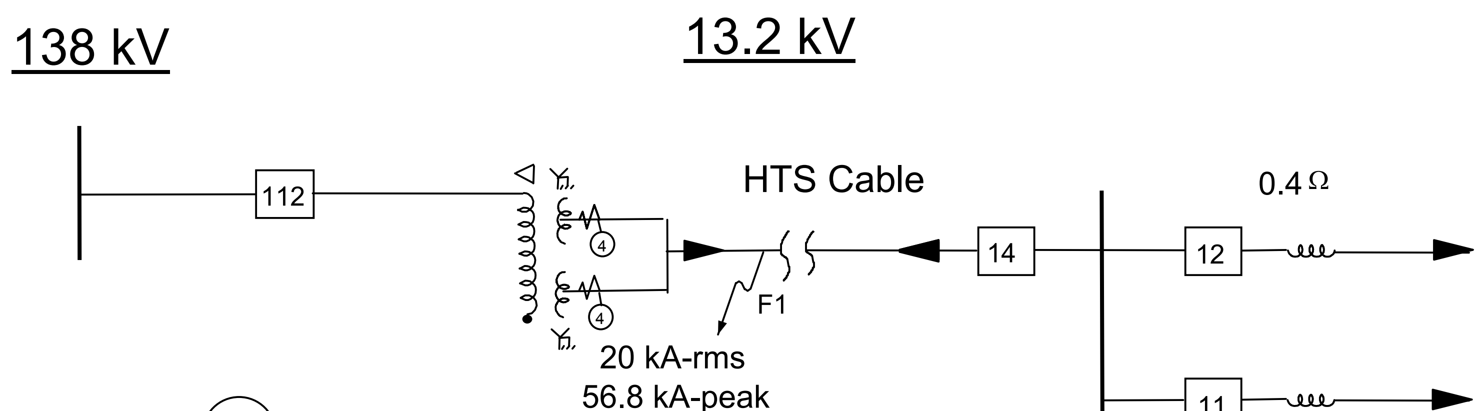
Faults at F4 for I_{flt} < 8500 A

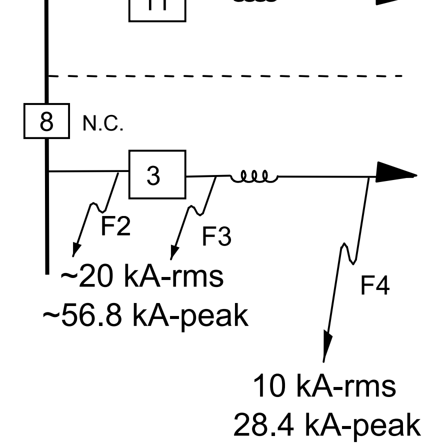
- 1st Trip clears in 5 cycles
- 1st Reclose in 25 cycles
- 2nd Trip clears in longer than 25 cycles, depending on the current level
- 2nd Reclose in 5 seconds
- 3rd Trip clears in longer than 25 cycles, depending on the current level

Faults at F4 for I_{flt} > 8500 A

- Sequence as above except all trips will be instantaneous (~5 Cycles)

Faults Between Dist. Breaker (s.a. CB3) and into Series Reactor with Breaker (CB3) Failure. $I_{fault} > 11kA$.



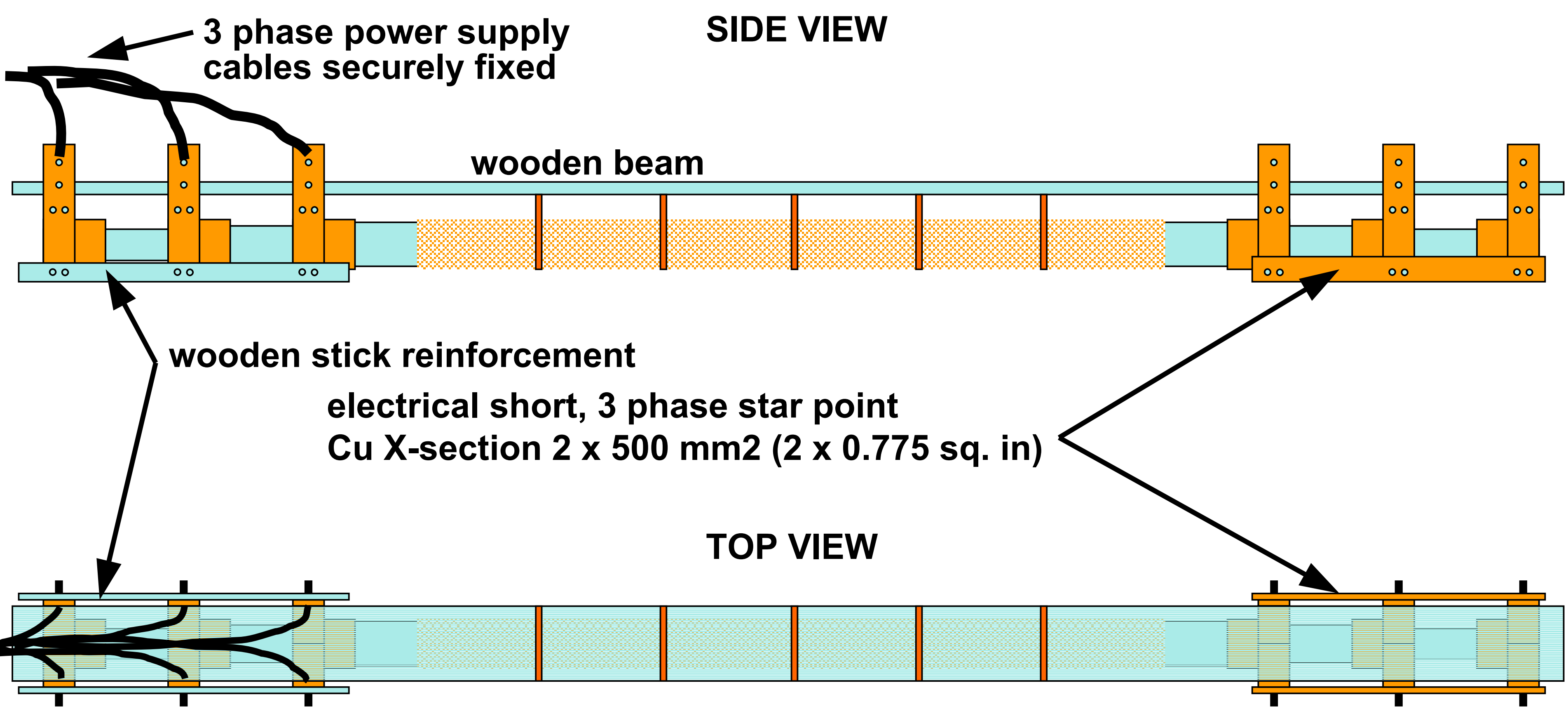


- Using Relay at (4), there will be a trip by CB14 with a 15 cycle fault duration (Inst. pickup of >11 kA and definite time delay of 11 cycles.)
- No reclosing of CB14.

An Exception

- For fault currents <11 kA, and with distribution breaker failure, fault clearing will follow back-up overcurrent relay time delay curve setting, at CB14.

Ultera 09, fault current set up



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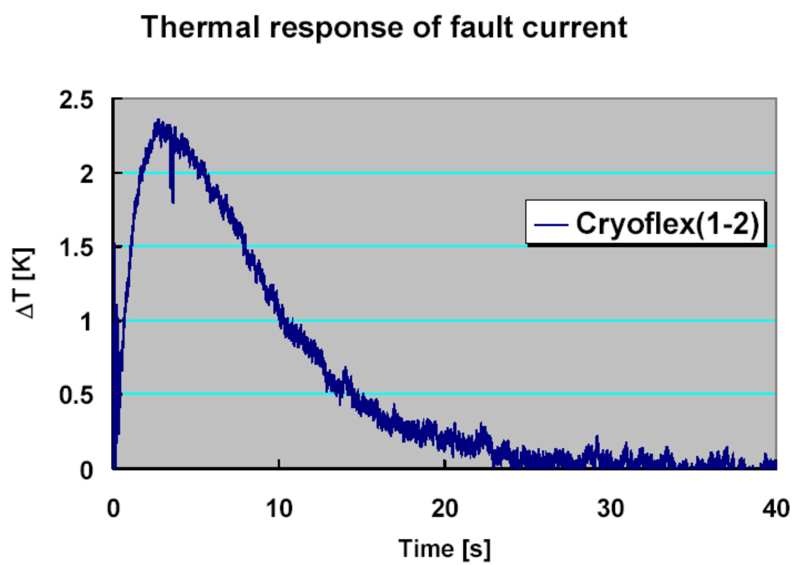
Worst-Case 'Thermal' Fault Current Test

Results of 3 phase "thermal" fault current

1) LN2 @ 77.3 K, ambient pressure (open bath)
2) 3 x Irms ≈ 22.2 kA, duration 246 ms (<2% off),
3) $I1_{peak}$ ≈ 44 kA, $I2_{peak}$ ≈ 39 kA, $I3_{peak}$ ≈ 46 kA
4) V1 not recorded (broken volt. leads), V2peak ≈ 8 mV/cm, V3peak ≈ 10 mV/cm
5) End of fault, cable still superconducting based on voltage trace
6) No dramatic effect, no obvious/visible damage



	I_{peak} [kA]	I_{rms} [kA]	U_{peak} [V/cm]	U_{rms} [V/cm]	$\int I^2(t)\cdot dt$
Ph 1	(-) 44.4	21.9	-	-	$121\cdot10^6$ A²s
Ph 2	(-) 39.2	23.1	1.36	1.26	$134\cdot10^6$ A²s
Ph 3	45.6	21.7	2.43	1.34	$118\cdot10^6$ A²s

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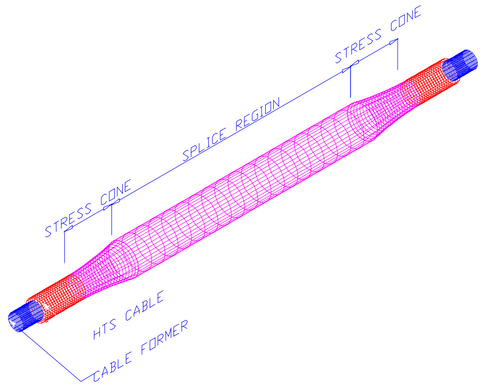
Cable Splice

Prior Experience:

12.4 kV, Single-Phase Coax Cable



Successful Testing:

- AC Withstand
- BIL to 110 kV
- FC to 12 kA, 60 cycles

Design Includes:

- HTS tape splices
- Dielectric splices
- Stress cones

Triax Cable Splice Design

- Based on coax experience
- Improved techniques
- Design will minimize radial build
- Approx 1.5 m total length for 3 phases
- Field weld vacuum enclosure around splice region
- Presented in detail to Readiness Review Panel

Multiple Prototypes to be made:

- Design will be build & tested using 3m & 5m cables from prior work
- Ic and voltage tests to verify design
- Work will be completed during 4Q, FY05

Triax Cable + Termination Qualification

The following has been successfully tested:

1. Single-phase DC current tests (measure critical current)
2. 3-phase DC currents at 3 kA for 14 hours (thermal stability)
3. Single-phase AC current to 3 kA (AC loss measurements)
4. 3-phase AC current to 3 kA (thermal stability for cable + terminations)
5. Single-phase rated voltage for 1 hour
6. 3-phase rated voltage for 1 hour
7. PD measurements at 15.6 kV, single-phase (per IEEE 48-1996 termination spec)
8. AC withstand to 39 kV, single-phase (per ICEA S-94-649-2000 cable spec)
9. BIL to 110 kV (per IEEE & ICEA specs)

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Triaxial cable bent 90° set-up for DC testing at ORNL.

Extensive series of tests for the straight configuration

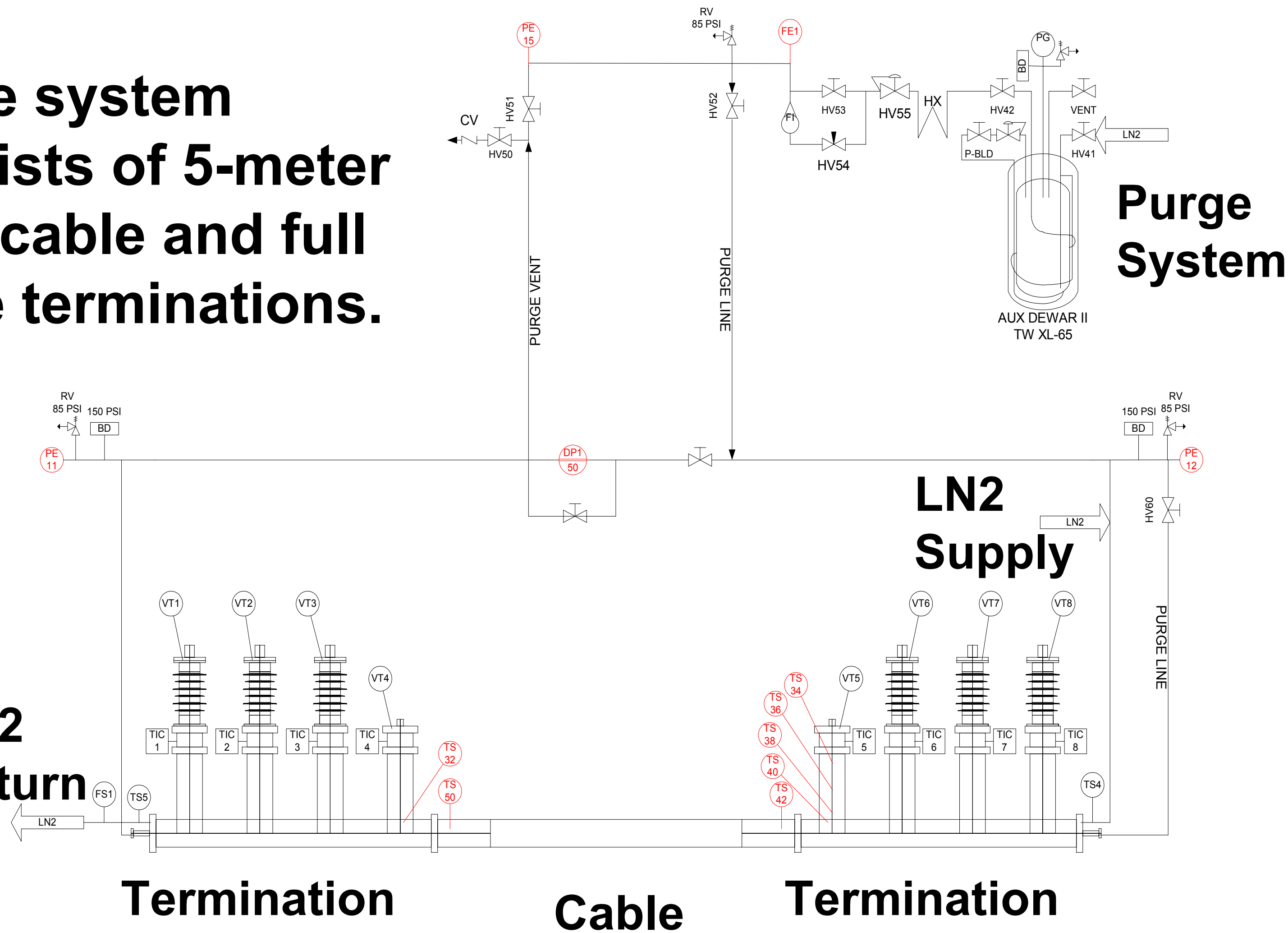
- Low Voltage DC Test
  - Measurement of V-I curves, I_c
  - Long duration hold at 3000 A for 14 hours in all 3 phases
- Low Voltage AC Test
  - Hold at 2500 A ac and 3000 A ac
- High Voltage, Low Current
  - Single phase hold at 7.6 kV 1 hour
  - PD measurement at 15.6 kV
  - AC Withstand to 34-39 kV for 5 minutes at 3.5 kV steps
  - Three Phase ac voltage for 1 hour at 7.4 kV
  - BIL test at +/- 110 kV (5 positive and 5 negative pulses) per phase
  - PD measurement at 15.6 kV
- Low Voltage Fault Current Test
  - Single phase 10 kA overcurrent for 0.7 sec
  - Three phase 10 kA overcurrent for 0.7 sec.

Extensive series of tests for the 90° bent configuration

- Low Voltage DC Test
  - Measurement of V-I curves, I_c
- High Voltage Low Current
  - Single phase hold at 7.6 kV 1 hour
  - PD measurement at 15.6 kV
  - AC Withstand to 34-39 kV for 5 minutes at 3.5 kV steps
  - Three Phase ac voltage for 1 hour at 7.4 kV
  - BIL test at +/- 110 kV until breakdown between phase 1 and 2
- Low Voltage Fault Current Test
  - Single phase 10 kA overcurrent for 0.7 sec
  - Three phase 10 kA overcurrent for 0.7 sec.
- Low Voltage DC hold at 3500 A for 3 hours

Simplified P&ID for triaxial HTS cable system without LN2 skid.

Cable system consists of 5-meter triax cable and full scale terminations.



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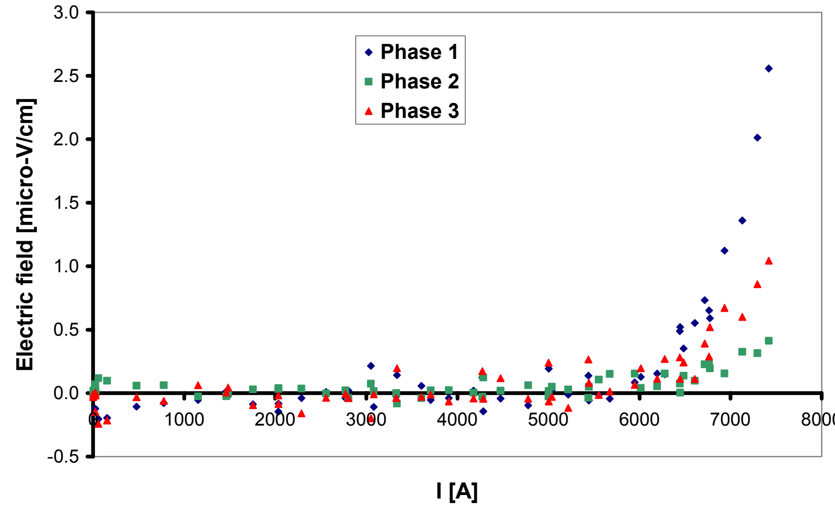
Initial DC V-I measurements in straight configuration show I_c > 7 kA for all phases

- **Nitrogen subcooler was under vacuum**
  - Cable system inlet at 75.9K
  - Cable system outlet at 81.1 K
  - Average temperature 78.5 K
- **All three phases measured simultaneously.**
- **Phase 2 I_c was extrapolated.**
  - n-value based on data for $I<I_c$



	Phase 1	Phase 2	Phase 3
Length (cm)	1058	881	716
Critical Current (A)	7017	7960	7454
n-Value	14.7	12.3	10.0

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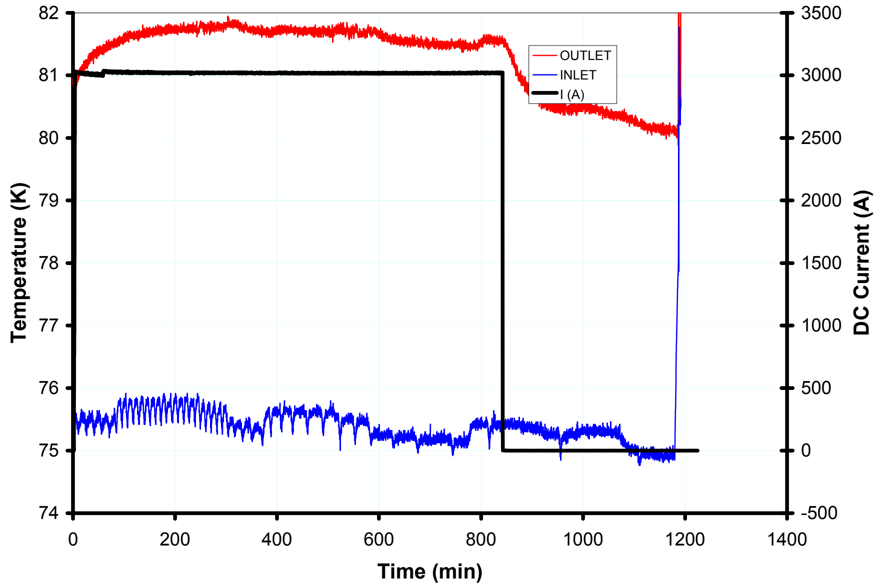
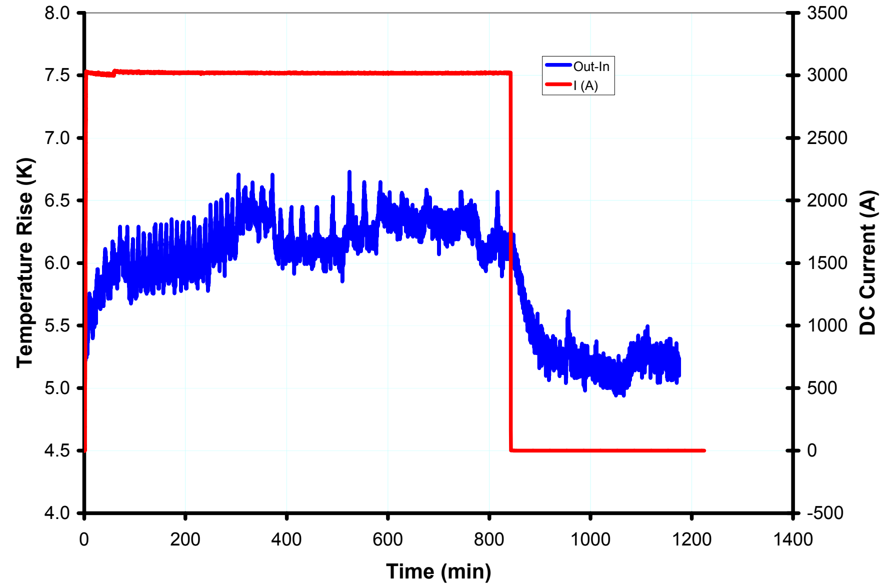
3000 A DC Testing with vacuum in subcooler.

- Inlet and outlet temperatures from cable system.
- Subcooler at ~6.4 psia, bath temperature ~ 71 K



- Temperature rise across cable system.
- Responds quickly to drop in current.



•Met AEP Bixby heat load budgets when extrapolated to 200 m cable.

•Increase in heating is 425 W with full current applied.

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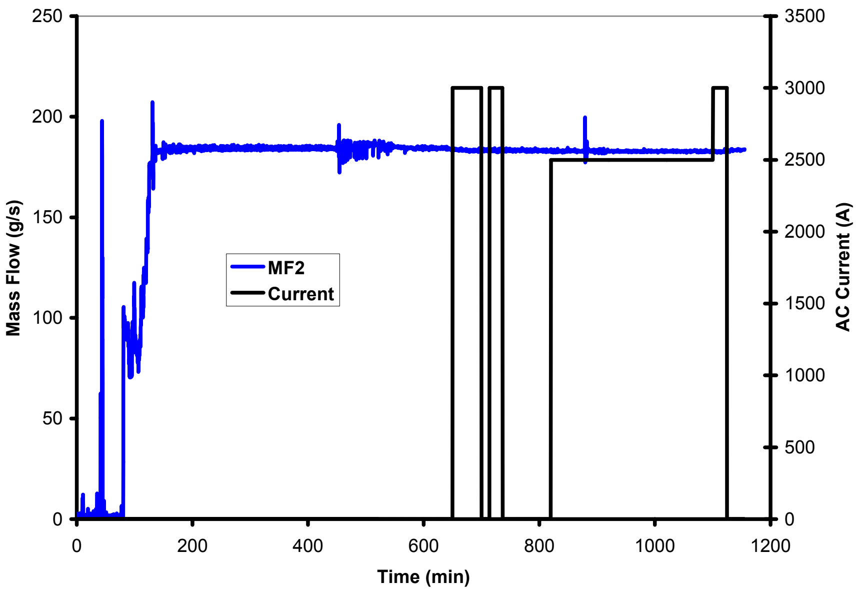
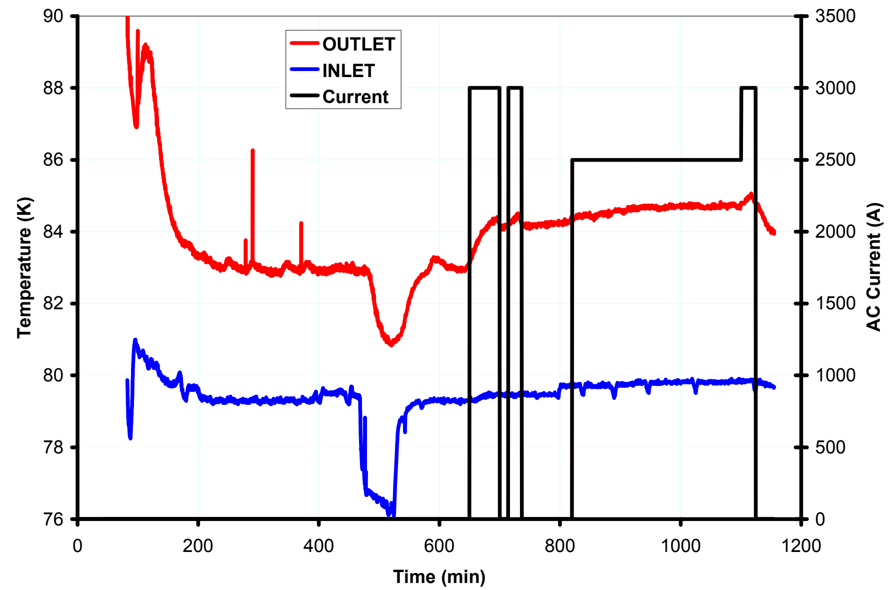
The cryogenic system parameters nearly steady during ac current testing at 2500 A_{rms}

- **Mass flow measured with coriolis flow meter was steady.**
- **Subcooler was open to atmosphere except for a short duration prior to applying current.**
- **Inlet temperature steady, and outlet temperatures approach steady state with current applied.**
- **Briefly operated at 3 kA_{rms}**





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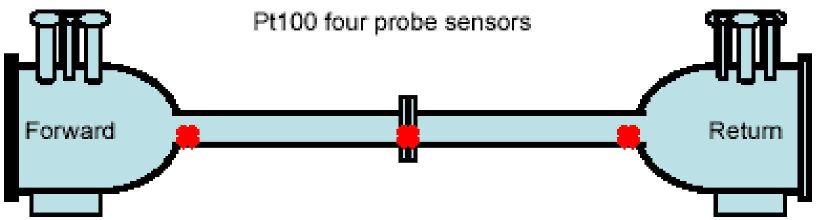
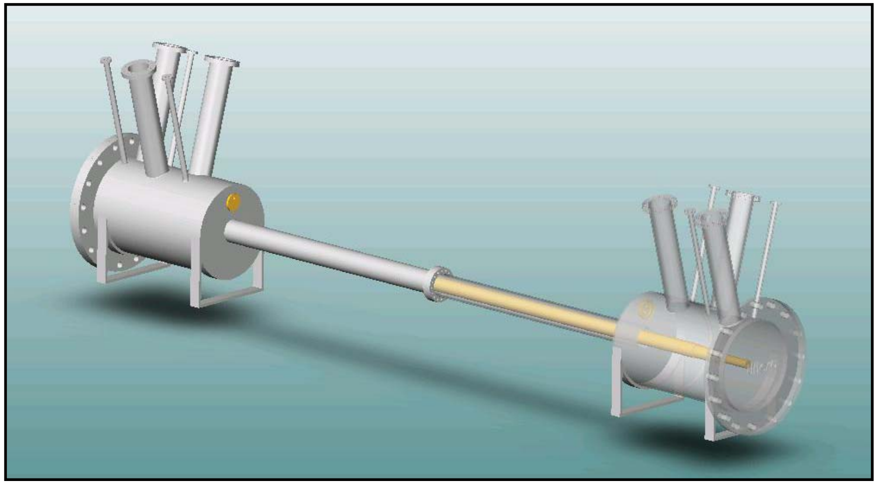
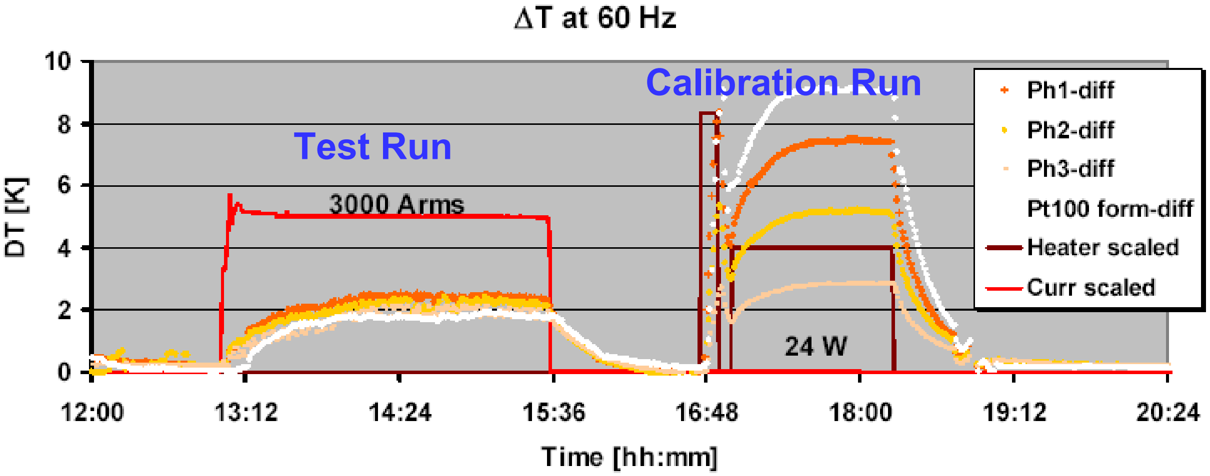
Ultera in Denmark has conducted 3-phase testing of a 3-meter triaxial cable at 3 kA to verify AC Loss



Tested in pressurized liquid nitrogen, T = 79 K





1st Proto-type:
3-Phase Triax conductor tested to 3.0 kA on all phases simultaneously. ΔT was within limits and stable. Acceptable ac loss results

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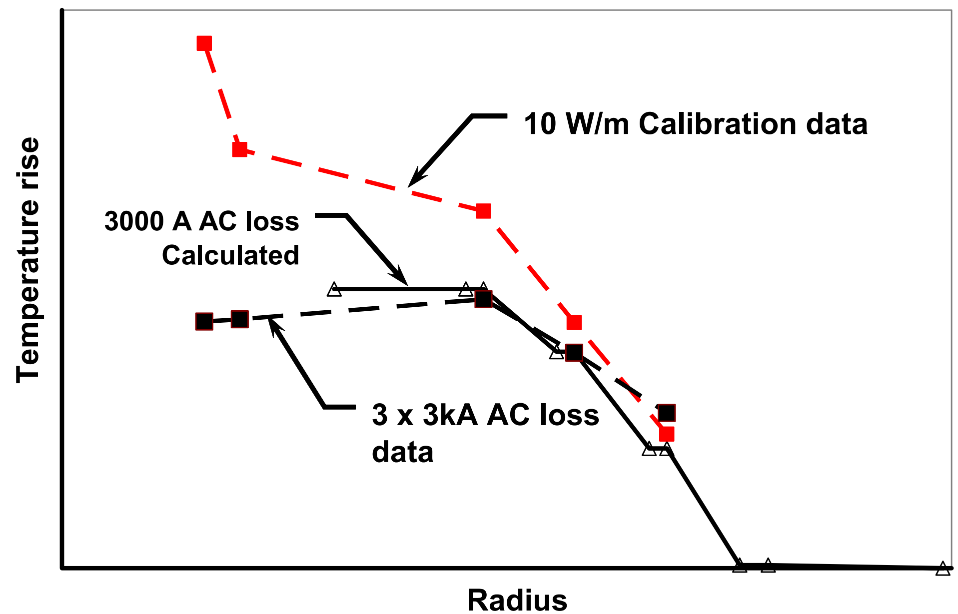
Ultera measured ac loss on the 3-meter triaxial cable with 3 kA on all three phases.



- Testing conducted in pressurized test chamber at around 2 bar.
- No high voltage testing was conducted.
- AC loss about 8.2 W/m for the three phases at 79 K.
  - AEP cable will operate at lower temperatures hence lower ac losses (~3-6 W/m, due to varying temperature along the cable).

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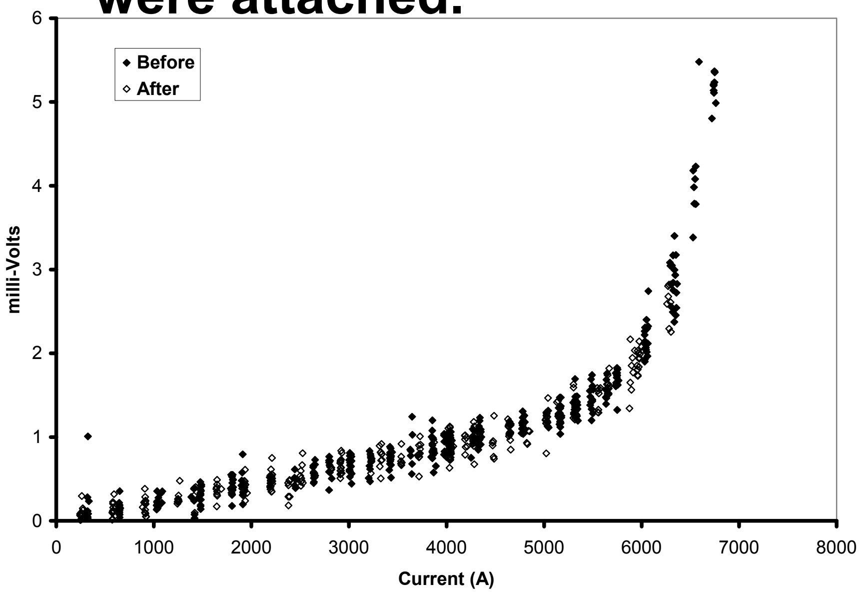
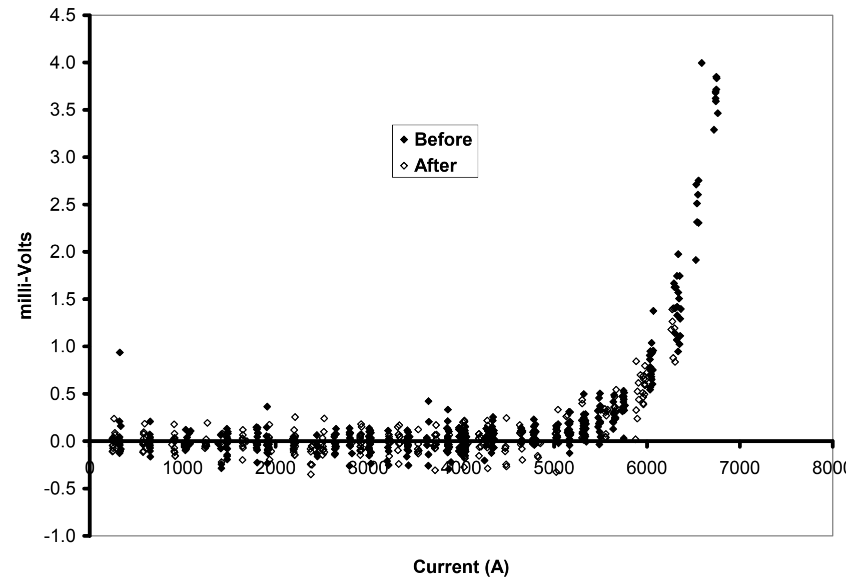
Phase 1 V-I characteristics did not change from application of overcurrent (fault)

- As measured data that includes the resistance of the copper block where the voltage taps were attached.



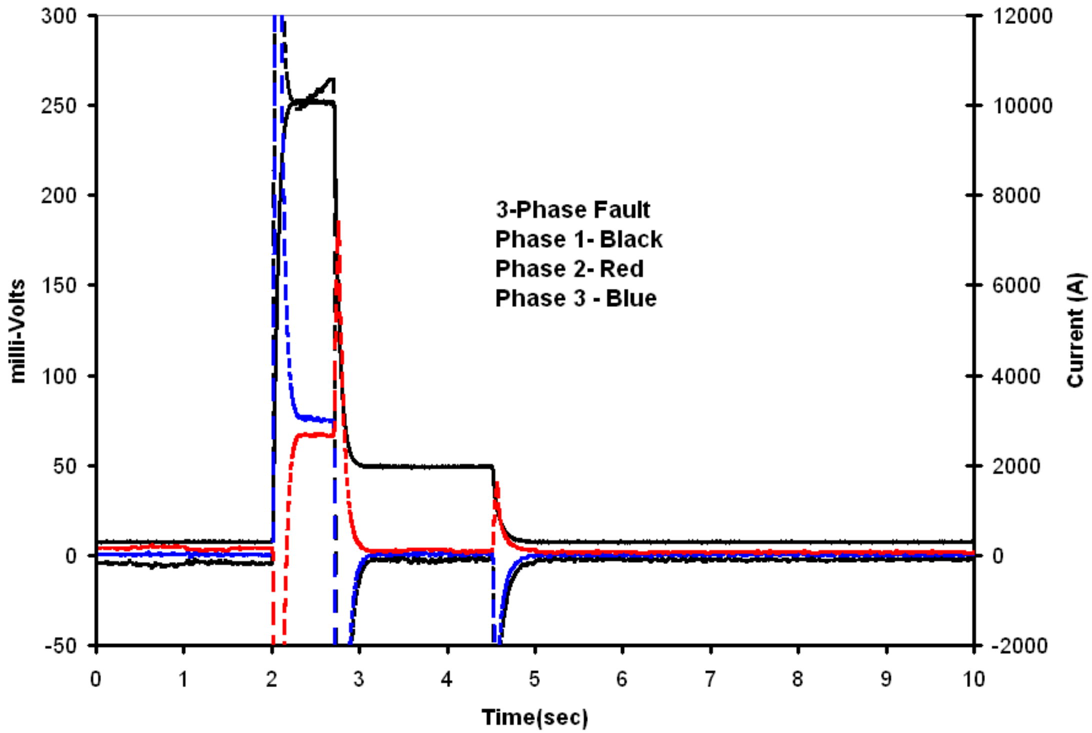
- After correcting for resistance.
- I_c unchanged after pulse.



- Similar data for phases 2 and 3.

Measured the response of the triaxial cable to a 3-phase fault.

- Response similar to individual phases.
- All phases remained superconducting.
- 10 kA for 0.7 sec is same requirement as Bixby 56 kA.
- Similar current to F4 fault (10 kA_{rms}).



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Presentation Outline

- Introduction (David Lindsay, Southwire)
  - Overall SPI Goals & Objectives
  - Design Approach
  - Review FY 2005 Milestones
- FY 2005 Results
  - 30-m Cable Operation and Testing (David Lindsay, Southwire)
  - AEP project scope & tech requirements
  - Cable Research at ORNL (Jonathan Demko, ORNL)
  - Cryogenic Dielectrics Research (Isidor Sauers, ORNL)
- FY 2005 Performance
- Planned FY 2006 & FY 2007 Milestones
- Program risk mitigation strategy
- Research Integration
- Summary

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High voltage and dielectrics tests were conducted to validate the design and minimize risk.

- **Composite cylinders and disks**
- **Axicom bushing**
- **Half scale termination model**
- **Full scale termination model**
- **5-m cable system tests**
  - **Triax Cable + Termination <u>Qualification Tests</u>**
    - **AC withstand**
    - **PD measurements**
    - **Impulse**
  - **Extended Test Program**
    - **Bend cable 90°**
    - **Repeat test sequence (rated voltage, AC withstand, PD, BIL)**

Passed All Qualification Tests !

Half scale model of termination dielectric parts were tested prior to fabricating full size parts

TEST ASSUMPTIONS

- IEEE Standard 48-1996 for terminations:
  - PD < 5 pC at 1.2 x 13 kV = 15.6 kV
  - Or PD extinction: 13 kV_{rms}
- AEP to be 7.6 kV_{rms} phase to ground
- Tested in HV cryostat in LN2 up to 6 Bar pressure
- Full scale should increase margin of safety

Conclusions

- Half scale provides validation of design
- Suggests that full scale will meet HV requirements

RESULTS

- PD inception exceeded 7.6 kV phase to ground.
- PD onset increased with N2 gas pressure
  - 6 bar N2 gas:
    - 11 kV_{rms} onset;
    - 7.5-8 kV_{rms} ext.
  - 6 bar LN2:
    - 10 kV_{rms} onset;
    - 8.5 kV_{rms} ext.
- Surface flashover occurred at 50 kV_{rms}

Full scale termination tested with Axicom bushing

- Full scale model too large for cryostat
- Initial testing in ambient air at room temperature
  - Tests were also made with the full scale model bagged with SF_6.
  - SF_6 has 3x strength of N_2 so that this test is equivalent to 3 bar air
  - Provides intermediate test between 1 bar N_2 and LN_2
- Full scale model withstood 10+/10- shots at 115 kV BIL
- PD inception reached 20 kV_{rms} with SF_6 (or 3 bar nitrogen equivalent)
  - Exceeds IEEE requirement of 15.6 kV_{rms}
  - Background < 5pC
- PD extinction same as inception

CONCLUSIONS

- Full scale termination passes IEEE requirement for PD inception/extinction and BIL

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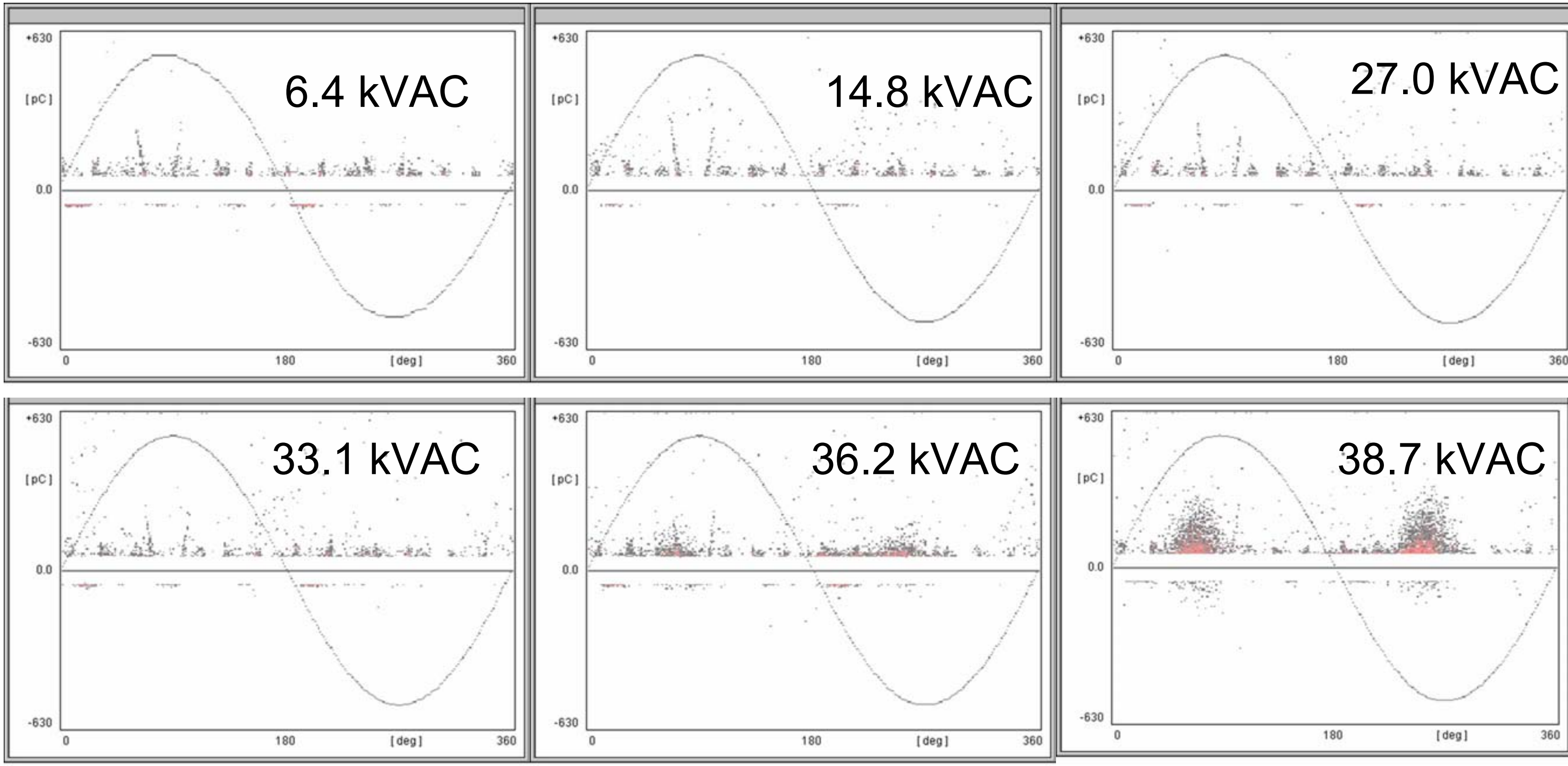
Partial Discharge vs Voltage on Phase 1 (straight)



Background noise at lower voltages (<33 kV)

Inception starts here

Increased PD

CONCLUSIONS

- **PD inception >33.1 kVrms**
- **PD <100 pC at 36.2 kVrms**

BIL test sequence conducted on each phase exceeds requirements.

	Phase tested in order of test	Insulation tested		
Before bend		P1-P2	P2-P3	P3-GND
	P1	5+/5-	0	0
	P2	5+/5-	5+/5-	0
	P3	0	5+/5-	5+/5-

Extended Test Program

After bend	P1	5+/5-	0	0
	P2	5-/3+ BD	5-/3+ no BD	0
	P3	0	5+/5-	5+/5-
	Total shots	38	38	20
Requirement		10+/10-	10+/10-	10+/10-

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Triax HTS cable successfully passed the required high voltage tests.

- **Required Testing**
  - Passed HV withstand at operating voltage
  - Passed PD inception >15 kVrms
  - Passed BIL all three phases before bending

- **Extended Testing**
  - Bend Cable 90°
  - Passed HV withstand
  - Passed PD inception >15 kVrms
  - Passed BIL on Phase 1 and 3
  - Failed BIL on 9th shot on phase 2 due to aging after basic IEEE requirement had been met.
    - Breakdown between phases 1 and 2
    - Phase 1-2 insulation experienced 38 shots at 110 kV
    - Bending particularly severe since terminations were attached
    - Still operated at rated voltage – LN fills void created by breakdown
    - Dissection underway to locate failure. Analysis results fed back into design.

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ORNL FY 2005 Performance

FY 2005 Plan

- Assemble and test full scale terminations for 3 kA 5-meter cable prototype.
- Fault current and bend testing of 3-meter triaxial cable.
- Finalize design of cryogenic system.
- Bend test of 5-meter triaxial cable.
- Splice test of 5-meter triaxial cable.

FY 2005 Performance

✓ Testing successfully completed at the end of May.

✓ Fault current and bend testing conducted at nkt

✓ Cable cryogenic system design is complete (Praxair).

✓ Testing successfully completed at the end of May.

➢ Splice design is completed. Test is planned.

ORNL FY 2005 Performance

FY 2005 Plan

- Continue operation of system with required PM and system management. Re-test dc-I_c of cables.
- Begin construction of triaxial cables for AEP project.
- Mechanical verification test of cryostat/cable assembly.
- Begin civil/electrical work at Bixby site.

FY 2005 Performance

✓Over 30,000 hours of operation

✓Critical current measurements show robust superconductor

✓Unattended operation (since 6/01)

✓Cables for AEP project have been started.

✓50-meter cryostat underwent pull testing through actual duct bank

- Responding to issues such as pulling forces, vacuum insulation, and cable installation.

✓Design is complete. Construction to begin this fall.

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ORNL FY 2005 Additional Tasks

FY 2005 Plan

- Tested 1- to 3-m cables to evaluate conductor architecture and minimize ac loss
- Participated in SPI Readiness Review
- Participated in HAZOP review of cryogenic system.

FY 2005 Performance

✓ Measured cables made with multiple HTS tape designs qualify design & performance.

✓ Mitigation plans have been prepared that address the issues identified by the Readiness Review Team.

✓ Issues that were identified are being addressed. No critical problems were identified.

Southwire/ORNL FY 2006 Plans
Oct. 1, 2005 to Sept. 30, 2006

- SPI-1: 30-m Installation, Carrollton, GA
  - Disposition of system – Southwire will continue operation.
- SPI-2: Bixby Substation, AEP, Columbus, OH
  - 1Q,FY2006 (Oct-Dec 2005)
    - Begin on-site installation of equipment.
    - Complete cable factory testing & ship to Bixby station.
    - Continued civil/electrical work at Bixby site.
    - Begin installation of cryostat and cable
  - 2Q,FY2006 (Jan-Mar 2006)
    - Complete cable & cryostat installation
    - Termination & splice assembly
    - Check-out and run-in of cryogenics system
  - 3Q,FY2006 (Apr-Jun 2006)
    - Finalize all installation items.
    - In-field testing completed
    - Operational control coordinated with AEP
    - Energize System
  - 4Q,FY2006 (Jul-Sept 2006) and FY2007
    - Operate system

Risk mitigation measures: HTS Cable

- Risk mitigation strategy is to address risks by incremental R&D steps on models and test cables:
  - Material tests on small scale samples and on scaled model components
  - System tests on full radial scale, short-length components (1-5 m HTS cables, full-scale terminations at ORNL).
  - System tests on full radial scale, moderate-length components (30-m HTS cables at Southwire).
  - Multi-year utility demonstrations with cables of length 100's of meters
  - Cryostat pull tests conducted using actual cable ducts.
- Conduct tough, comprehensive design reviews
  - SPI Readiness Review (Webex) October 2004
  - SPI readiness review in June 2005.
  - Conducted HAZOP analysis of cryogenic system with Praxair in January 2005.

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Risk mitigation measures: HTS Cable

- **Risk mitigation strategy**
  - **Assembly:**
    - **Do stringent 300 K leak testing on individual components to minimize global leak rate while cold.**
    - **Extreme care in assembly so as not to introduce shorts or continuous current loops.**
    - **Cleanliness, material control to reduce out-gassing and contamination.**
  - **Testing:**
    - **Develop test plans up-front to ensure sufficient data for successful demonstration and for relevant standards development.**
    - **Proceed from lower risk to higher risk testing.**
    - **Key sensors are interlocked for operator warning and then automatic actions for component protection and continuity of power.**

Research Integration - Partnerships

- **Project is being conducted as a DOE SPI with equal cost sharing by Ultera and DOE. Ultera expertise includes:**
  - **Wire and cable manufacturing,**
  - **Established utility customer base,**
  - **Design and installation of turn-key systems for utilities,**
  - **Design and construction of copper rod mills world-wide,**
  - **Design and construction of manufacturing plants,**
  - **Cold dielectric design developed by Southwire (successful 30-m demo)**
  - **Warm dielectric design developed by nktc (successful 30-m demonstration in Copenhagen, Denmark)**

And now:

- **Design, installation & operation of superconducting cables for utility customers.**

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Research Integration - Partnerships

- FY 2005 progress is evidence of well functioning team.
  - Triax cable research conducted on 5-m system jointly with Southwire/*nkt* at ORNL.
  - Multiple short, 1- to 3-m cables fabricated by Southwire tested at ORNL and *nkt*.
  - PRAXAIR and AMSC brought on to the team.
- Ultera and ORNL exchange technical information and data regularly
  - Teleconferences & Videoconferences
  - Interactive web conferencing
  - personnel exchanges
  - 30-m cable operation and testing at Southwire.
  - site visits and technical meetings

Research Integration - Expertise and Facilities

- **Efficient use of equipment and personnel between ORNL/Ultera.**
  - Assembly of 30-m cables has involved a team of ORNL, Southwire and subcontracted technicians.
  - Shared use of SW ac power supply, ORNL dc power supply, SW PD detector, fault current testing to over 56 kA in Denmark.
- **Technical capability is being established in industry by subcontracting for subsystems and components.**
  - Cryogenic system partnership was formed with Praxair (U.S. industry).
  - Components for terminations were manufactured by U.S. industry resulting from competitive request for quotations.
  - Several key consultants have provided technical expertise and analysis.

Research Integration – Publications and Outreach

- **Presentations and publications during the year**
  - **Four technical papers were presented at the 2004 ASC and published in the *IEEE Transactions on Applied Superconductivity, Vol. 15, No. 2, June 2005***
  - **One paper was presented at the International Conference on Electricity Distribution (CIRED) in June 2005.**
  - **One paper will be presented at the Cryogenic Engineering Conference in August 2005 and will be submitted for publication in the, *Advances in Cryogenic Engineering*.**
- **Web Sites**
  - **ORNL Superconductivity Web Site includes Annual Reports, Peer Review presentations and other project information**
    - **www.ornl.gov/HTSC/htsc.html**
  - **Southwire and Ultera Web Sites includes press releases and project information**
    - **www.southwire.com, www.ultera.net, www.supercables.com**

Thank You !