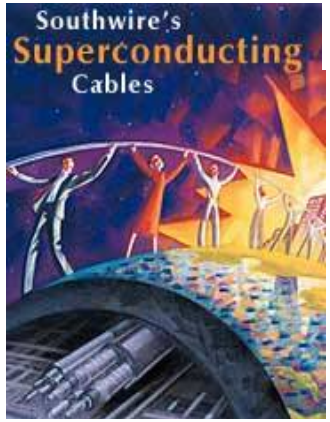

High Temperature Superconducting Cable

2006 Annual Peer Review

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

July 25-27, 2006
Washington, DC

Southwire
WE DELIVER POWER

AEP

Ultera™
A Southwire / nkt cables Joint Venture

PRAXAIR

nkt cables

American Superconductor™

OAK RIDGE
National Laboratory

Presentation Outline

- Introduction (David Lindsay, Southwire)
  - Overall SPI Goals & Objectives
  - Design Approach
  - Review FY 2006 Milestones
- FY 2006 Results
  - AEP project
    - Overview
    - Cryogenics
    - Cable & cryostat pulling, splicing, terminations
    - Testing: DC current to 6 kA, VLF to 20 kV, Soak at 13 kV
  - Cable/Term. Research & Testing at ORNL (Jonathan Demko, ORNL)
    - Cable thermal-hydraulics
  - Cryogenic Dielectrics Research (Isidor Sauers, ORNL)
- FY 2006 Performance
- Planned FY 2007 Milestones
- Program risk mitigation strategy
- Research Integration
- Summary

AEP Project Partners

Partner		***Area of Responsibility/Expertise***
Southwire/nktc/Ultera	Ultera™ A Southwire / nkt cables Joint Venture	**Cable design, manufacturing, termination design, installation, cryo system design, systems integration, O&M, project management**
AEP	AEP®	**Installation site engineering, site civil & electrical construction, commissioning, monitoring, O&M**
ORNL	ornl	**Cable research, termination research, testing, cryo design**
Praxair	PRAXAIR	**Cryogenics system design, construction, operations & service**
AMSC	American Superconductor™	**HTS tape supplier**

Oak Ridge National Laboratory American Superconductor™ AEP® PRAXAIR Ultera™ A Southwire / nkt cables Joint Venture

Project Participants

- **Southwire/Ultera**
  - John Armstrong
  - Randy Denmon
  - Terry Dyer
  - Mark McCulaugh
  - Norbert Lisson
  - David Lindsay
  - Jimmy Barr
  - 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
  - Stanley Wilson
  - Jay Ingam
  - David Browning
- **Oak Ridge National Laboratory**
  - Jonathan Demko
  - Robert Duckworth
  - Alvin Ellis
  - Paul Fisher
  - Mike Gouge
  - Randy James
  - Marshall Pace
  - Chris Rey
  - Isidor Sauers
  - Bill Schwenterly
  - Dennis Sparks
  - Enis Tuncer
- **Praxair (PX)**
  - John Royal
  - Rick Fitzgerald
  - Nancy Lynch
  - Barry Minbiole
  - Maurice VanCleave
- **AMSC**
  - Larry Masur
  - Angelo Santamaria

SPI Project Goals & Objectives:

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

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 *prototyped 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 cable 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 2006 Plans
Oct. 1, 2005 to Sept. 30, 2006

- **SPI-2: Bixby Substation, AEP, Columbus, OH**
  - **1Q,FY2006 (Oct-Dec 2005)**
    - **Begin on-site installation of equipment. - COMPLETE**
    - **Complete cable factory testing & ship to Bixby station. - COMPLETE**
    - **Continued civil/electrical work at Bixby site. - COMPLETE**
    - **Begin installation of cryostat and cable - COMPLETE**
  - **2Q,FY2006 (Jan-Mar 2006)**
    - **Complete cable & cryostat installation - COMPLETE**
    - **Termination & splice assembly - COMPLETE**
    - **Check-out and run-in of cryogenics system - COMPLETE**
  - **3Q,FY2006 (Apr-Jun 2006)**
    - **Finalize all installation items. - COMPLETE**
    - **In-field testing completed – COMPLETE IN JULY**
    - **Operational control coordinated with AEP – COMPLETE IN JULY**
    - **Energize System – COMPLETED JULY WITH VOLTAGE SOAK**
  - **4Q,FY2006 (Jul-Sept 2006) and FY2007**
    - **Operate system – INSERVICE DATE 8/1/2006**

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Project transformer delayed due to emergency replacement needs of AEP

nbc4i.com - News - Thousands Without Electricity After Explosion At Power Station - Mozilla Firefox

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Thousands Without Electricity After Explosion At Power Station

Homes Evacuated, Schools Closed

POSTED: 6:32 am EST November 28, 2005
UPDATED: 7:41 pm EST November 28, 2005

COLUMBUS, Ohio -- American Electric Power officials said they anticipate all customers to have fully restored electricity by 5 a.m. Tuesday after a substation exploded Monday morning, leaving at least 35,000 customers on the city's north side without power.

Chopper 4

The explosion was reported at about 5:20 a.m. at the substation, located along Karl and Norma roads, **NBC 4**'s Kyle Anderson reported.

NBC 4 Team Coverage
SLIDESHOWS: Images From Scene | Chopper 4 Images
LIVE: Traffic Cameras/Road Conditions

A vortex of bright orange, swirling flames and thick black smoke could be seen for miles.

A toxic smoke poured across Karl Road and blanketed neighborhoods for blocks. As the sun rose, the intensity of the smoke became clearer, forcing fire officials to evacuate six homes in the area.

"We told everybody else to just basically stay inside until we could determine exactly what was burning," said Columbus fire battalion Chief Doug Smith.

Two of three transformers at the substation were burning, Anderson reported.

For a while, the fire was out of control.

Firefighters could not extinguish the blaze with water because of the electricity. Instead, they had to use barrels of solvent and mix them with water to make foam.

"Each one of those transformers contained about 6,000 gallons of petroleum and that was our problem this morning – we didn't have enough foam on the scene to put the fire out," Smith said.

Marketplace
NBC 4 TODAY/COLUMBUS BRIDE VIEWER'S CHOICE
Find Out Who Won
CHILDREN'S HOSPITAL
Sign up for Health e-hints newsletter
NEW NBC 4 EXPERTS
J&D Basement Systems
More Categories:
Olympic Viewing Party Sweepstakes
Win Tickets to the Boat & RV Show
Win a Fresh Look Friday Monthly Makeover!
Back To School Learning Tips from Dr. Rick
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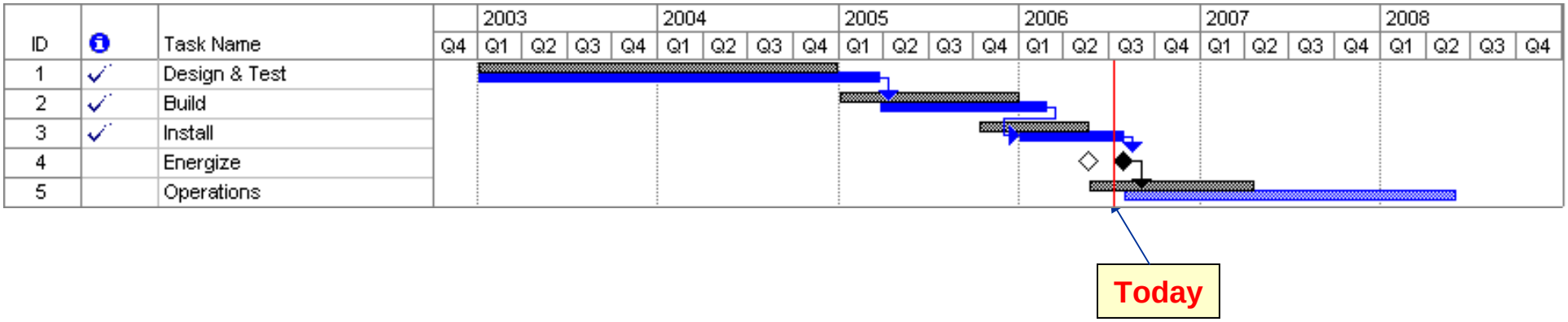
AEP-Southwire Project Timeline

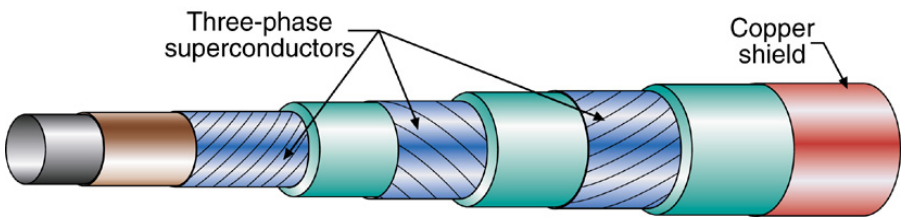


Project Status:

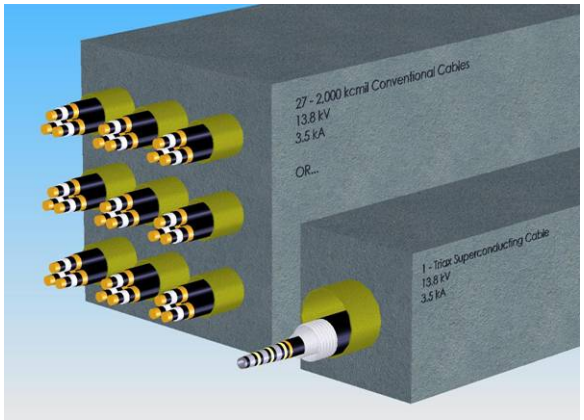
- Design & Qualification tests ran longer than expected
- Delay due to transformer delivery issue.
- Overall – project still on schedule to energize summer of 2006.

Triaxial HTS cable design offers many benefits.

Bixby System
3-Phase, Triax Design



Comparison with conventional cables for same capacity.



- **Features of the tri-axial cold dielectric HTS cable**
  - **Highest current density design.**
    - **Transmission voltage level power delivered at distribution voltage level.**
    - **Cable + Termination designed for 3000 A_{rms} to meet AEP project requirement.**
  - **Potential to reduce the required HTS tape by ~1/2 (no shield required for each phase). Lowers the cost.**
  - **Potential to reduce heat loads by ~1/2 (single cryostat). Lowers the cost.**
  - **Flexible cable to allow reeling.**

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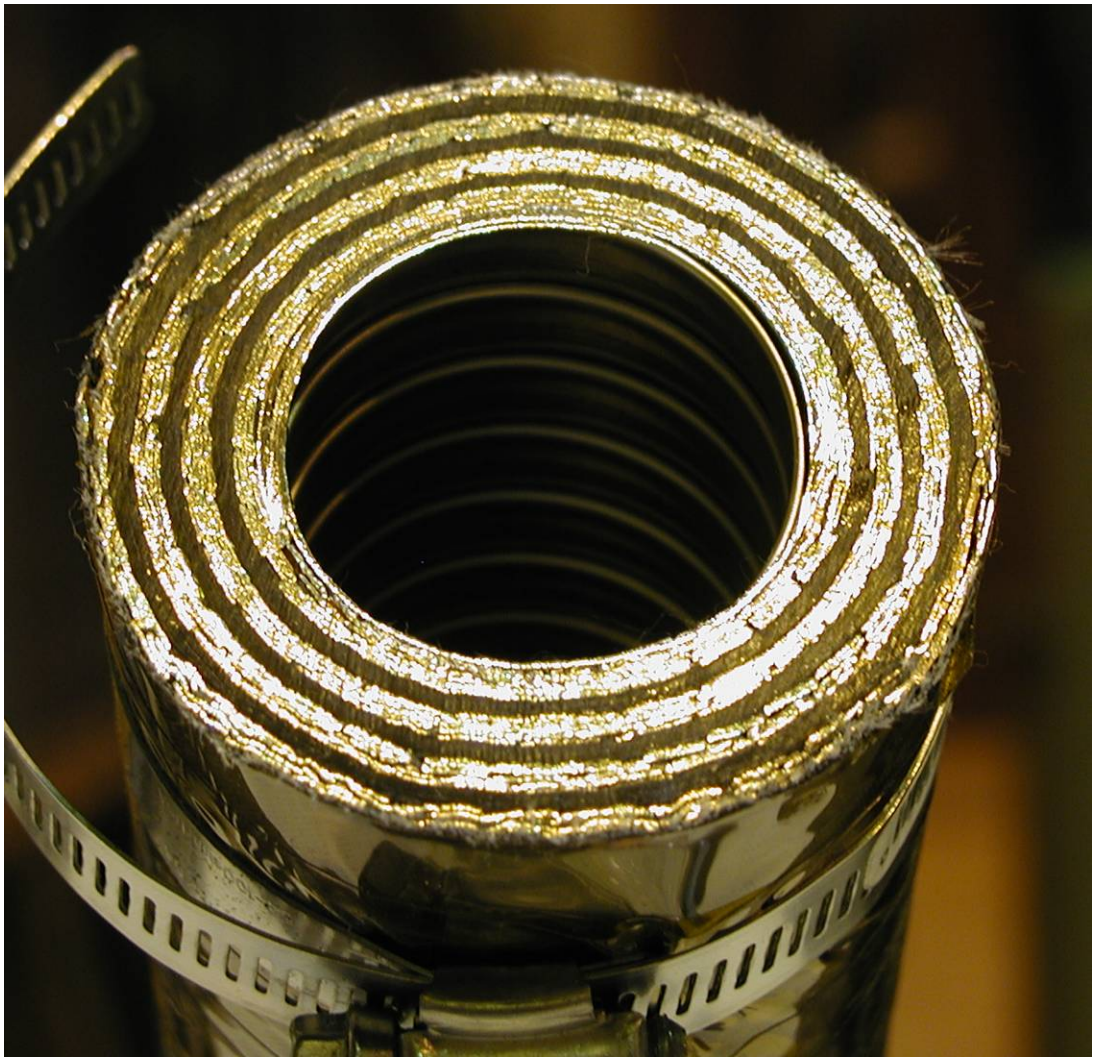
HTS Triax Cable Capable of Carrying 3000 A was Manufactured by Ultera



‘AEP Project’

U.S. Department of Energy
SPI Phase-III

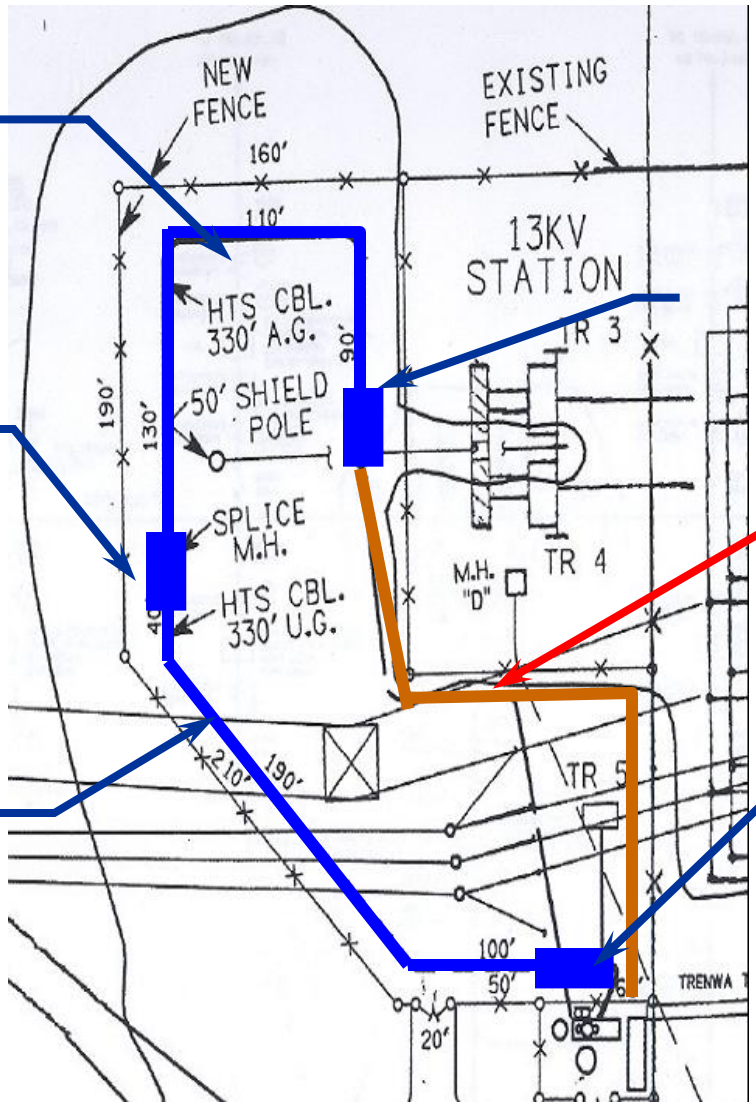
- **Utility Partner = American Electric Power**
- **Location = Bixby Substation, Columbus, OH**
- **Length = 200 meters**
- **Voltage = 13.2 kV**
- **Load Rating = 3.0 kA_{rms} AC / 69 MVA**
- **Fault Current Peak = ~57 kA asymmetric**
- **Cable Design = Triax**
- **Other Features = Splice**
  Underground
  Multiple 90° Bends
- **Energize mid-2006**

AEP Site Layout

Triaxial HTS above ground cable section

Manhole with splice

Triaxial HTS underground cable section

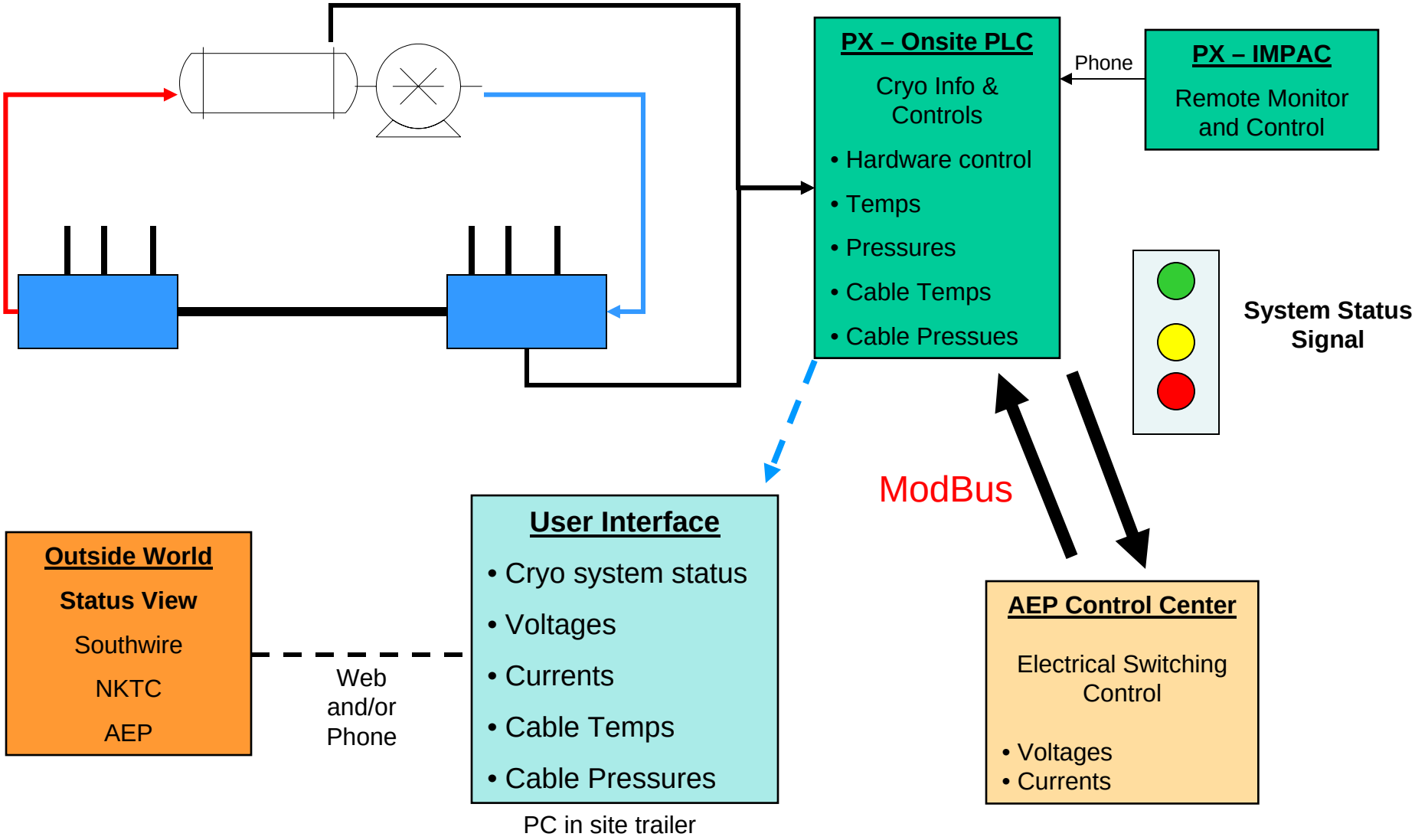


Termination

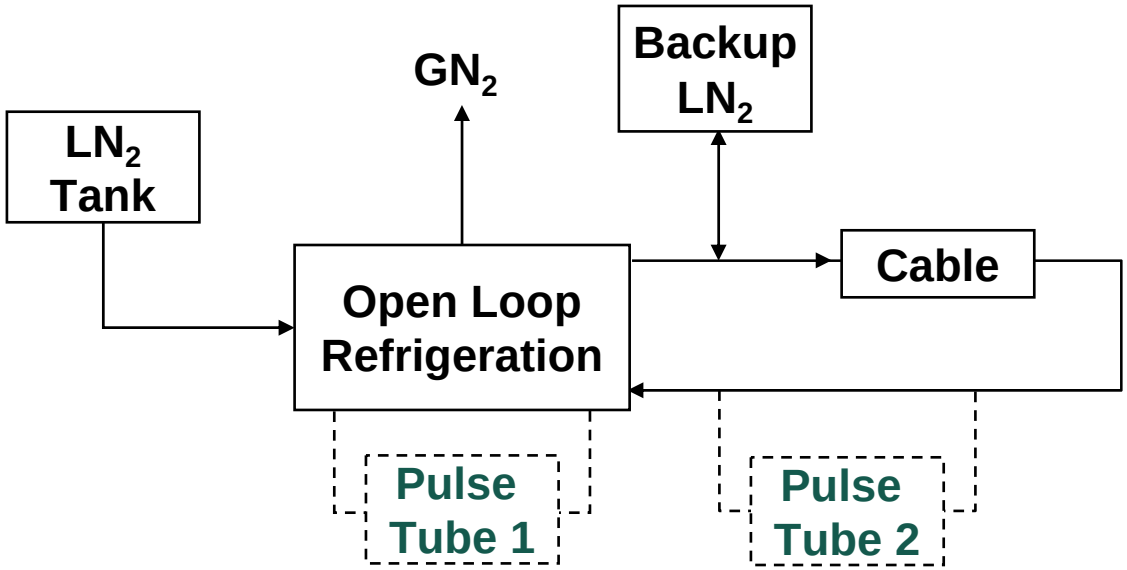
Liquid Nitrogen Return

Termination

System Operational Monitoring and Controls



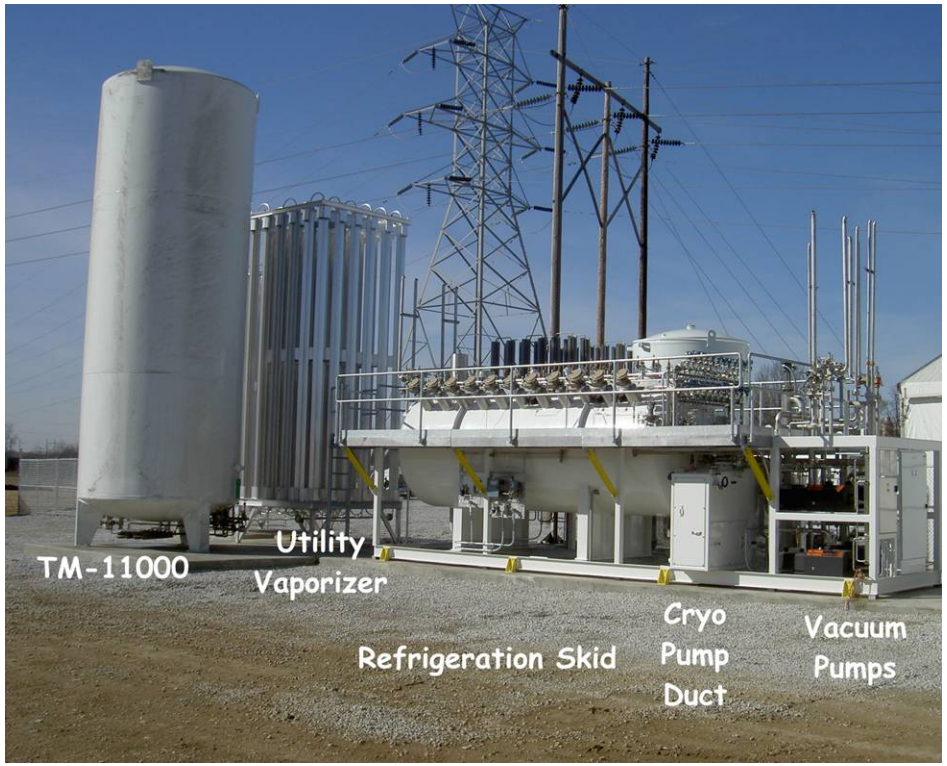
HTS Cable Demonstration
Cryogenic System Overview Integration



The Bixby Cryogenic System

- **Operation**
  - **Two separate LN2 streams**
    - **One is pressurized and moves through the cable**
    - **The second is boiled under vacuum to cool the first**
      - **Consumable**

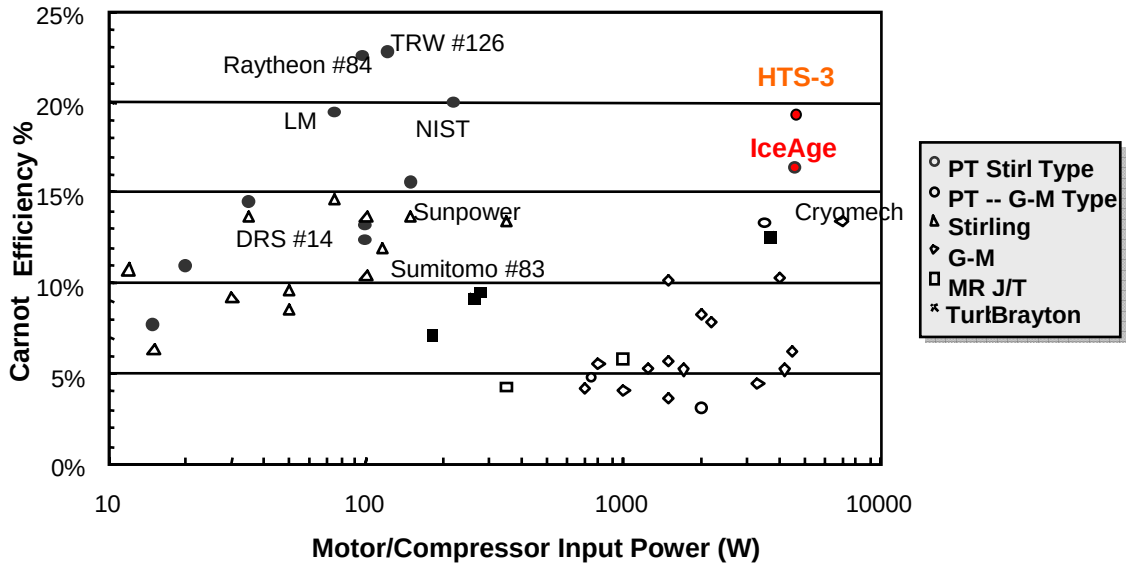
- **The System**
  - **Provides**
    - **Cable cooling**
    - **LN2 pumping services**
    - **Cool down resources**
    - **Backup system demonstrator**
    - **Contingency refrigeration**
    - **Docking sites and resources for PTRs**
  - **<u>Reliable</u>, and available in the power needed**
    - **~10 kW @ 70 K**



Very capable cryogenic resources are available at the Bixby Site

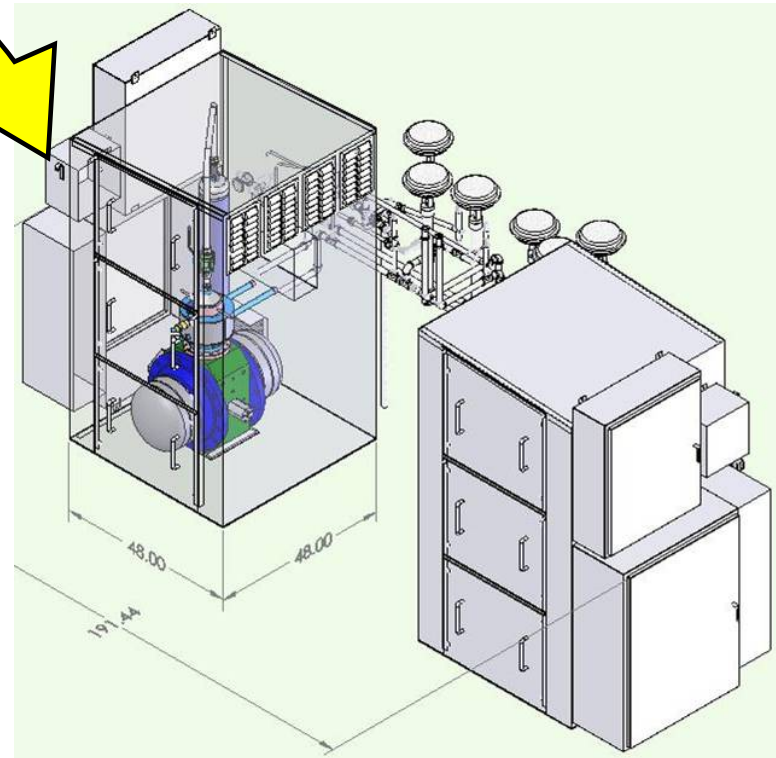
Pulse Tube Refrigeration

- Generation of large amplitude sound waves from electrical or thermal drivers
  - Direct conversion of sound waves to refrigeration without moving parts using an orifice pulse tube refrigerator (OPTR)
- Electrically driven pulse tubes have been available for ~30 years
- Pulse Tubes are very simple
  - No moving cold parts
    - Very reliable
    - Low Capital
  - Promise to be efficient
  - Environmentally unobjectionable working fluid



Pulse Tube Refrigerators promise to be efficient, compact robust and reliable

HTS-4 has about 1 kW of refrigeration at 70 K



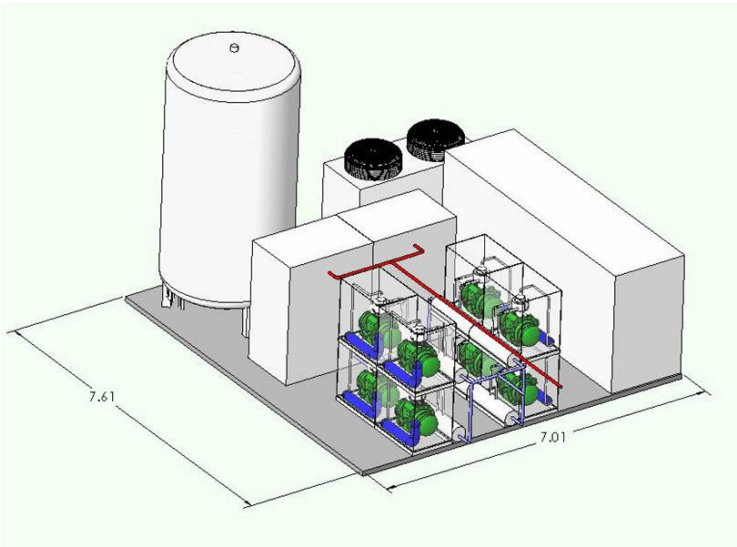
Lab Unit: ~700 W @ 65 K to date

Bixby Demonstrator: 2 x HTS-4s

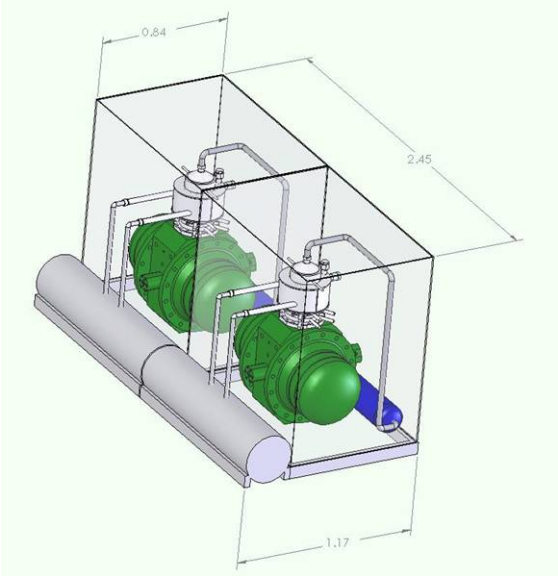
With 2 kW of cooling at 70 K

Refrigeration Systems for Commercial HTS Cable Systems

- **Terminus Stations provide:**
  - Refrigeration for terminations and portions of the cable
  - Controls and utilities for the entire refrigeration system
  - Liquid pumping services
  - Liquid reserves for the entire cable
  - Heat rejection services



- **Line stations provide**
  - Refrigeration for portions of the cable
  - Heat rejection
  - May be placed underground



- **Foot print, m^2/kW**
  - Terminus Station 5 to 7 including auxiliaries
  - Line Station 1.5

- **On-site Business Model:**
  - Refrigerators leased to Customers
  - Maintained by Praxair
  - Refrigeration is supplied 24/7
    - Contractually guaranteed
    - Uninterrupted supply is insured by reservoir of reserve liquid
  - Real time central monitoring
  - Real time data downloads to customer

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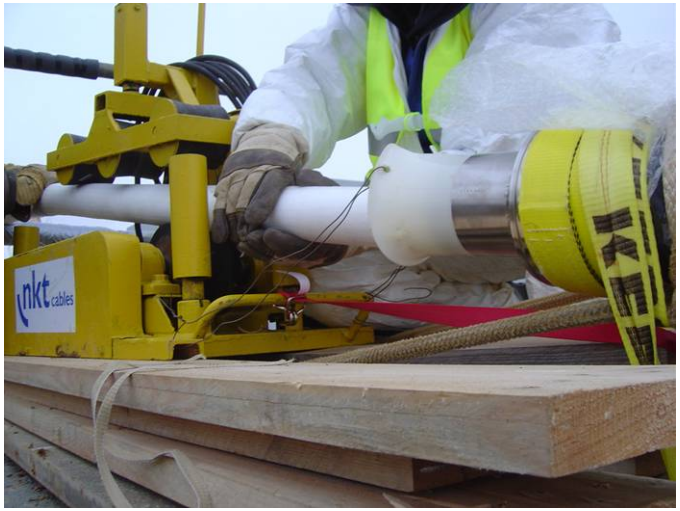
Cable & Cryostat Installation

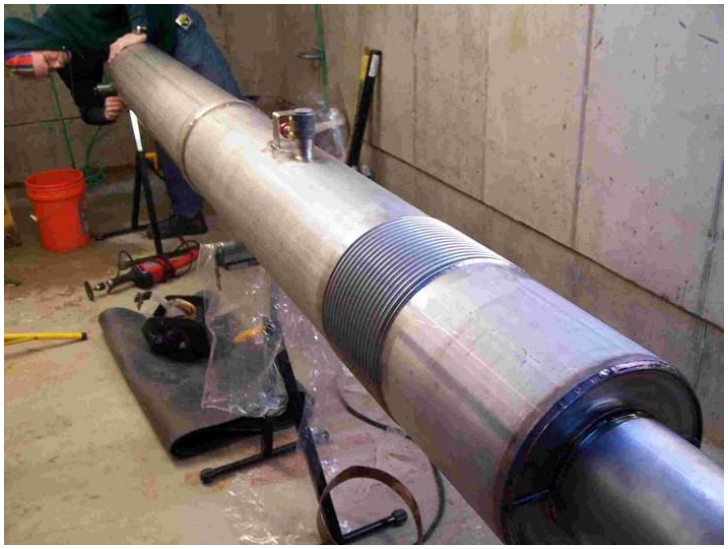
- **Southwire and nkt cables provide turn-key installation services for conventional High Voltage underground cables (69- 400 kV)**
- **Southwire and NKTC installation crews pulled cable and cryostat into duct bank.**
- **Conventional pulling and rigging equipment was utilized to install HTS cable.**
- **Pulling tensions were much reduced vs. conventional cables due to lighter weight**

Pulling Cryostat into Duct Bank February 2006

Pulling Cable Into Cryostat February 2006



Splice Assembly in Manhole February 2006.



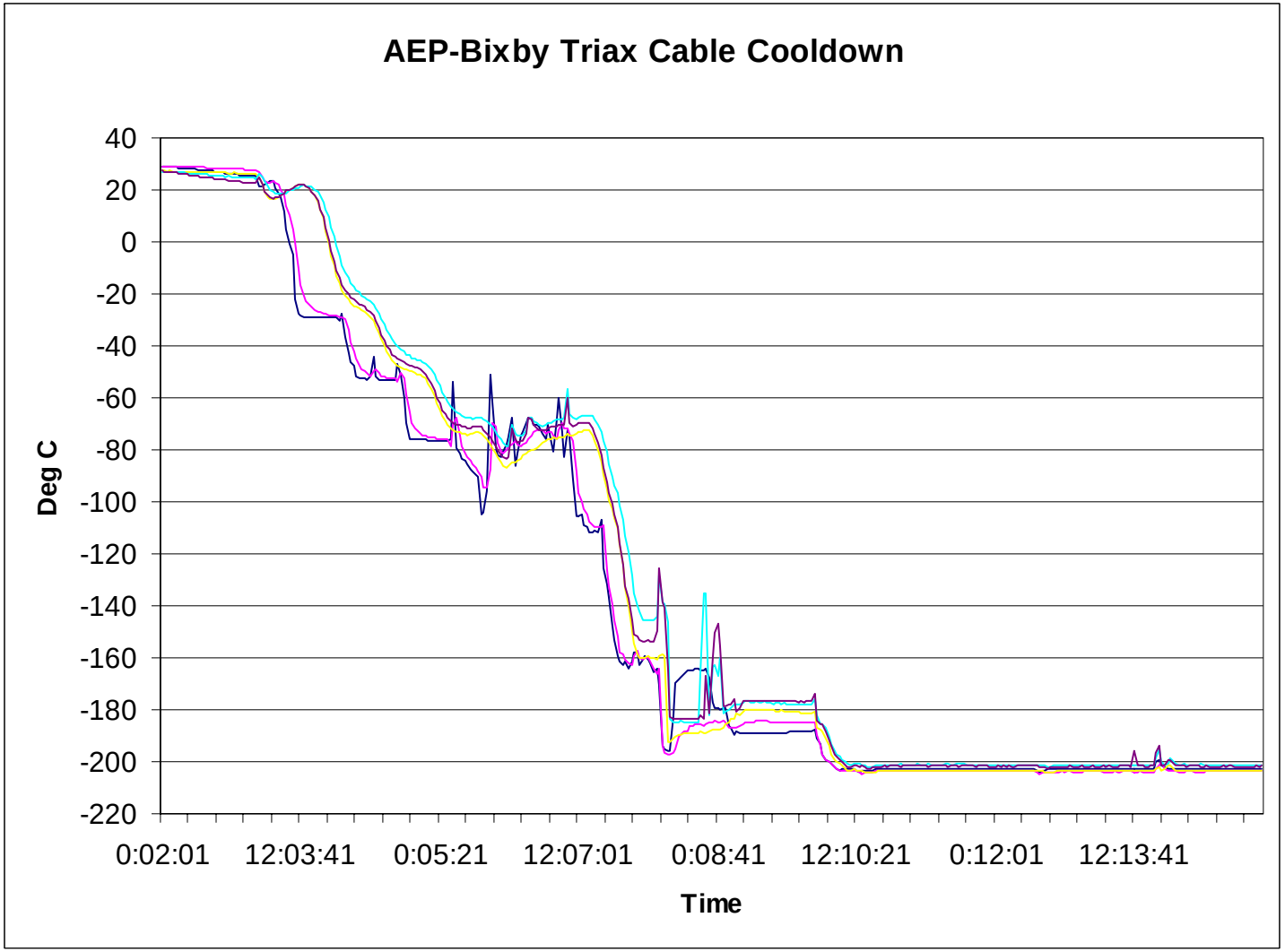
Termination Assembly Spring 2006

Transformer & Breakers

Electrical Connections Complete

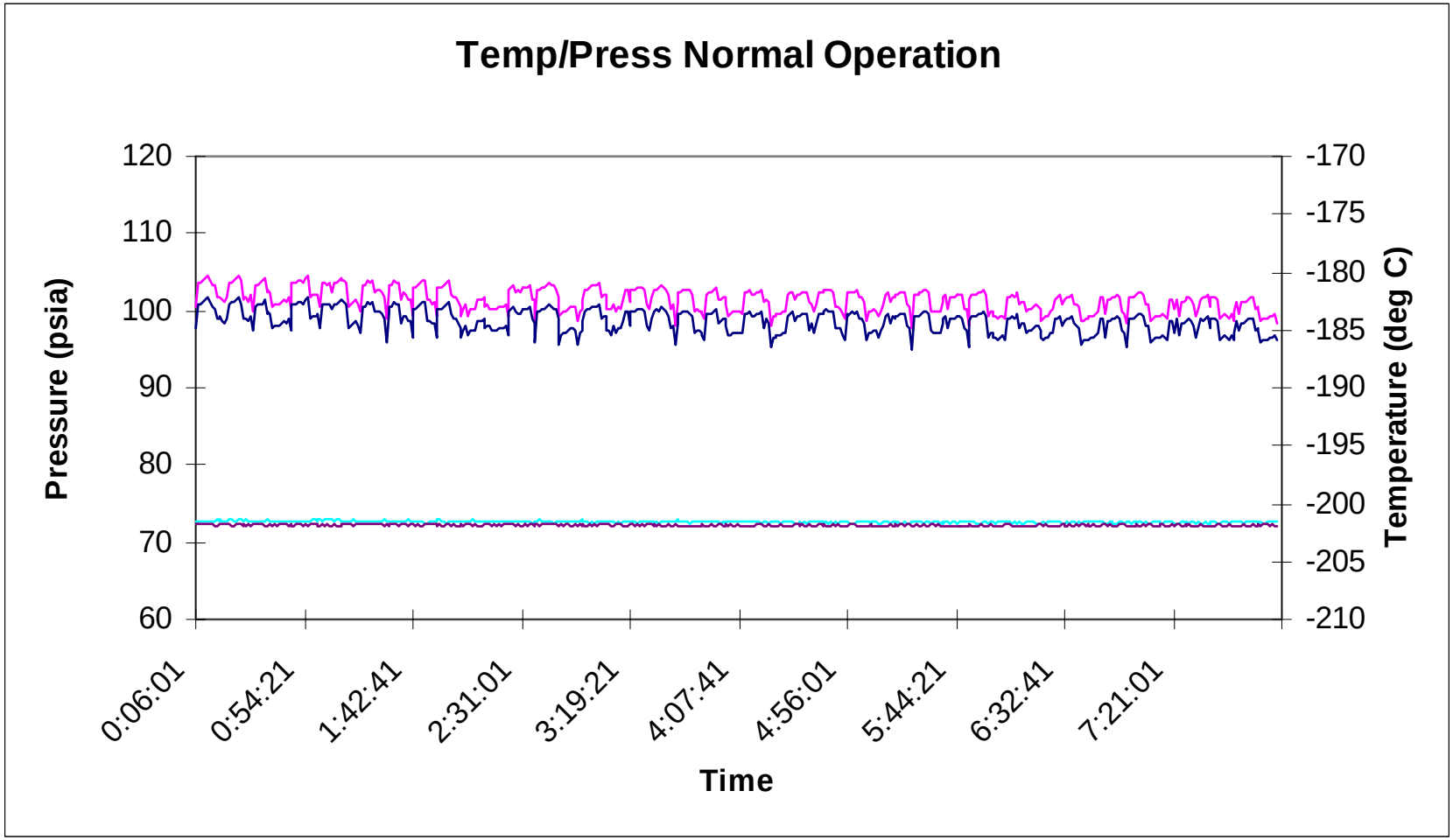
200m Cable Cool Down

6/19 – 6/21/2006



Normal Operation Cryogenics

8 hr period, 6/29/2006



Cryo/Thermal Statistics

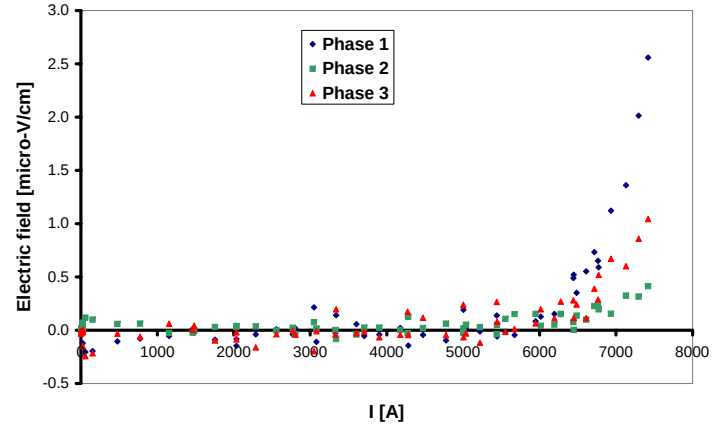
No Load Conditions:

- Cable-only ΔT = 0.4 deg C
- Cable + Termination ΔT = 1.2 deg C
- Cable run ΔP = 3 psia
- Return line ΔP = 3 psia
- **Cable + Terminations Heat Load = 1.4 kW**

DC Current Testing to 6 kA conducted June 2006.

- Each phase conductor was taken to minimum of 6 kA.
  - Experienced instability with the DC power supplies.

- DC-Ic data from 5-meter Triax prototype test indicated I_c 7 kA to 8 kA at 78.5 K.
  - Same design as 200-meter AEP cable.

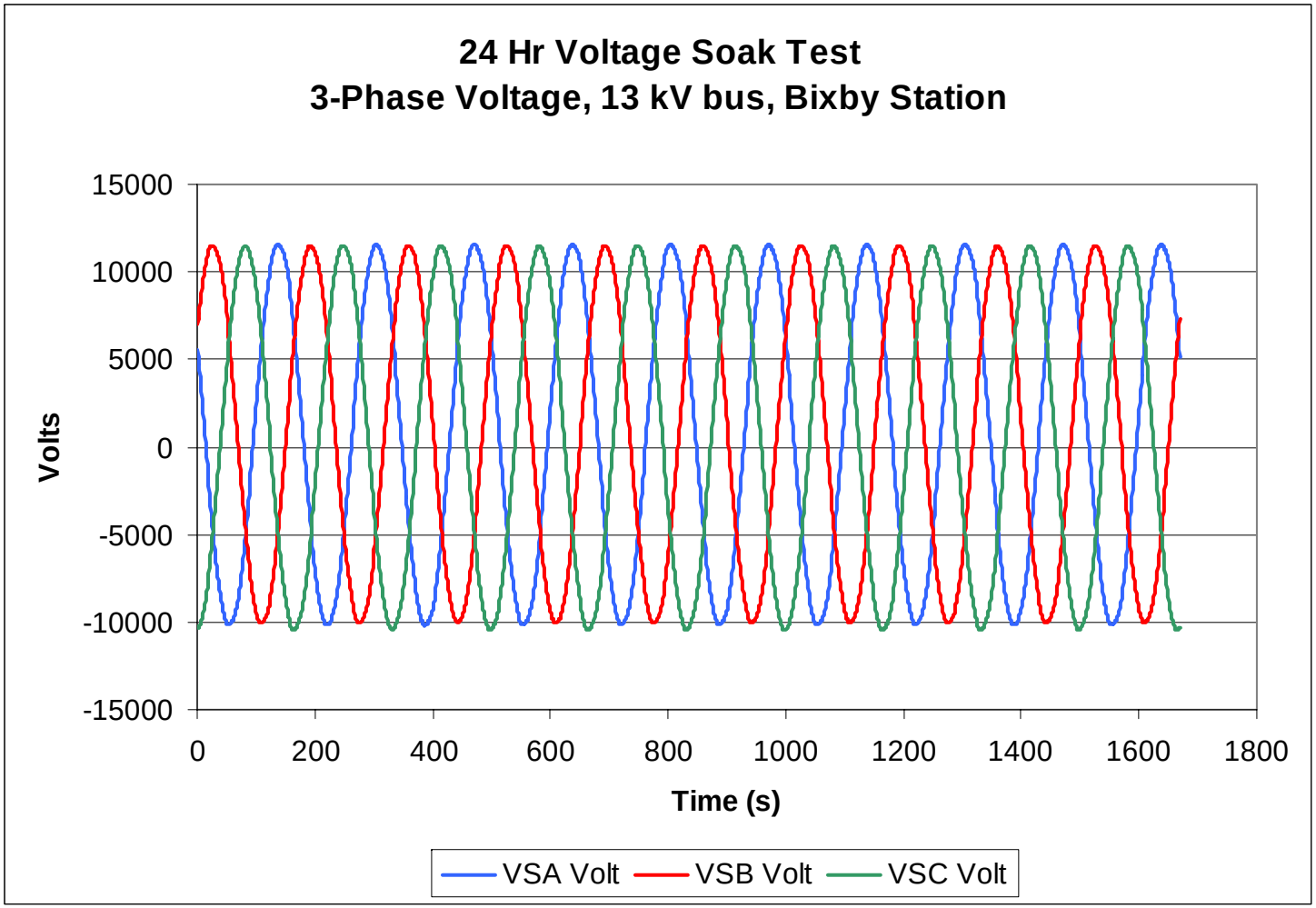


Offline Voltage Tests – VLF per IEEE 400.2

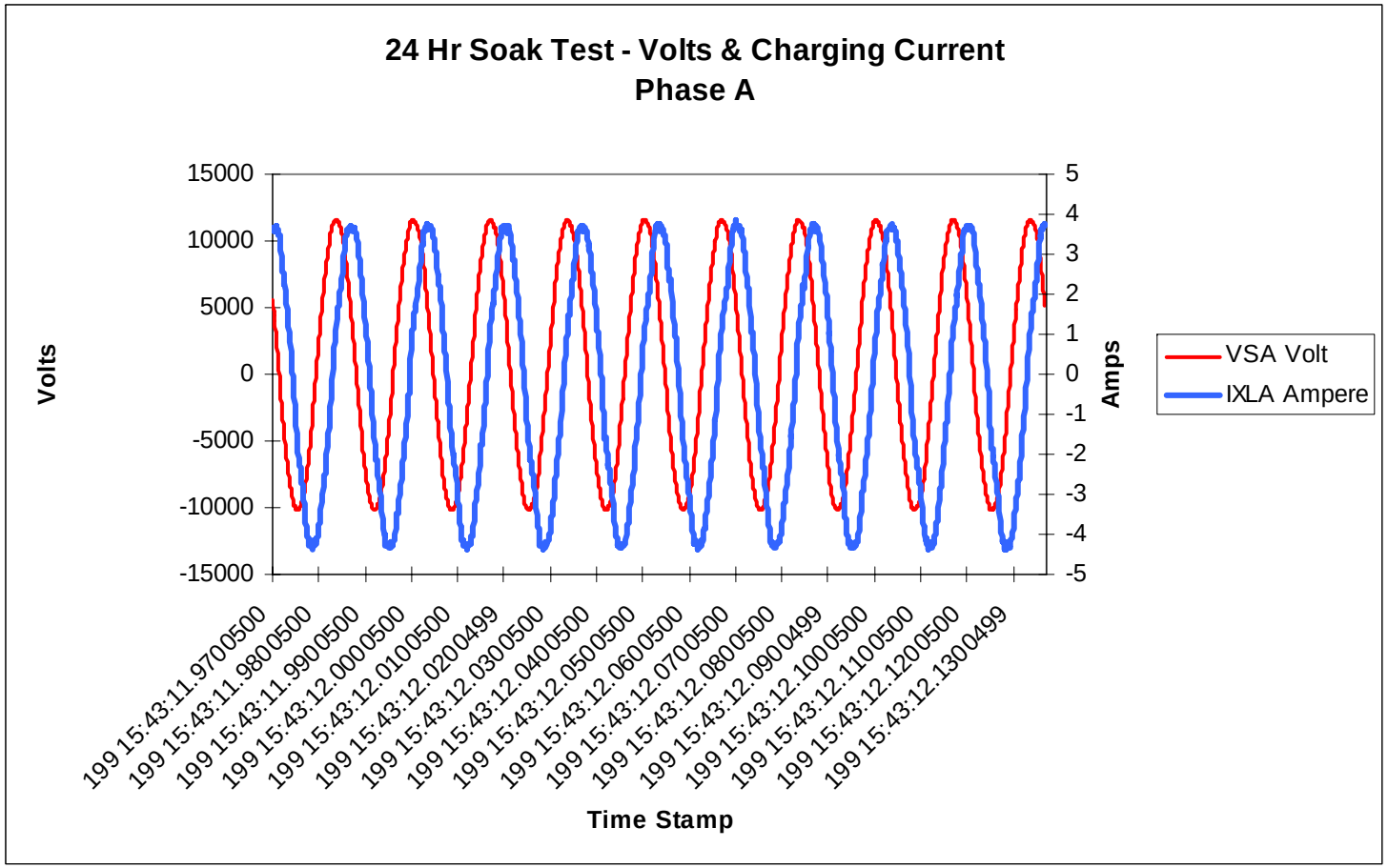
- Dielectric of each phase tested to 20 kVrms for 30 minutes. Neutral isolation to cryostat tested to 1 kV.
  - Very Low Frequency (VLF) of 0.1 Hz.
- All off-line high current and high voltage tests passed.
- Cable ready for high voltage soak.

Cable Energized with 13 kV Line Voltage Voltage Soak Test – July 18, 2006

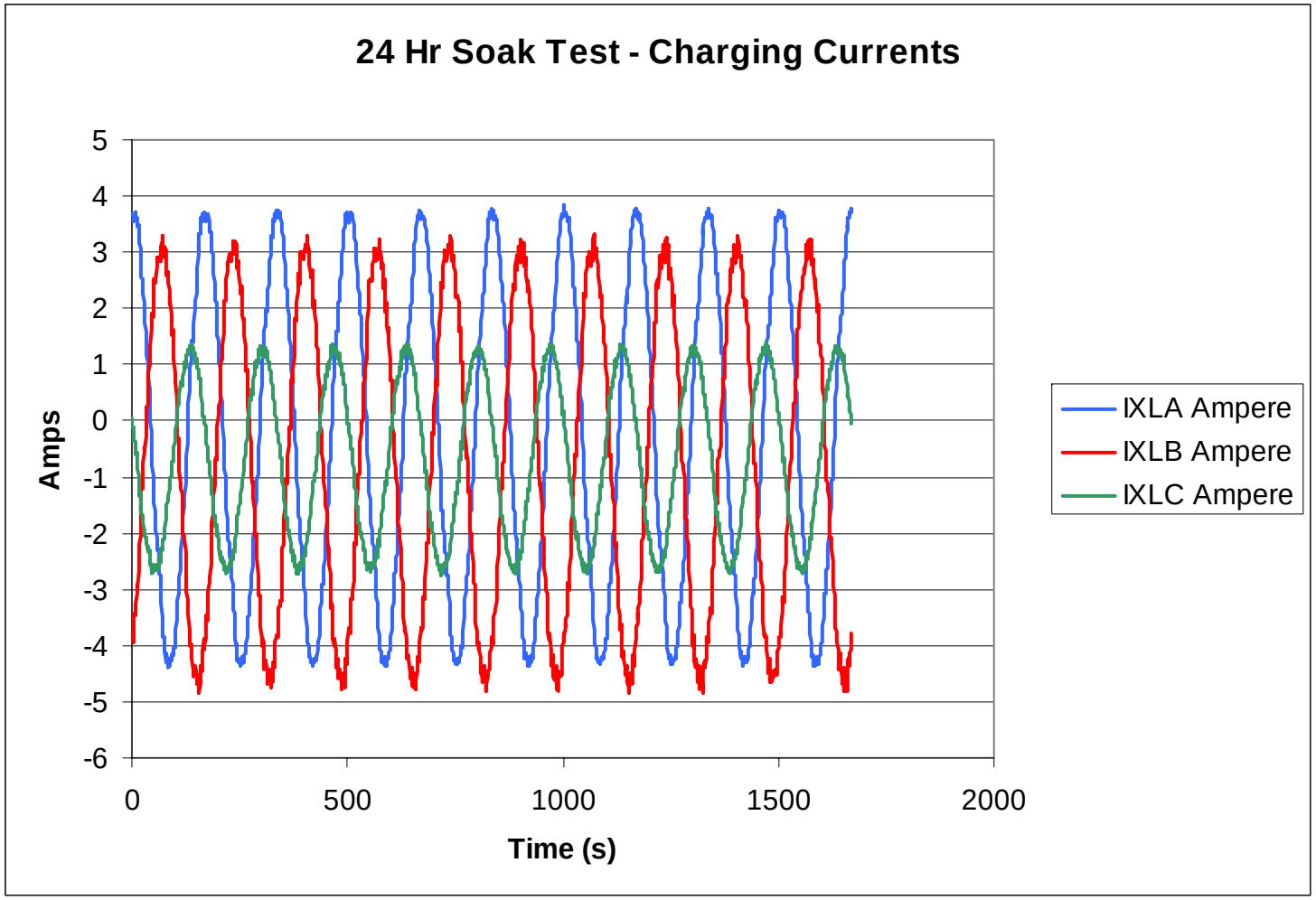
Cable Energized with 13 kV Line Voltage Voltage Soak Test – July 18, 2006



Cable Energized with 13 kV Line Voltage Voltage Soak Test – July 18, 2006



Cable Energized with 13 kV Line Voltage Voltage Soak Test – July 18, 2006



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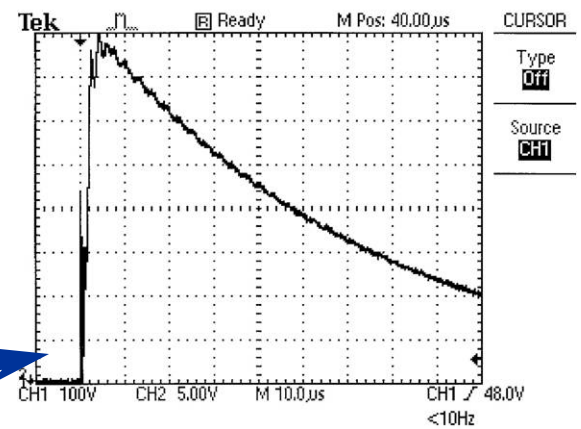
  - Design Approach
  - Review FY 2005 Milestones
- **FY 2006 Results**
  - 30-m Cable Operation and Testing (David Lindsay, Southwire)
  - AEP project scope & tech requirements
  - Cable Research at ORNL (Jonathan Demko, ORNL)
  - Cryogenic Dielectrics Research (Isidor Sauers, ORNL)
- **FY 2006 Performance**
- **Planned FY 2007 & FY 2008 Milestones**
- **Program risk mitigation strategy**
- **Research Integration**
- **Summary**

Triaxial cable AEP prototype tested at ORNL in FY 2005.

- **Data used to support analysis and design of AEP cable system.**
- **Many high voltage components re-used on AEP cable.**
  - **5-meter prototype was same design and radial build.**

Tests conducted on the AEP prototype terminations and cable (straight and bent 90°) was extensive.

- Low Voltage DC Test - PASSED
  - Measurement of V-I curves, I_c
  - Long duration hold at 3000 A in all 3 phases (straight) and 3500 A (bent)
- Low Voltage AC Test -PASSED
  - Hold at 2500 A ac and 3000 A ac
- High Voltage, Low Current -PASSED
  - Single phase hold at 7.6 kV 1 hour.
  - PD inception around 36 kV.
  - AC withstand to 34-39 kV.
  - Three phase ac voltage for 1 hour at 7.4 kV
  - Multiple BIL tests at +/- 110 kV



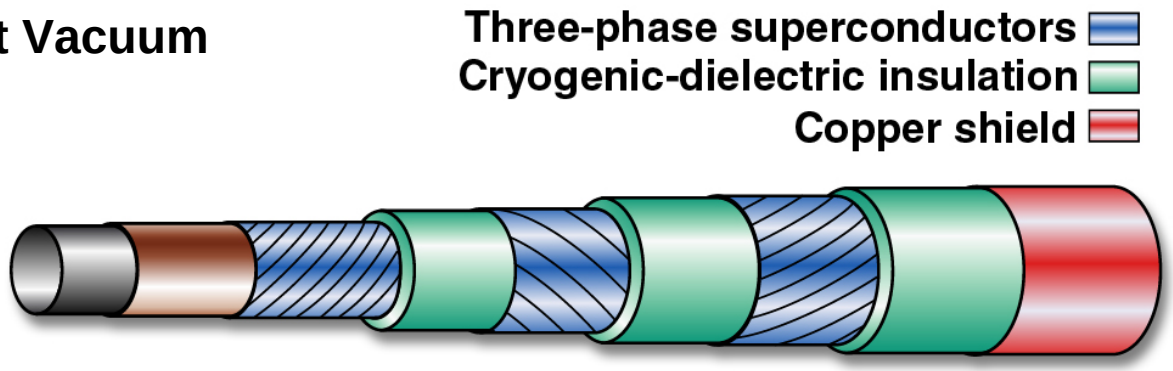
- Low Voltage Fault Current Test for single and three phases
- Cable Passed IEEE and IEC Requirements.

Cable test lab has been relocated to the new multi-program facility, and equipment has been commissioned.

- **Capabilities of new facility are expanded.**
  - **Capable of testing cables longer than 5-meters.**
  - **Capable of testing > 15 kV voltage class cables.**

Thermal hydraulics of AEP triaxial HTS cable installation has been analyzed for several situations.

- **Analysis conducted to ensure safe operation.**
  - **Provide adequate nitrogen relief capacity during faults.**
  - **Prevent bubble formation in nitrogen (part of cable dielectric system).**
- **Several operating modes analyzed.**
  - **Cool-down**
  - **Baseline operation at 3 kA**
  - **Thermal-Hydraulic response**
    - **Overcurrent Fault**
    - **Loss of Cryostat Vacuum**



Thermal-Hydraulic Model Overview: HTS cable energy balance differential equations are solved.

- **Cable energy balance**

$$\rho C_{HTS} \frac{\partial T_{HTS}}{\partial \tau} = \frac{\partial}{\partial z}\left(kA_{HTS} \frac{\partial T_{HTS}}{\partial z} \right) + P'_{AC} - \sum_i Q'_{conv,i}$$

- **Energy balance for nitrogen streams**

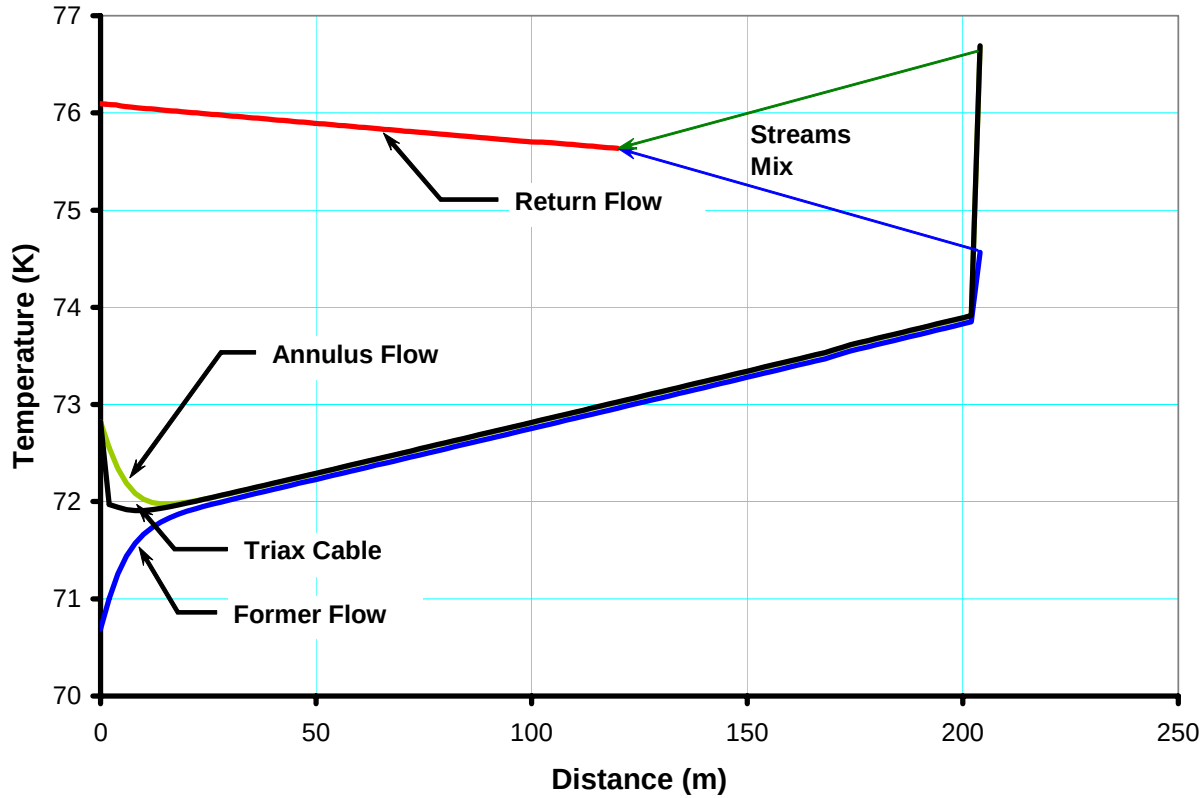
$$\rho_{vi} c_{p,vi} \frac{\partial T_{vi}}{\partial \tau} = \dot{m} \frac{\partial h_{vi}}{\partial z} + \sum_i Q'_{conv,i}$$

- **Pressure drops**

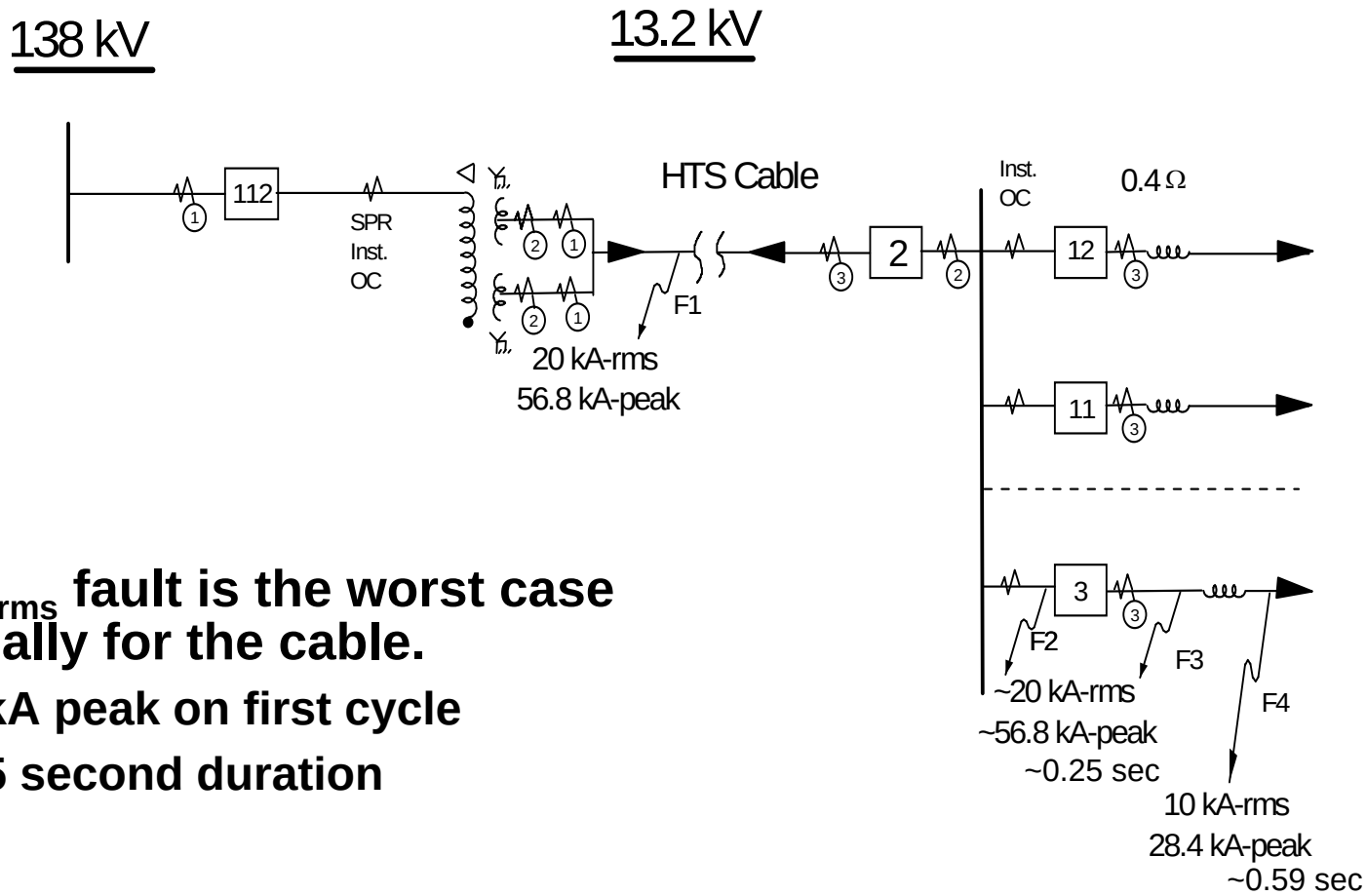
$$dP + \rho V dV + f \frac{\rho V^2}{2} \frac{dz}{D_{hyd}} = 0$$

Baseline temperatures for 3 kA steady state operation have been determined.

- **Used in development of baseline system design specifications.**

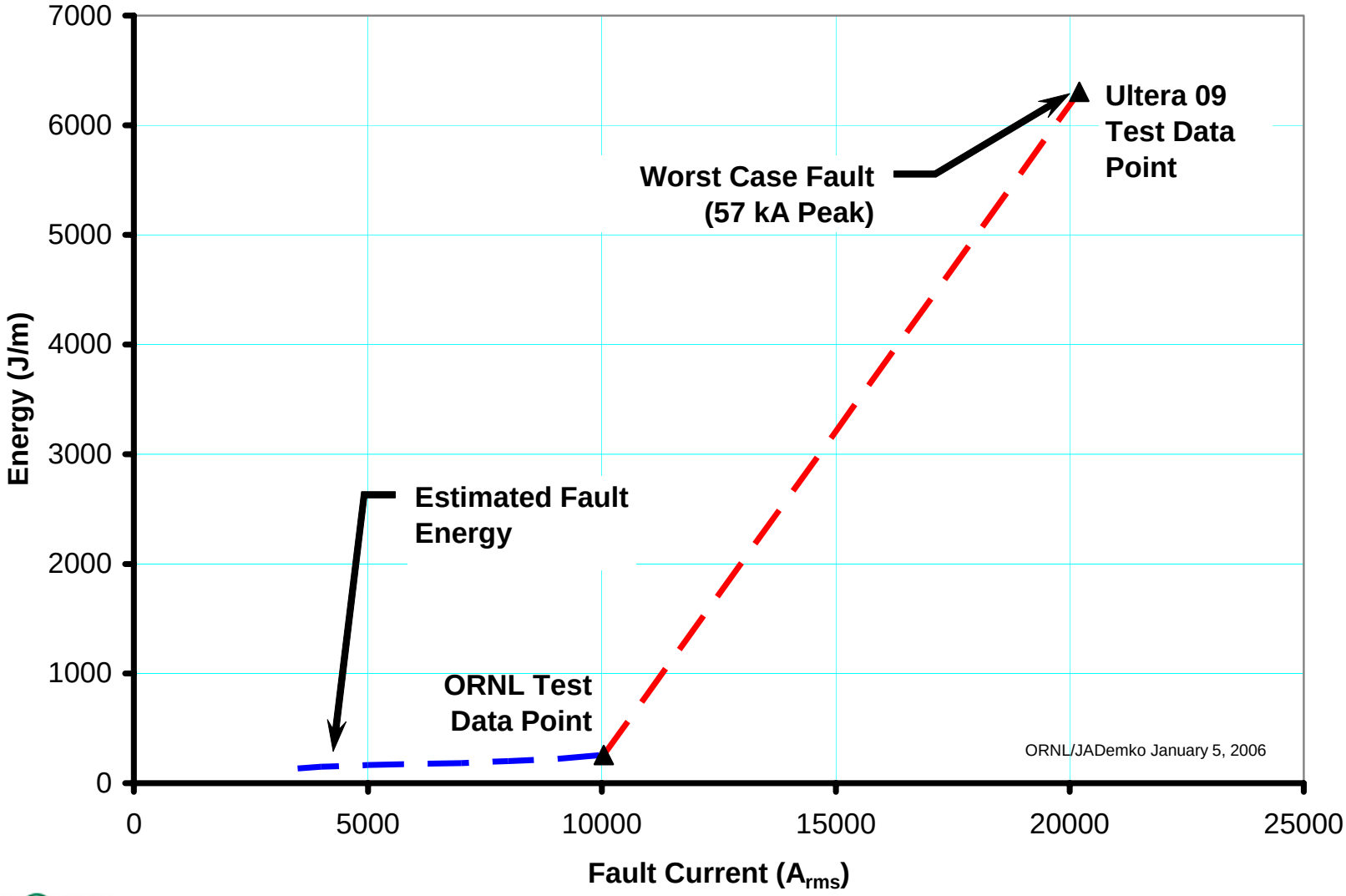


Thermal response of cable to fault currents were analyzed.



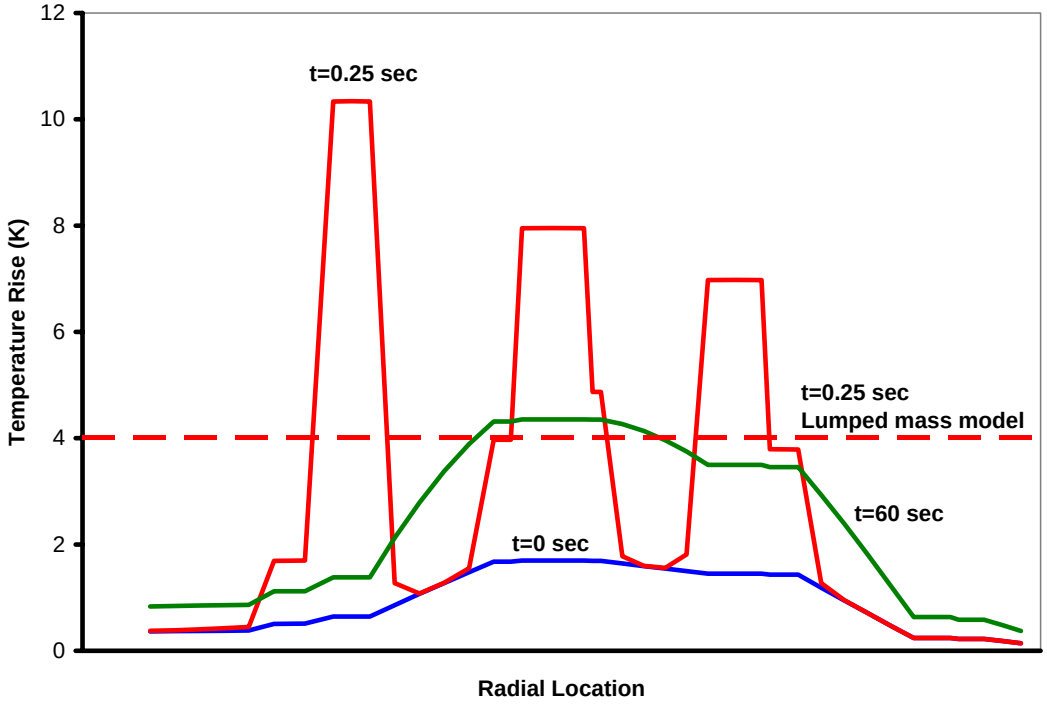
- **20 kA_{rms} fault is the worst case thermally for the cable.**
  - **57 kA peak on first cycle**
  - **0.25 second duration**

Energy deposited in the cable during a fault was estimated from test data.



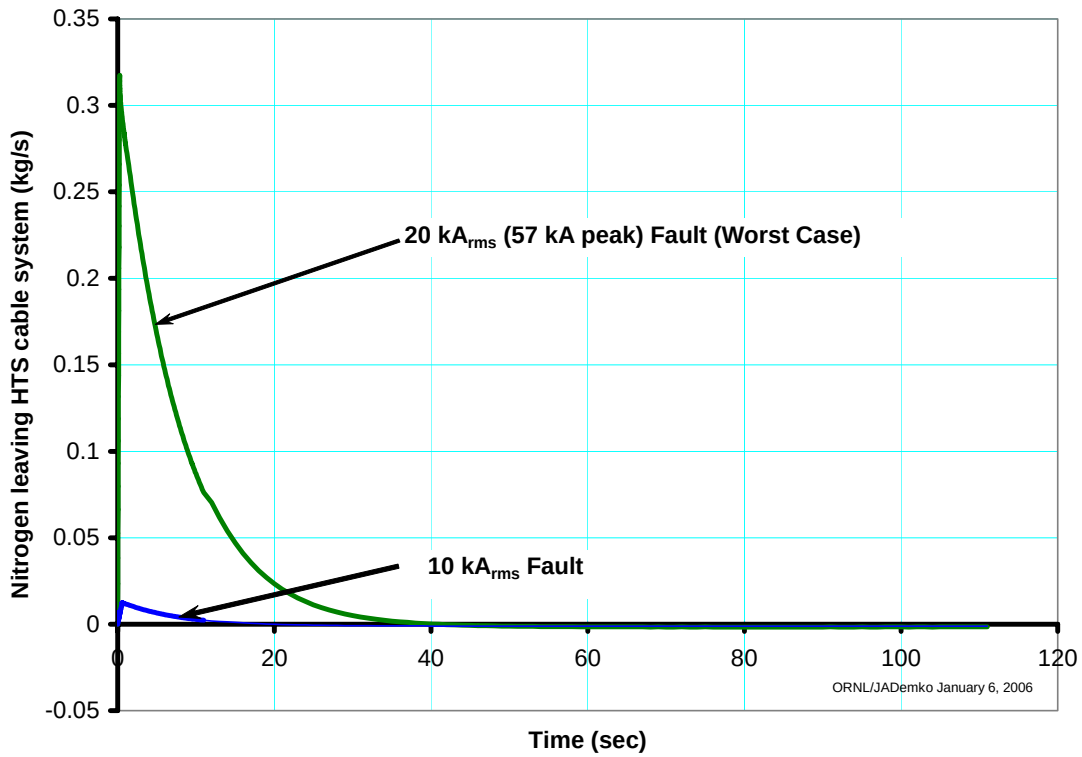
Detailed thermal response of triax to 57 kA peak fault compared with lumped mass model.

- **Lumped mass model provides conservative estimate of hydraulic response.**
  - **Radial thermal diffusion slows the rate which the fault energy reaches the nitrogen streams.**
- **Nitrogen remains single phase for worst case fault.**



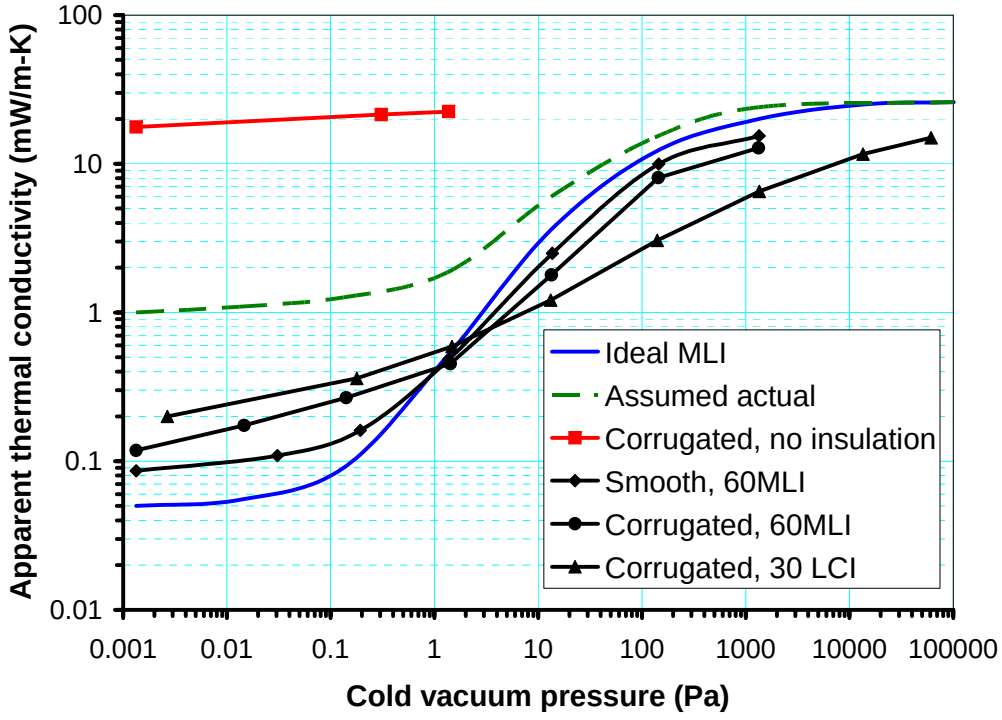
Mass expelled is conservative for the lumped mass assumption.

- **Used to estimate safety valve requirements.**
- **57 kA overcurrent fault is the worst case expected at Bixby.**



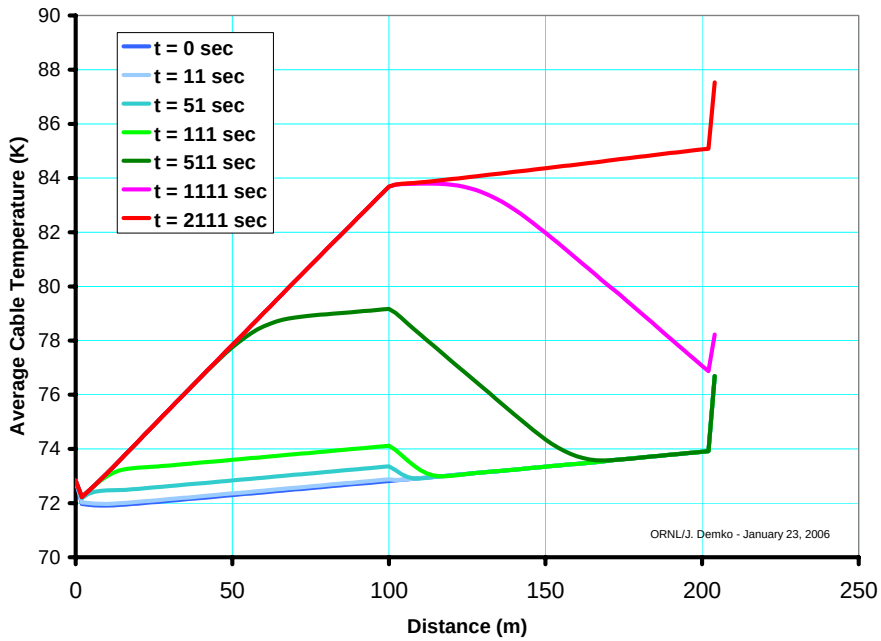
Loss of Cryostat Vacuum Failure Scenario

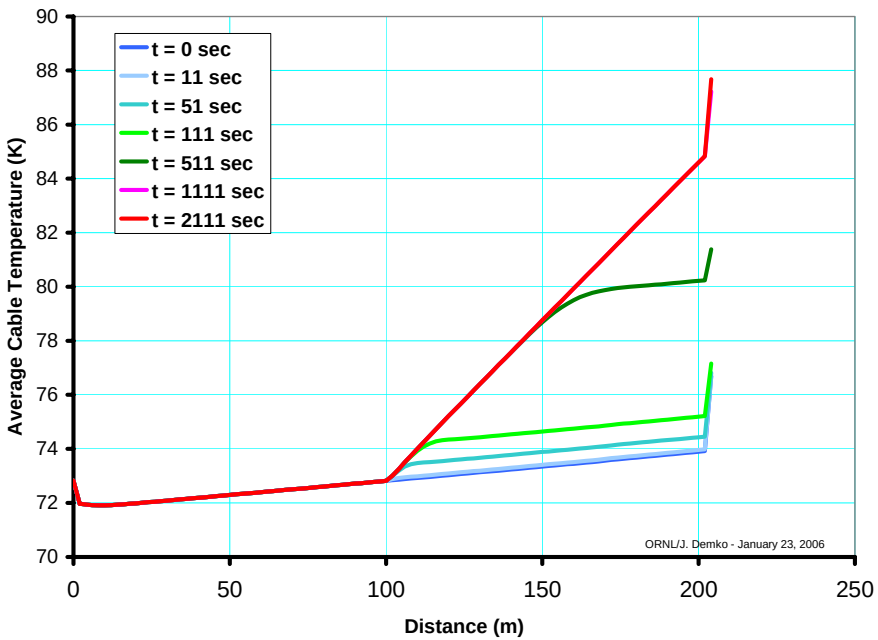
- **Assumes that outer vacuum jacket fails and warm air fills vacuum space.**
  - **Only looked at failure in one of the two 100-meter sections at a time.**
- **Apparent conductivity of insulating region increases by ~25X.**
  - **About 8 kW increase in system heat load.**
- **This estimate is lower than Compressed Gas Association Standard (~165X increase).**
  - **CGA based on the assumption that the cryostat is filled with saturated liquid.**



Cable temperature response to loss of vacuum is slower than overcurrent fault scenario.

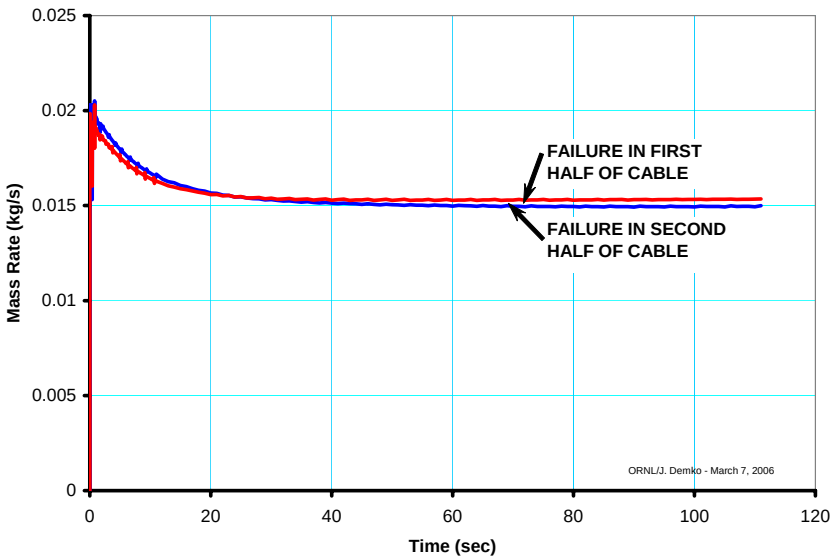
- **Loss of vacuum in first 100-meter cryostat section.**
- **Loss of vacuum in second 100-meter cryostat section.**



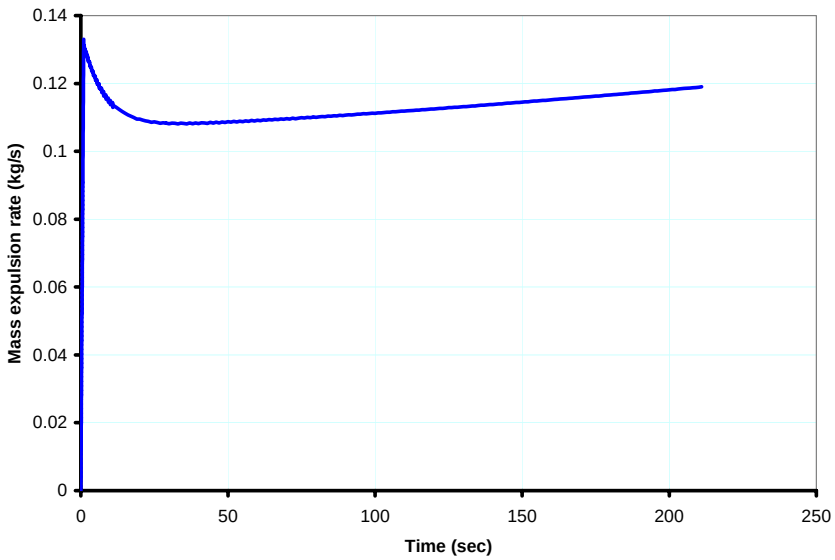


For times immediately following a loss of insulating vacuum, the relief requirements are less than the 57 kA overcurrent requirement.

- **Nitrogen relief requirement for 25X multiplier.**



- **Nitrogen relief requirement for CGA calculation.**



Expected operational conditions are within the system capabilities.

- **Baseline operation at 3 kA was used to develop system design specifications.**
- **Fault conditions used to estimate safety relief requirements.**
  - **Overcurrent faults worst case**
    - **Largest energy deposition in shortest time.**
    - **Energy deposited within the cable.**
  - **Catastrophic loss of cryostat vacuum**
    - **Highest system heat load but long time constant.**
    - **Energy deposited in annular nitrogen stream.**
    - **Sufficient time to respond and take the cable system off-line.**
    - ***Magnitude of heat load open to wide interpretation (25X to 165X baseline heat load), R&D planned in 2007.***

Presentation Outline

- **Introduction** (David Lindsay, Southwire)
  - Overall SPI Goals & Objectives
  - Design Approach
  - Review FY 2005 Milestones
- **FY 2006 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 2006 Performance**
- **Planned FY 2007 & FY 2008 Milestones**
- **Program risk mitigation strategy**
- **Research Integration**
- **Summary**

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

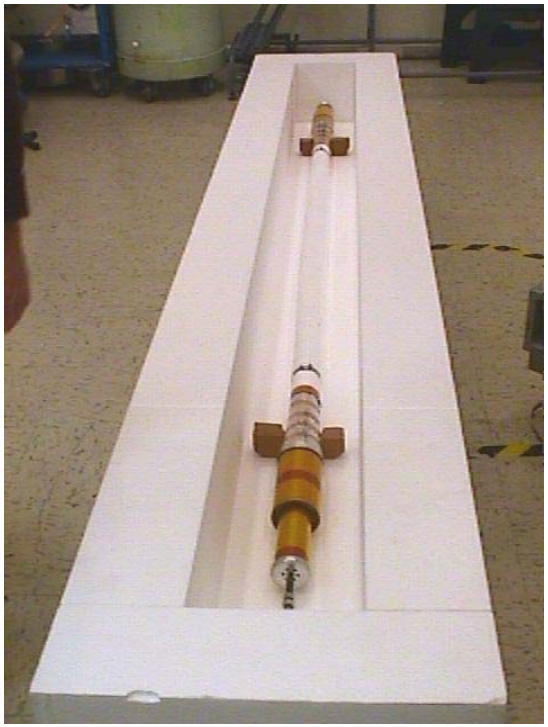
- Composite cylinders and disks
- Axicom bushing
- Half scale termination model
- Full scale termination model
- 5-m cable system tests
  - Triax Cable + Termination Qualification Tests
    - AC withstand
    - PD measurements
    - Impulse
  - Extended Test Program
    - Bend cable 90°
    - Repeat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

Passed All Qualification Tests !

High voltage tests of spliced triax cable were performed on each phase

Screen to P3:

- **Open bath tests**
  - **Many bubbles present are problem for high voltage**
- **PD onset 15 kVrms**
- **Withstood 39 kVrms for 5 min**
- **Pass 10+ impulse at 110 kV BIL**



Splice cable in open bath

Spliced triax P2 to P1 insulation passes AC Withstand and BIL tests

- Eliminate the bubbles by testing in pressurized LN
- Cable cut on ends to fit into large cryostat
- Test region included all splices in P2 and P1
- Passed 110 kV BIL Test
- PD onset 25 kVrms, 20-40 pC
  - Well above operating voltage
- Withstood 39 kVrms for 5 min
- Increased pressure to 8 bar
  - Withstand at 145.2 kV pos. imp.
  - Breakdown at 158.2 kV neg. imp.

Alvin Ellis attaching grounding springs. Note styrofoam at upper end of extension rod for thermal insulation.

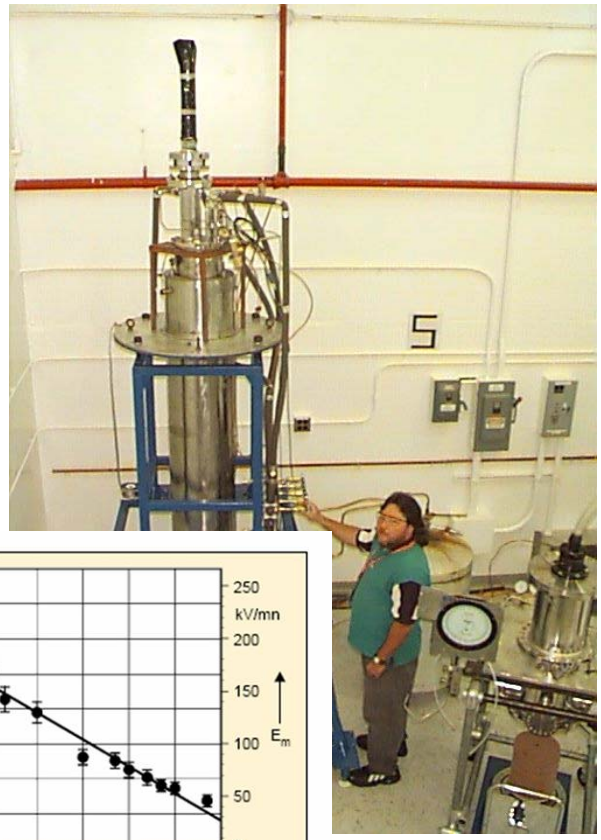
ORNL Award Fee Milestone 2006

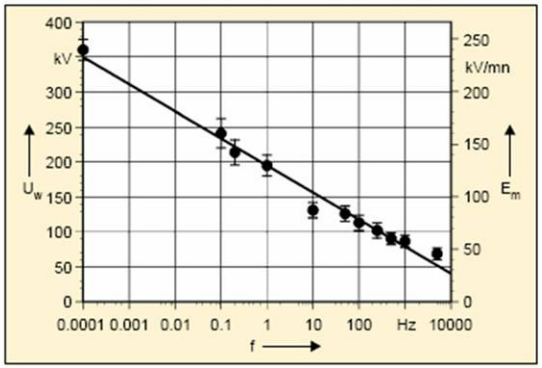
AEP triax sample passes impulse and impulse aging tests

- Excess cable from 200 m manufactured cable at the AEP site
- Splice in former
  - Phase 2 to Phase 1 to be tested to check effect of splice
- Screen to P3 tests
  - Passed 10 +/- impulses (1.2/50 µs) at 110 kV at 6 bar pressure
  - Could not break cable due to flashovers to wall or in stress cone
  - Withstood 200 shots alternating 10+/- at 110 kV
  - PD onset 17-18 kVrms (~ 5 pC)
  - Withstood 39 kVrms for 5 min
  - Withstood another 100 impulse shots at 110 kV
- Triax insulation had 300 withstands at 110 kV under pressure

AEP sample passed DC test in lab to simulate VLF on-site tests

- On-site tests were VLF (Very Low Frequency) 0.1 Hz
- DC test simulate "worst case" scenario
- P3-P2 of spliced former sample
- AC Partial Discharge onset 20.1 kV_{rms} (6-7 pC)
- Withstand 39 kV_{rms}/5 min
- Passed 42 kVDC (neg) and (pos) for 30 min each
- PD and 39 kV_{rms} repeated
- Conclusion: DC tests did not affect PD or AC withstand





Breakdown voltage as function of frequency for extruded insulation (Gockenbach,IEEE Electr. Insul. Magazine, vol. 16, no. 6, p11, 2000)

Impulse tests following DC aging on AEP sample were successful

- Impulse tests were done following DC aging
- Intermittent flashovers (in stress cone not cable region)
- Passed series of impulse tests at BIL level
- Conclusion: DC tests did not appear to affect AC or impulse characteristics
- Long term effects for DC aged cables not known

# Shots	Pol.	Voltage (kV pk)
10	Pos	111
25	Neg	113
15	Pos	112

ORNL FY 2006 Performance

FY 2006 Plan

- Begin on-site installation of equipment.
- Complete cable & ship to Bixby station.
- Continued civil/electrical work at Bixby site.
- Installation of cryostat and cable
- Termination & splice assembly
- Check-out and run-in of cryogenics system

FY 2006 Performance

- ✓Cable duct bank, manhole and foundations completed
- ✓Cable shipped in December 2005
- ✓Splice assembled in the manhole.
- ✓Cryostat and cable installed
- ✓Terminations assembled in the substation
- ✓Cryogenic system commissioned

ORNL FY 2006 Performance

FY 2006 Plan

- Finalize all installation items.
- In-field testing completed
- Operational control coordinated with AEP
- Energize System
- Operate system

FY 2006 Performance

- ✓Bus work installed
- ✓Critical current measurements conducted, VLF, HV soak
- ✓Cable cryogenics monitored by Praxair IMPAC system
- ✓Date to place AEP cable on the power grid August 2006.
- ✓After cable on AEP power grid.

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ORNL FY 2006 Additional Tasks

FY 2006 Plan

- **Participated in SPI Readiness Reviews**
- **Cable Test Laboratory move to new Multi-Program Research Building at ORNL completed.**

FY 2006 Performance

- ✓**Reviews conducted in May and July 2006. Mitigation plans have been prepared that address the issues identified by the Readiness Review Team.**
- ✓**High Current Power supplies installed and commissioned.**
- ✓**Cryogenic system installed and commissioned.**
- ✓**High Voltage ac and impulse power supplies installed.**

Southwire/ORNL FY 2007 Plans
Oct. 1, 2006 to Sept. 30, 2007

- **SPI: Bixby Substation, AEP, Columbus, OH**
  - **FY2007 (Oct 1, 2006 - Sept 2007)**
    - **Monitor operation of cable at AEP through seasonal cycles.**
  - **HTS Cable Systems Research and Development**
    - **Test model cables and terminations to higher ac voltages (up to 69 kV).**
    - **Conduct test of short sample (1- to 5-meter) 2G HTS cable sections.**
    - **Instrument and test a 5-meter vacuum multi-layer insulated cable cryostat at the ORNL HTS Cable Test Lab for thermal-hydraulic response to a loss-of-vacuum event.**
- **Respond to solicitation for new superconducting power equipment expected to be issued in August 2006.**

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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**
  - **Conducted HAZOP analysis of cryogenic system with Praxair in January 2005.**
  - **SPI readiness review in May and July 2006.**

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 2006 progress is evidence of well functioning team.**
  - **Triax cable research conducted jointly with Southwire/*nkt* , ORNL, PRAXAIR and AMSC.**
- **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 200-m AEP cable involved a team of ORNL, Southwire and subcontracted technicians.**
  - **Shared use of ORNL and SW power supplies, (ac and dc), SW PD detector, fault current testing to 57 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 consultants employed as needed.**

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Research Integration – Publications and Outreach

- **Presentations and publications during the year**
  - **One paper was presented at the Cryogenic Engineering Conference in August 2005 and published in the, *Advances in Cryogenic Engineering Vol*. 51A, AIP.**
  - **Three technical papers on HTS DC cable technical issues were published in the *IEEE Transactions on Applied Superconductivity, in Vol. 15, No. 4 and Vol 16, No. 1***
  - **Four technical papers will be presented at the 2006 ASC and submitted for publication in the *IEEE Transactions on Applied Superconductivity.***
  - **One paper was presented at the International Conference on Electricity Distribution in June 2005.**
  - **Organized session at DOE 2006 Wire Development Workshop on Cable Thermal-Hydraulics.**
  - **Joint Southwire/ORNL patent issued on pressurized termination.**
- **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**

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