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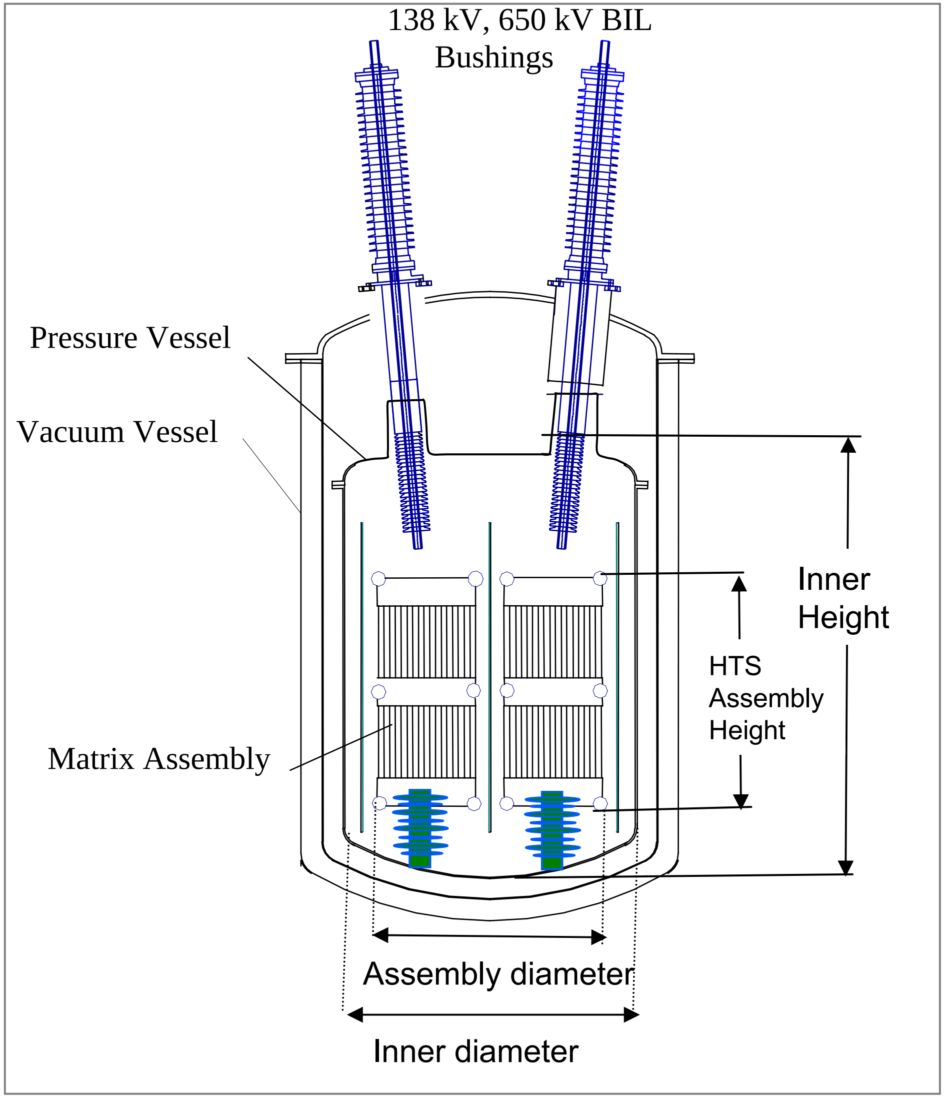
Transmission Level HTS Fault Current Limiter

Chuck Weber

8th Annual EPRI Superconductivity Conference
Oak Ridge, TN
November 12, 2008



SFCL program overview

Partners

AEP AMERICAN ELECTRIC POWER · Department of Energy · EPRI · Los Alamos National Laboratory · Oak Ridge National Laboratory · SUMITOMO ELECTRIC

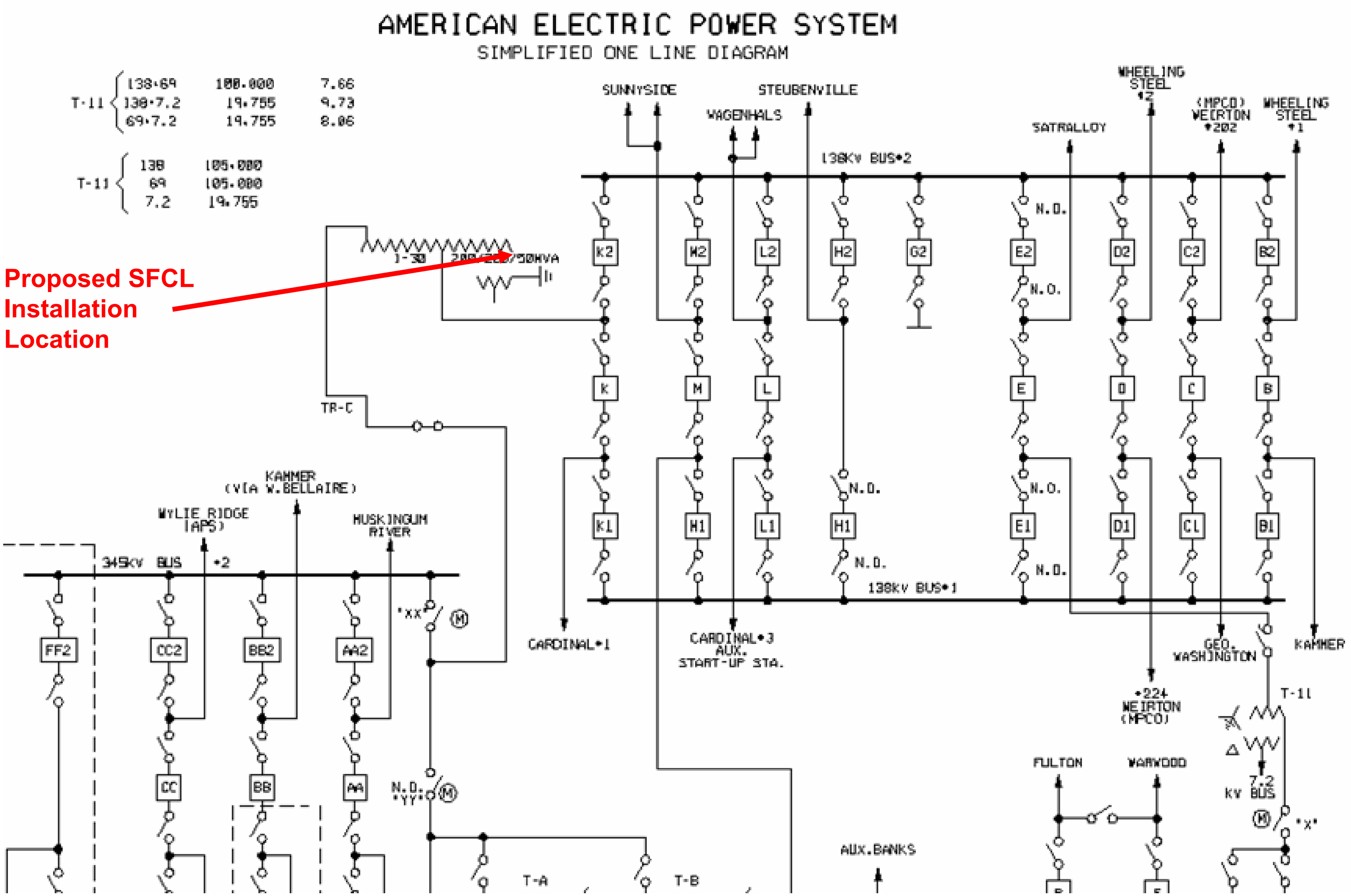
Specifications

- YBCO based, resistive type FCL
- 138 kV class device
- Fault Current – 13.8 kA
- Load Current – 1,200 A_{rms}
- Design fault current – 37 kA
- Design device response – Recover to superconducting state after a fault carrying full load current

Generalized SFCL Specification Development

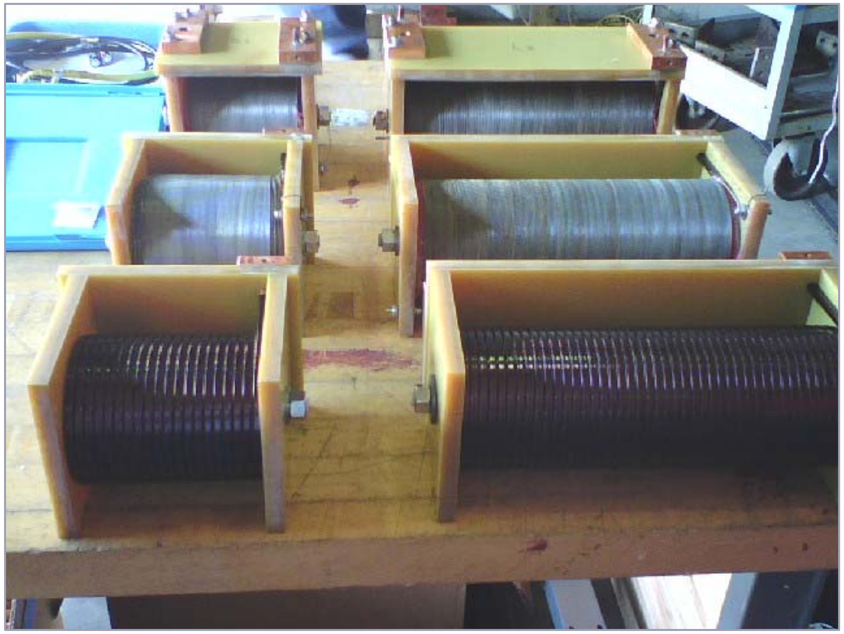
- Baseline Design for Program was the AEP SPORN substation site
  - This is a niche application site, operating at 400Arms, 138 kV
  - Prospective fault current 26 kArms (~90 kA peak) and 13.8 kArms (~ 37 kA peak)
- Working with AEP, we have identified a site with broader general application
  - TIDD substation
  - 1,200 Arms, 138 kV
  - Prospective fault current is 13.8 kArms (~37 kApeak)

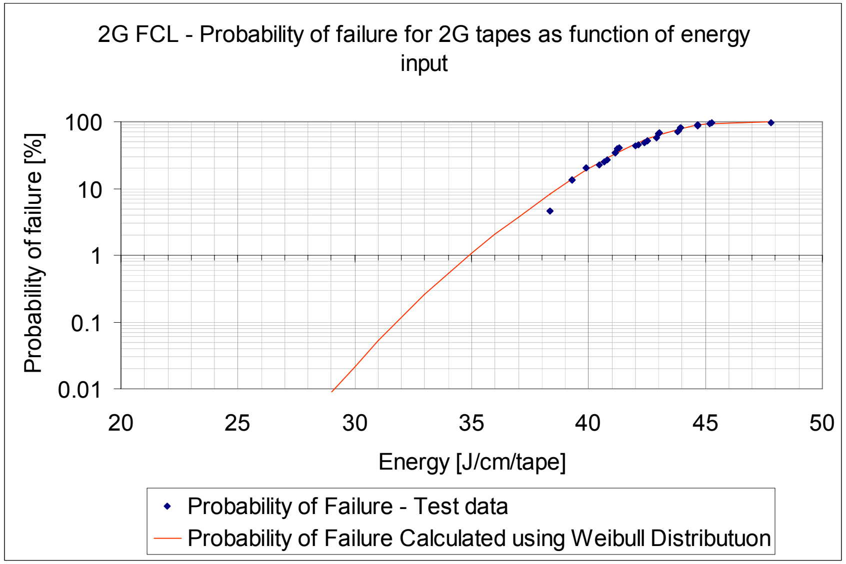
TIDD Substation – (Partial) One-Line Diagram



Prior accomplishments

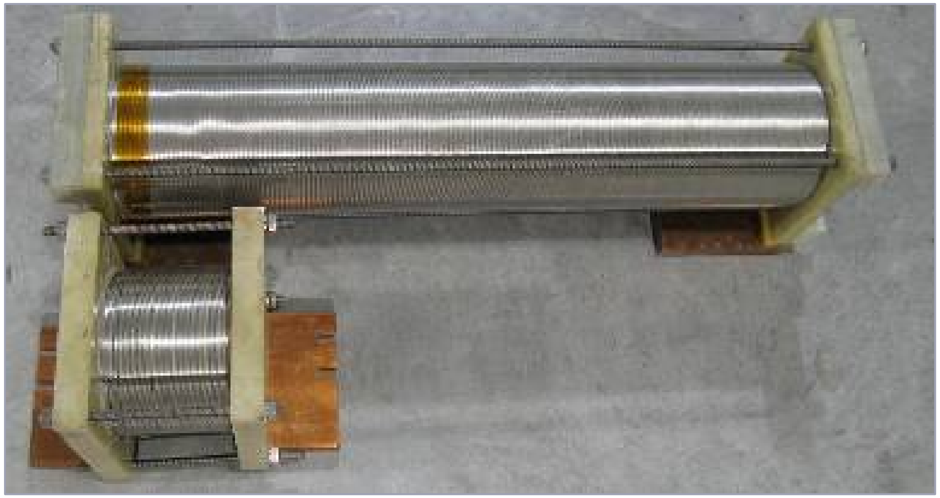
- Proof-of-Concept demonstrated
  - MCP 2212 (2004)
  - 2G YBCO (2006)
- Beta device testing specifications established
- Completed design and testing of HV bushings (SEI)
- Investigated several 'engineered' 2G architectures for improved RUL
- Design and laboratory testing of shunt coils to withstand high fault transient loads
- Thermal simulation of RUL process
- Weibull plots of 'standard' 2G failures
- Conceptual CRS & vessel design
- Investigated LN_2 dielectric properties



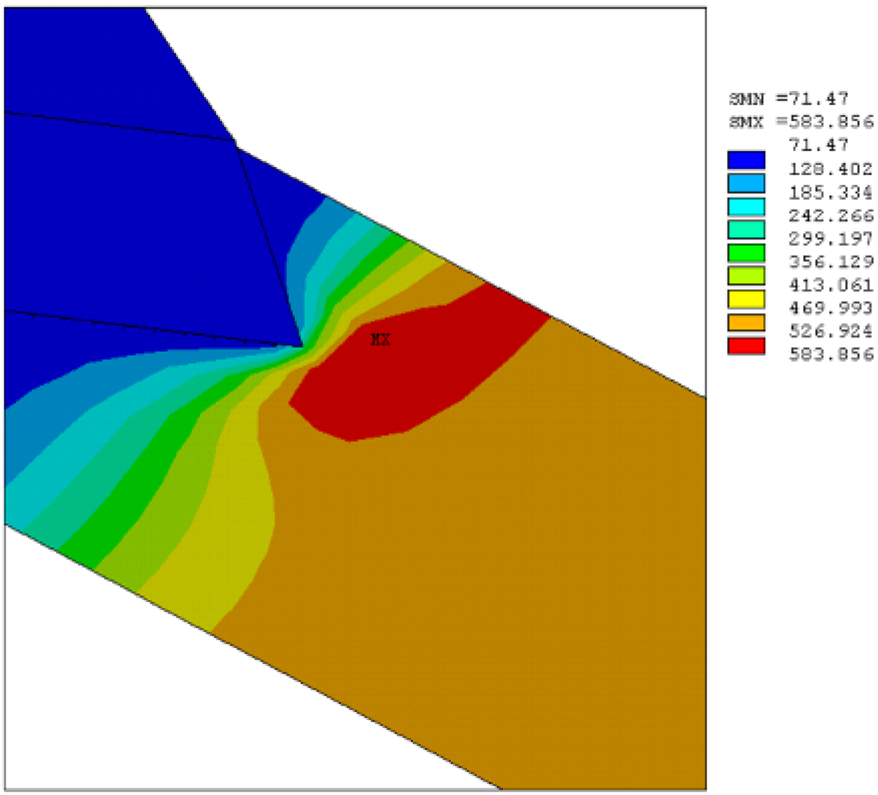


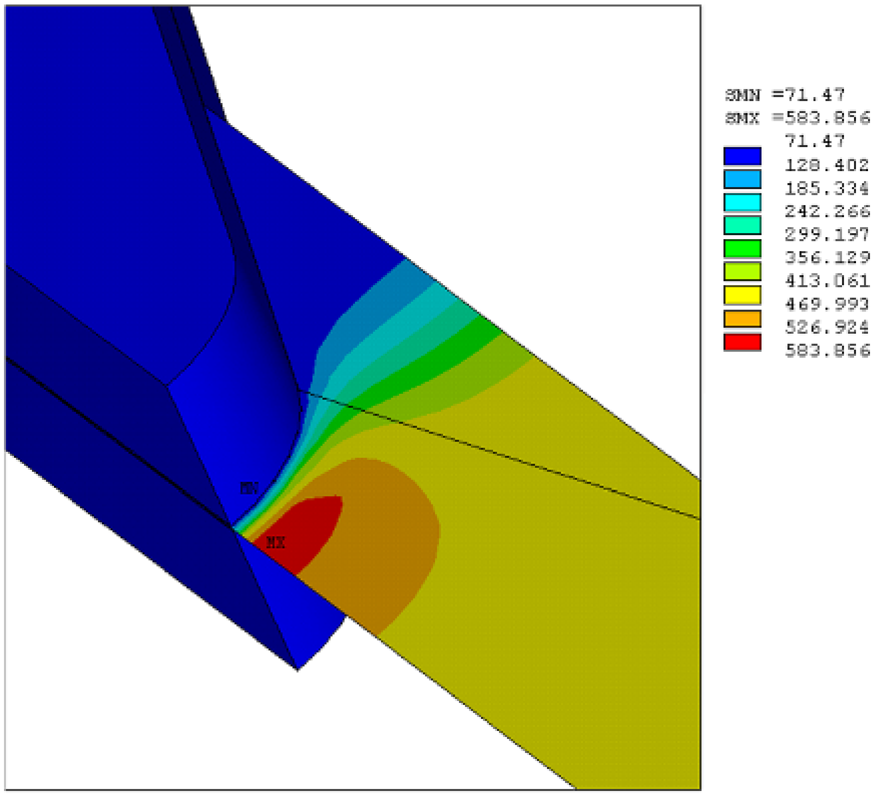
Improvements to shunt coil and contact design

- Shunt coil improvements:
  - Manufacturing improvements (easier assembly, more robust coil)
  - Mechanical strength
  - Multi-Layer winding (size reduction)
- Connector improvements:
  - Shape optimization to avoid contact hotspots
  - Improvement in RUL Time
  - Improvement in RUL Current
  - Improvement in consistency of contact resistance

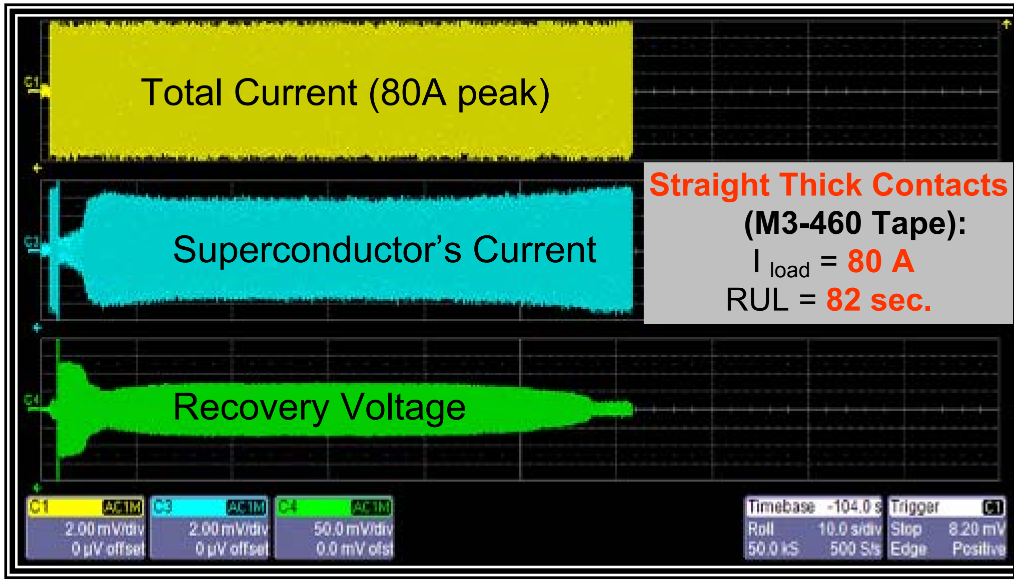


Tape heating near contact during fault impacts RUL

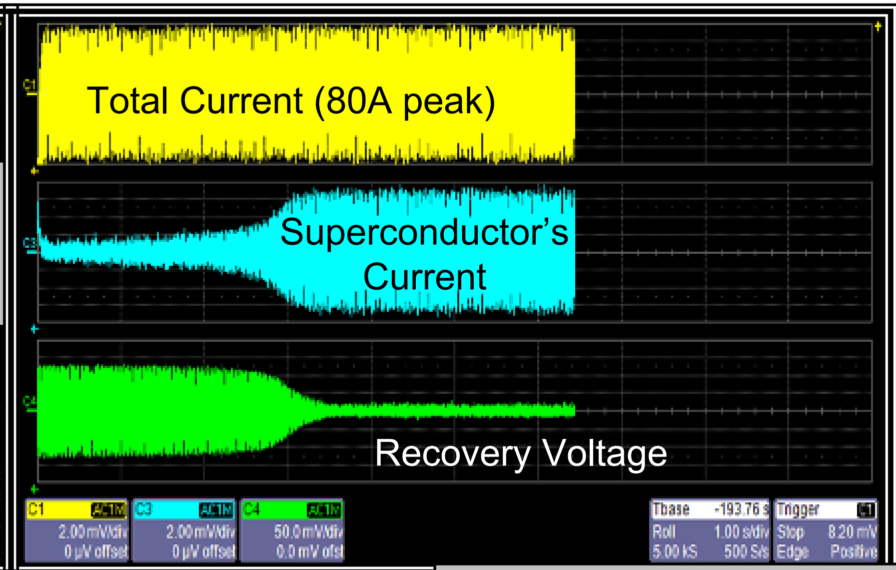




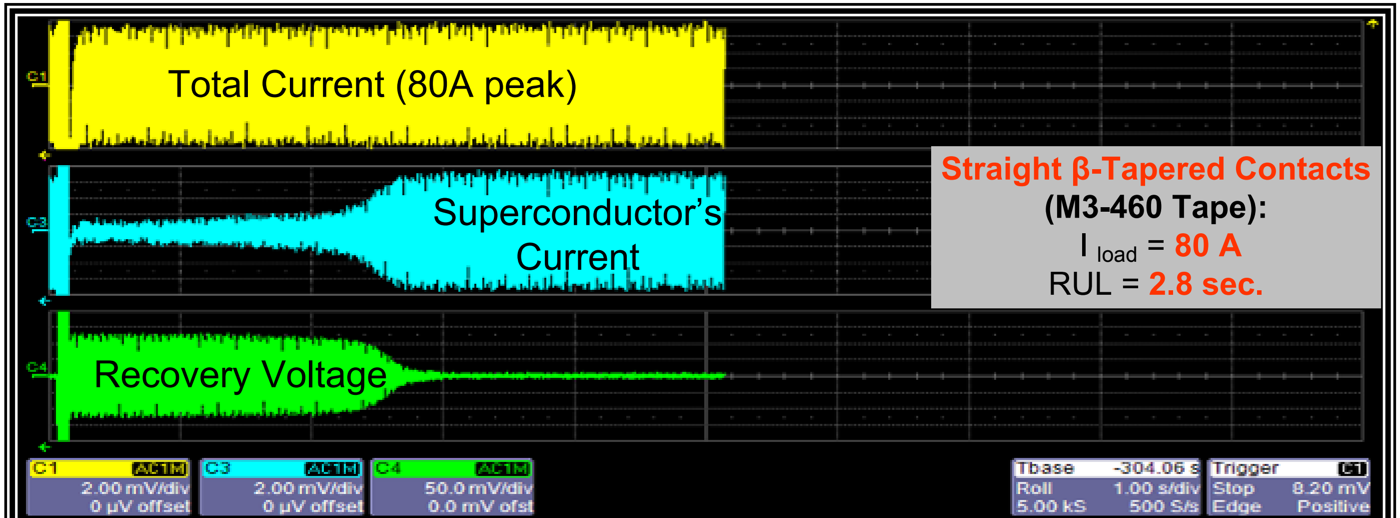
Correlation between different contact geometries



Straight Thick Contacts
(M3-460 Tape):
I_{load} = **80 A**
RUL = **82 sec.**



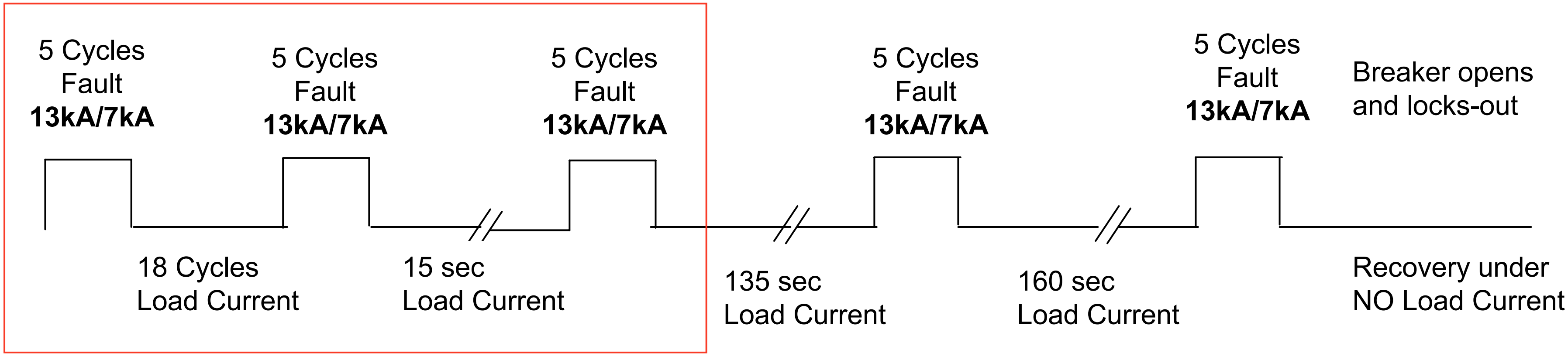
Straight α-Tapered Contacts
(M3-460 Tape):
I_{load} = **80 A**
RUL = **3.5 sec.**



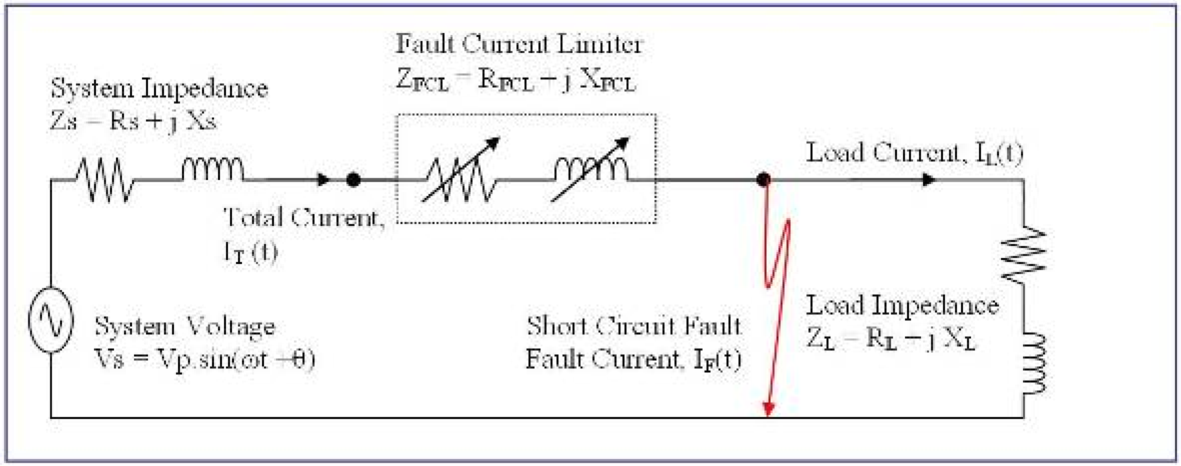
Straight β-Tapered Contacts
(M3-460 Tape):
I_{load} = **80 A**
RUL = **2.8 sec.**

Recent KEMA tests

- Recent rounds of KEMA testing focused on critical AEP reclosure sequence on an HTS element



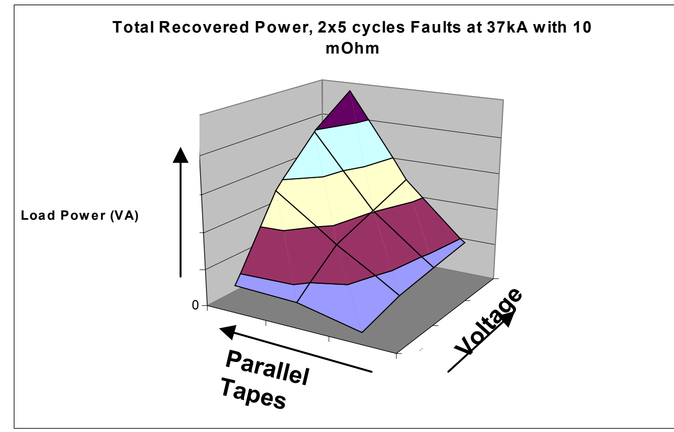
- Straight elements were used
- Improved connector designs were used
- “Standard”, pre-qualified tapes were used
- Test Dates: May 2008, July 2008

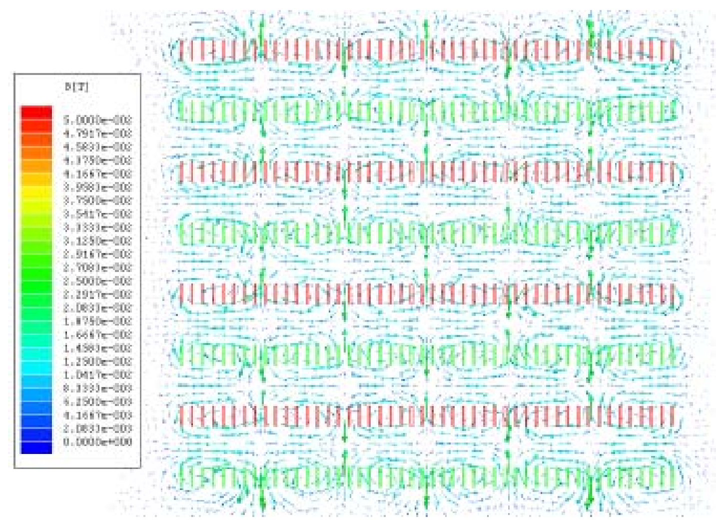


SuperPower Inc.

2G RUL capabilities tested at KEMA

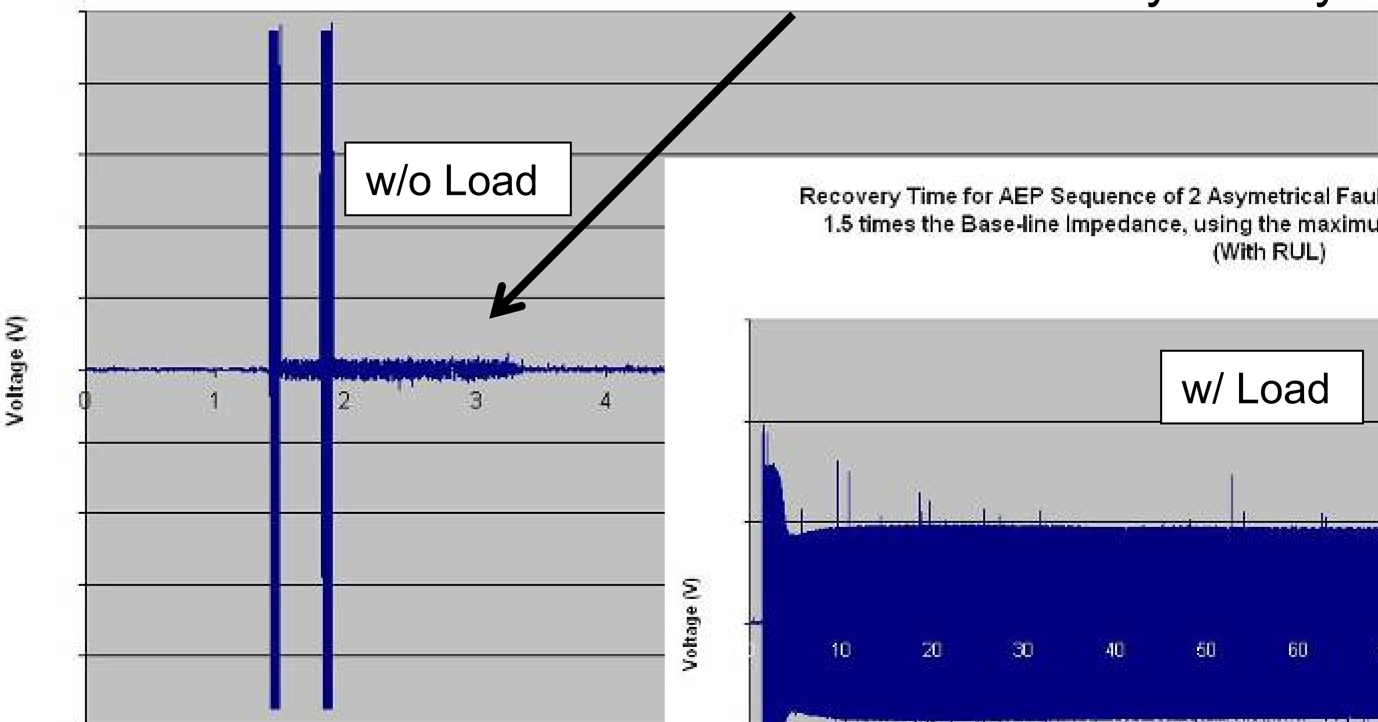
- 'Standard' SF12100 2G wire used
- Test conditions
  - 37 kA fault
  - follows AEP sequence
- Test variables
  - Shunt impedance
  - Number of parallel tapes
  - System voltage (v/cm/tape)
  - Load Current

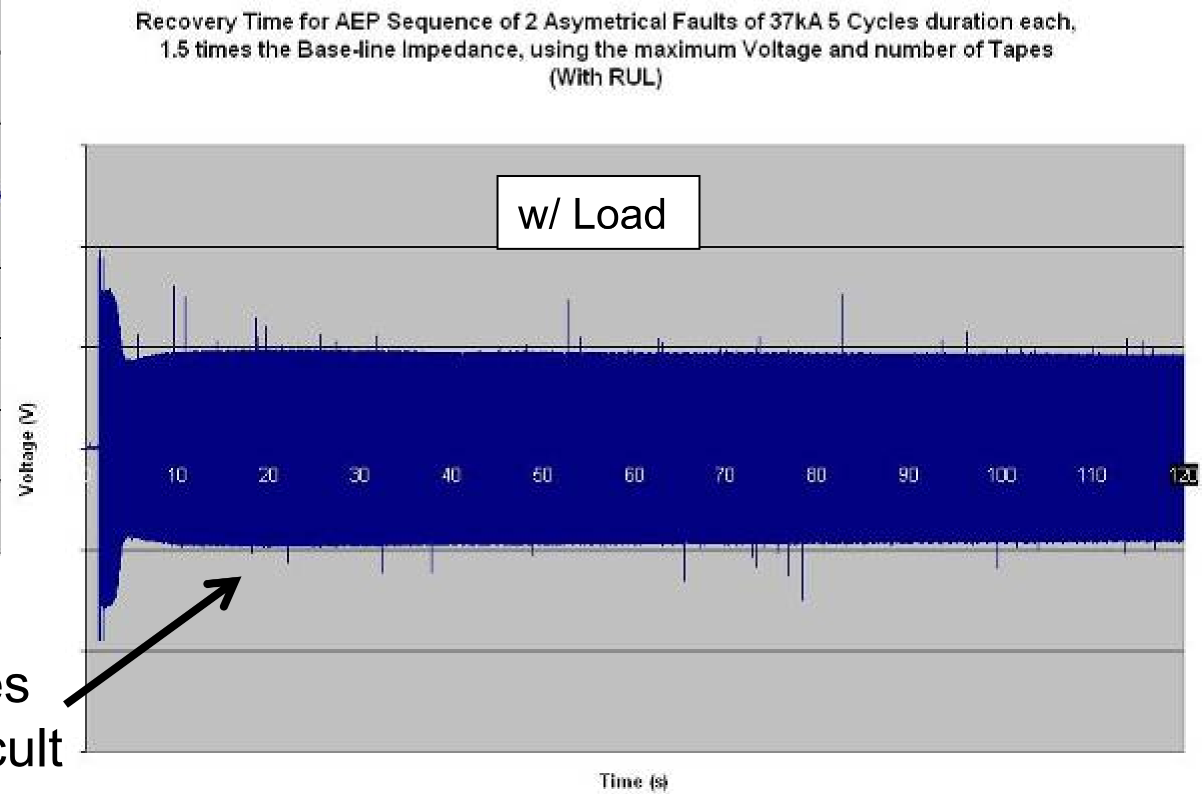




Achieving RUL is a difficult task

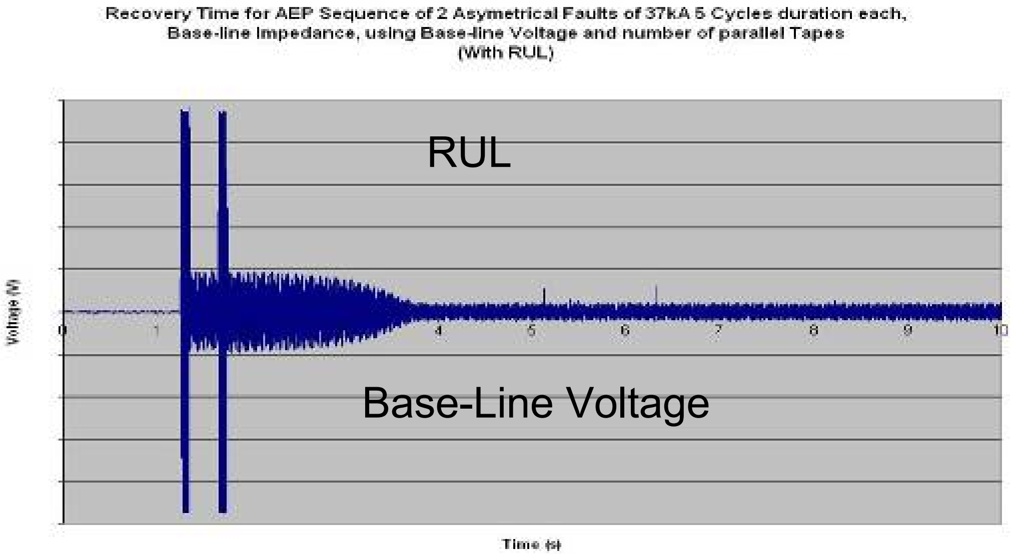
Without load current recovery is very fast



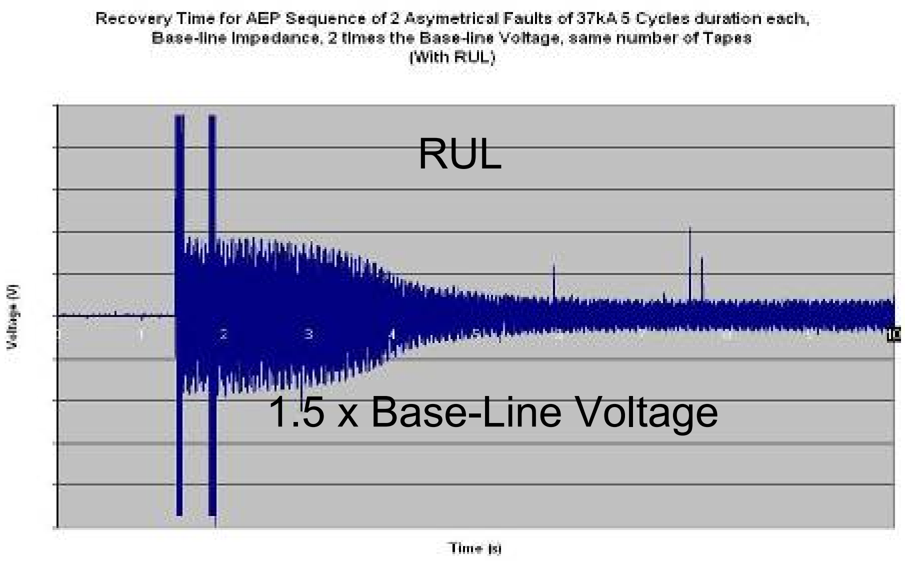


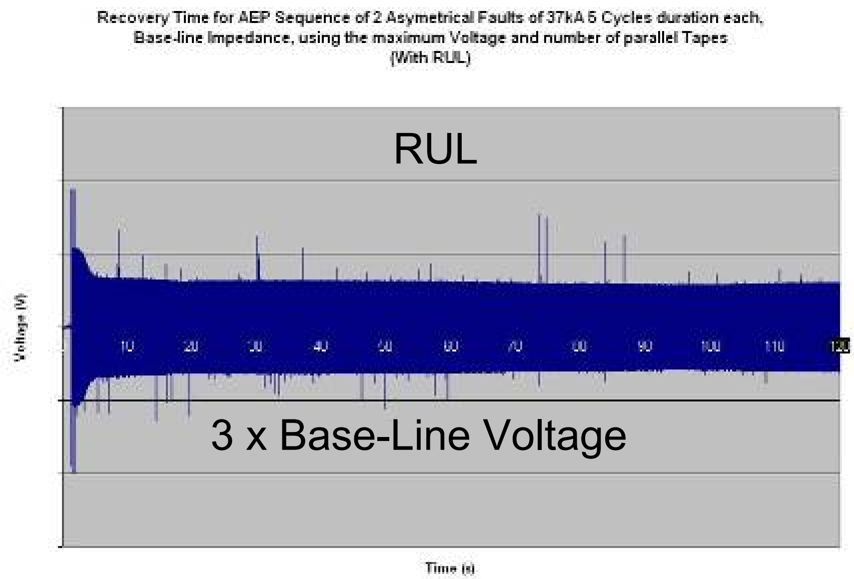
Adding load current makes recovery much more difficult

Electrical stress on the tapes can limit RUL

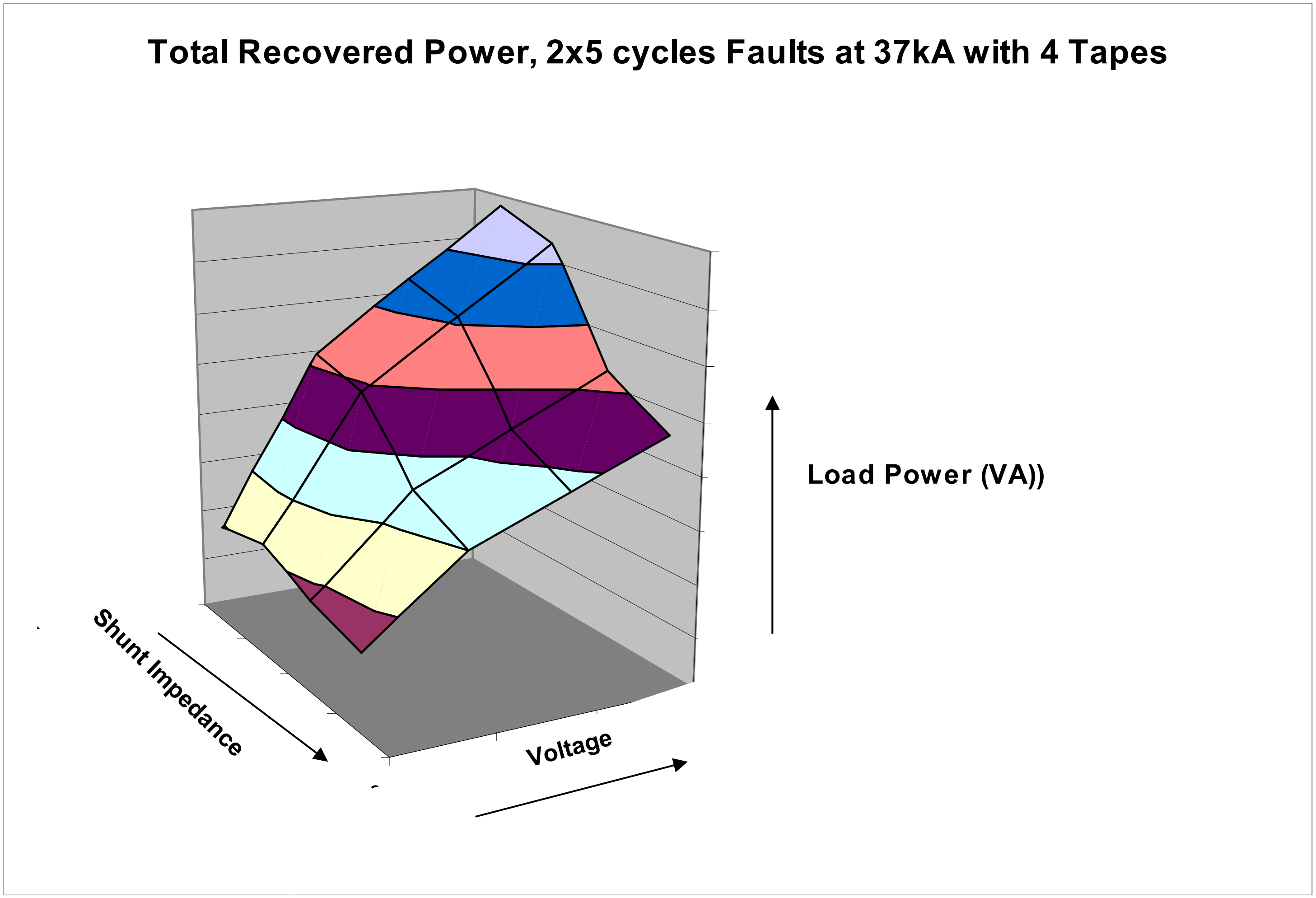


- RUL time can affected by increasing the V/cm on the tape
- Limits of the design optimization are understood





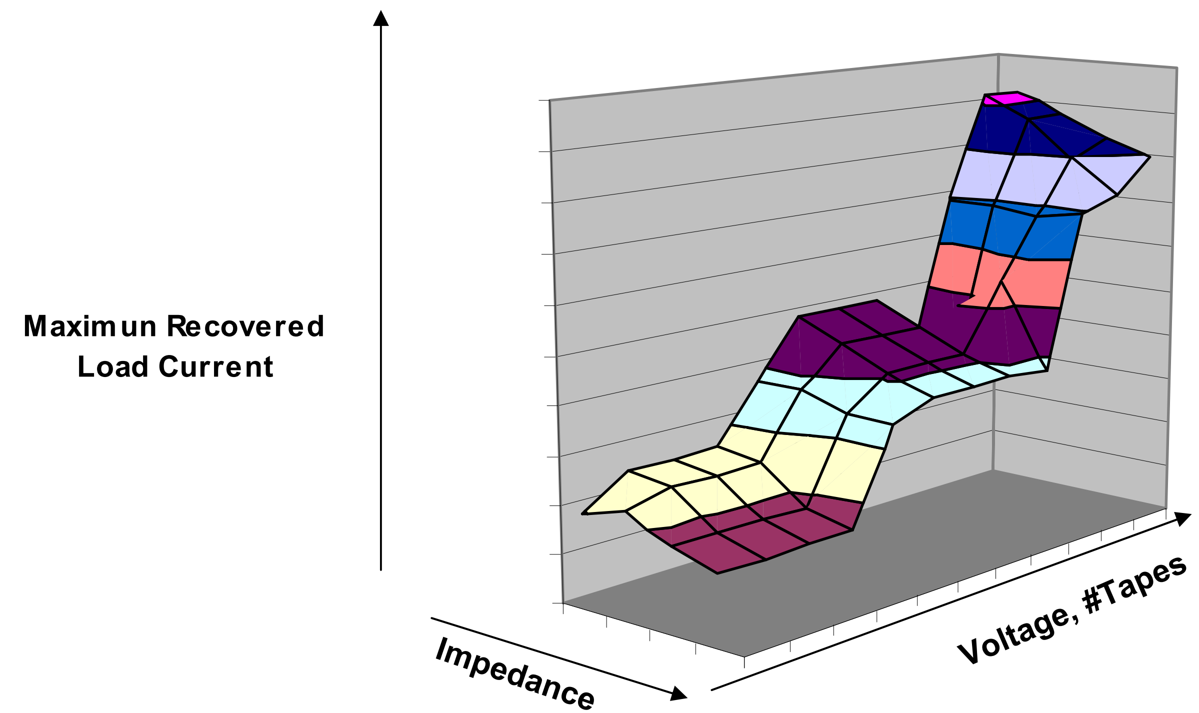
Factors impacting RUL defined by test results



Sample surface plot of RUL conditions

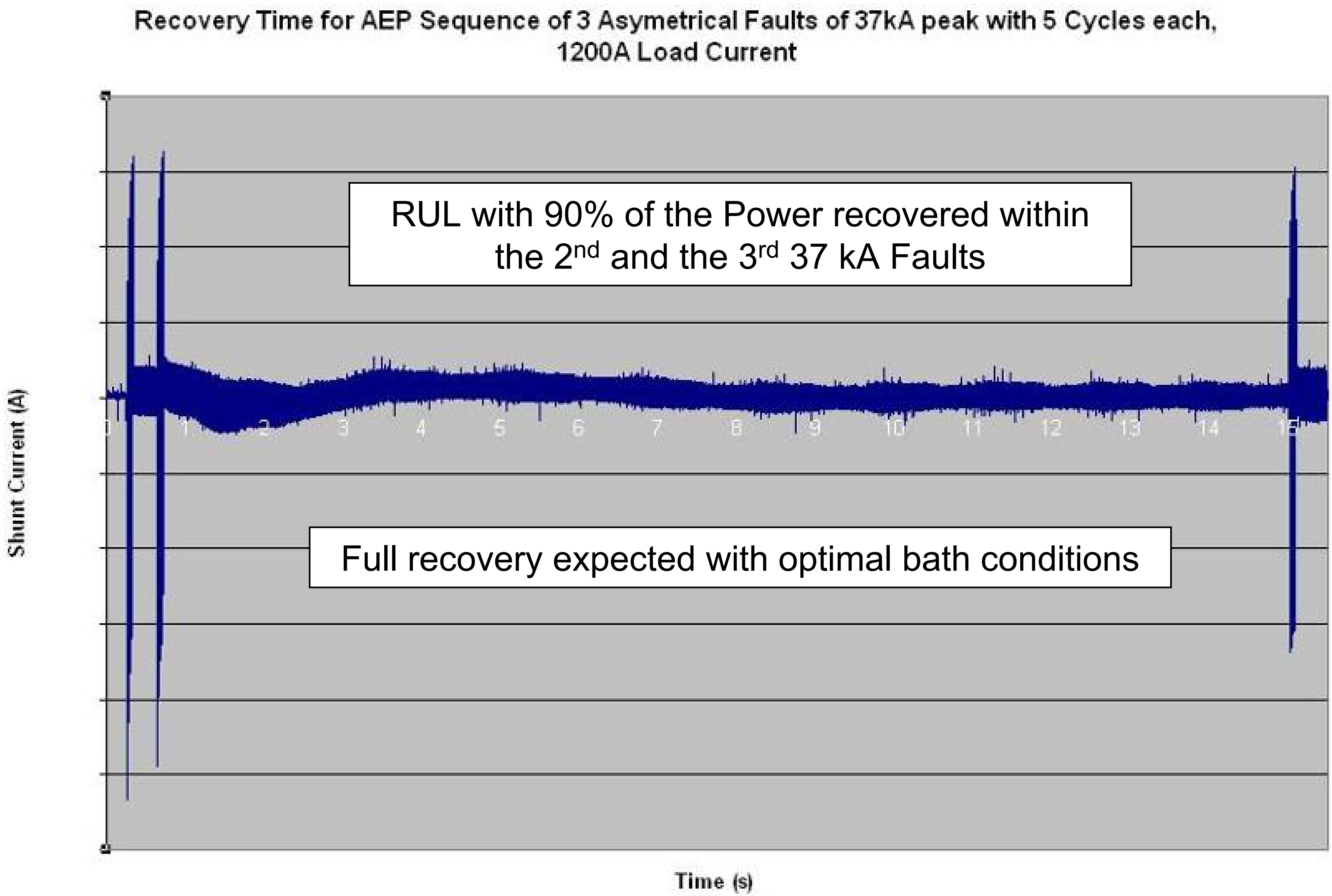
Ability to predict RUL over wide design space

Maximum Load Current as a function of shunt impedance, operating voltage & number of tapes



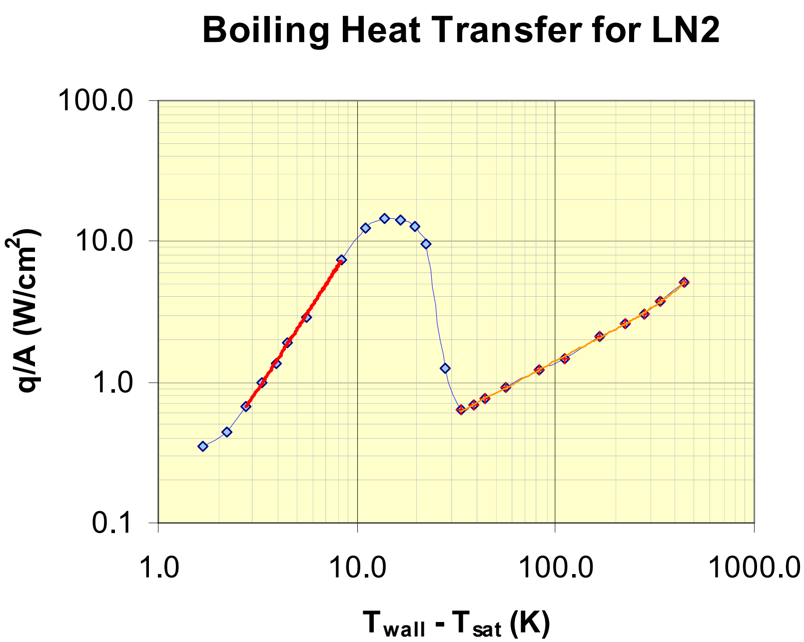
Recovered Current with 2 Asymmetrical 37kA Faults, 5 cycles each

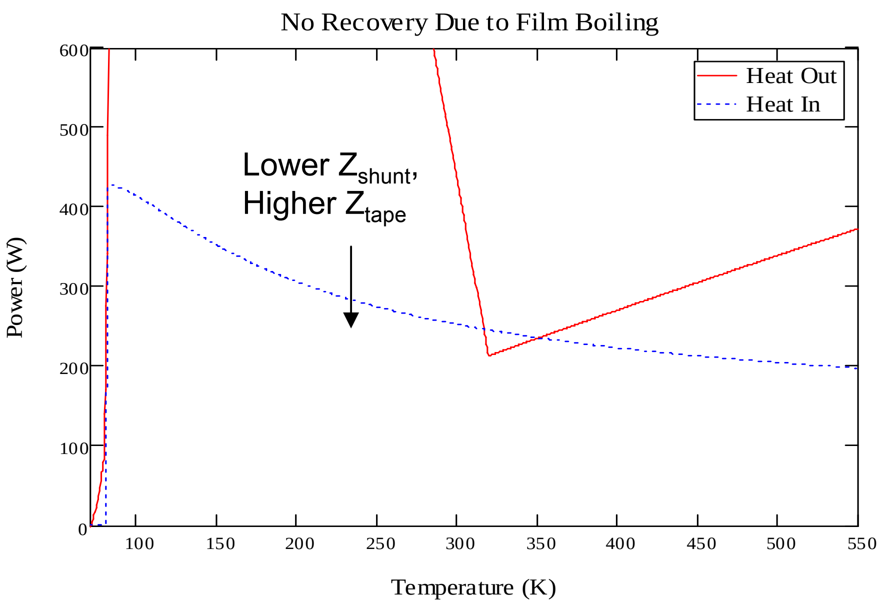
Worst case conditions at Tidd can achieve RUL



Bath Conditions Impact on Ability to Recover

During the fault transient, tape heats up to film boiling region.
Bath conditions (pressure, subcooling) shift boiling heat transfer curve
Bath conditions have an impact on the dielectric strength of LN2

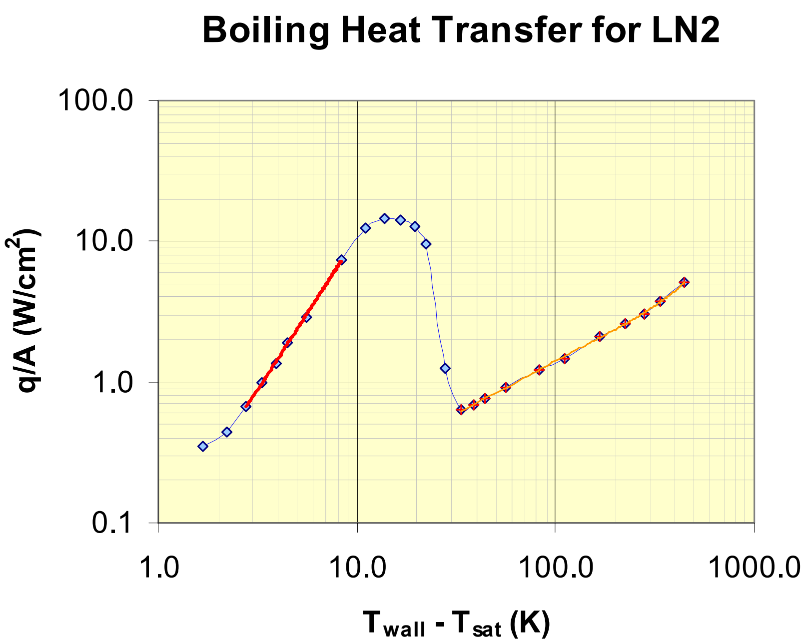


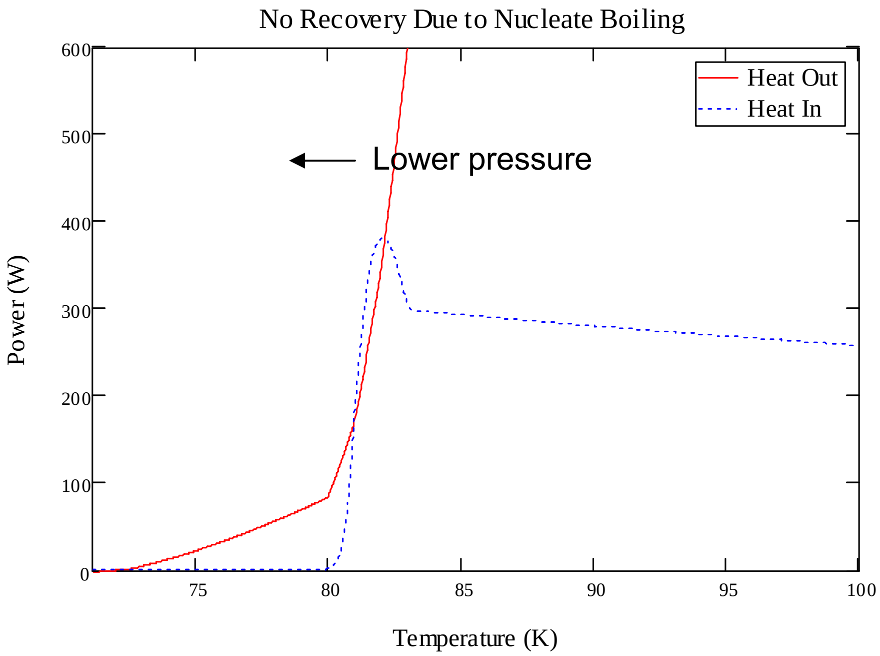


Lowering the shunt coil value or increasing the resistance of the stabilizer layer will help with film boiling.

Bath Conditions Impact on Ability to Recover

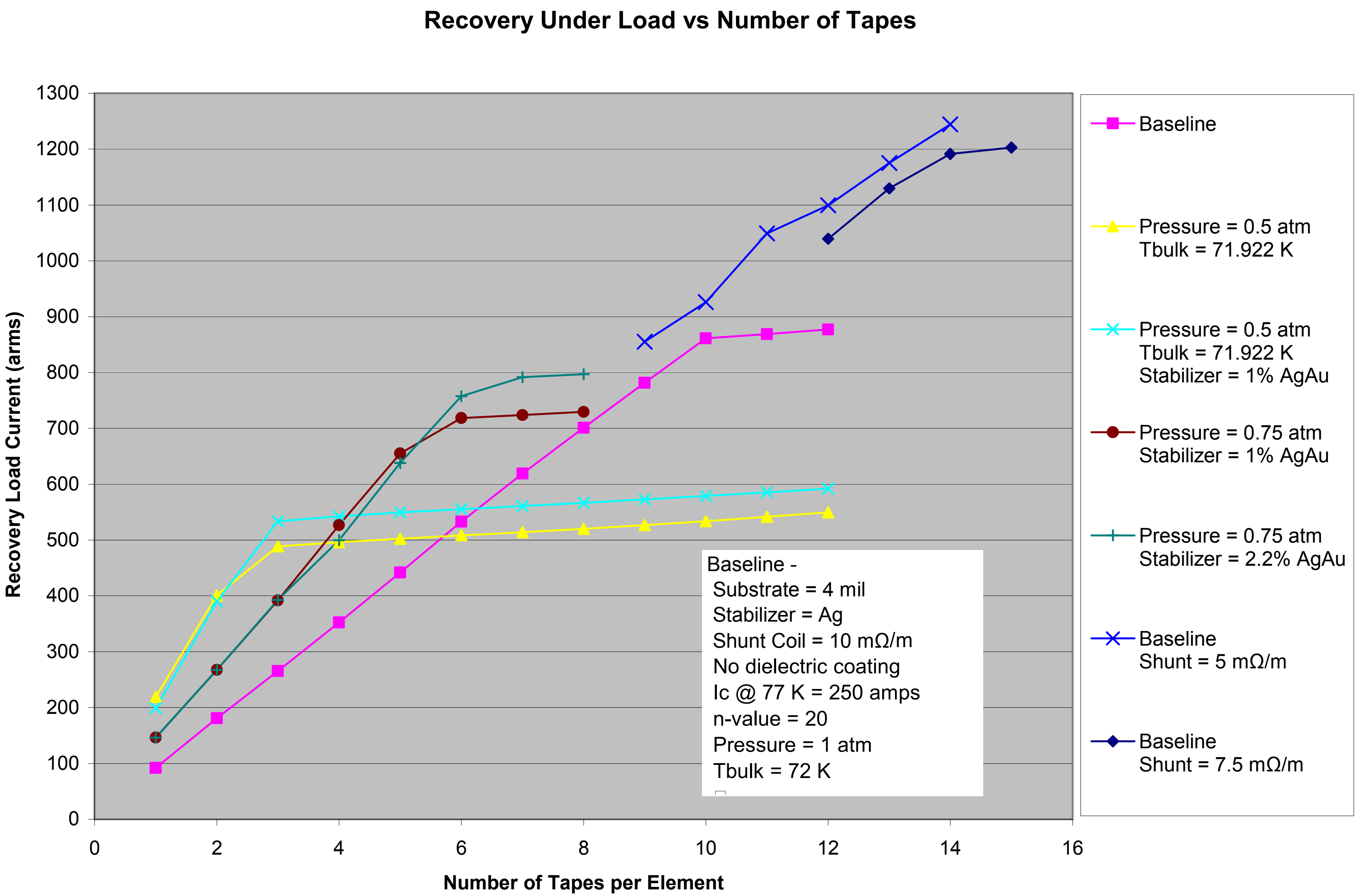
Once film boiling threshold is crossed, nucleate boiling ensues
Bath conditions (pressure, subcooling) shift boiling heat transfer curve
Bath pressure shifts saturated boiling temperature, limiting nucleate boiling recovery





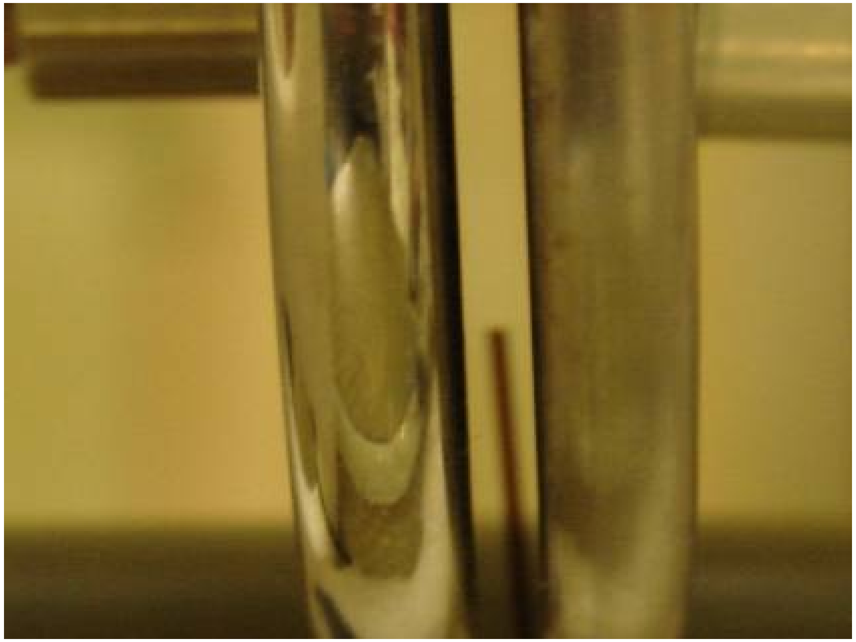
Lowering the operating pressure will help with nucleate boiling, but decreases dielectric properties

Modeling indicates where operating conditions for successful RUL exist



Introducing bubbles in LN lowers breakdown strength: FCL recovery

Bubbles form thermally or electrically and can affect the breakdown strength

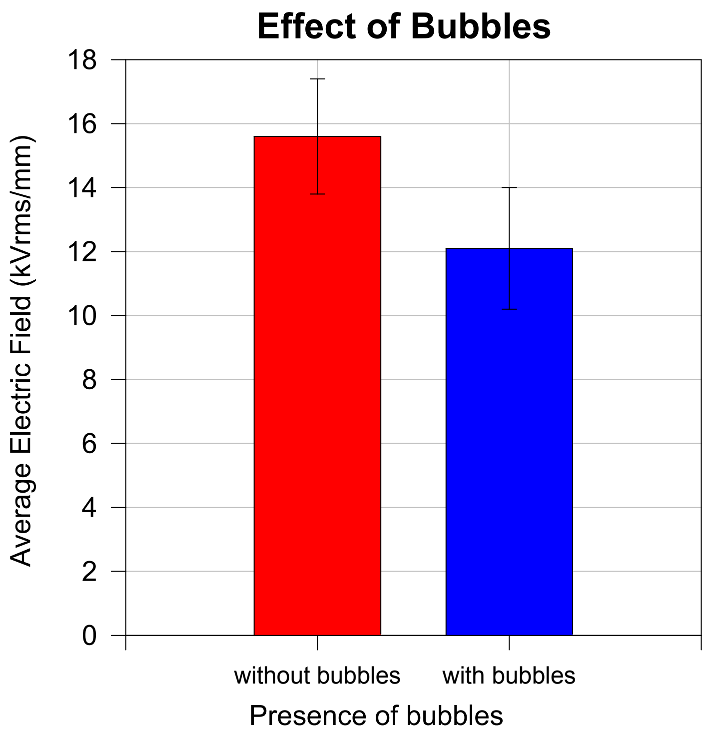


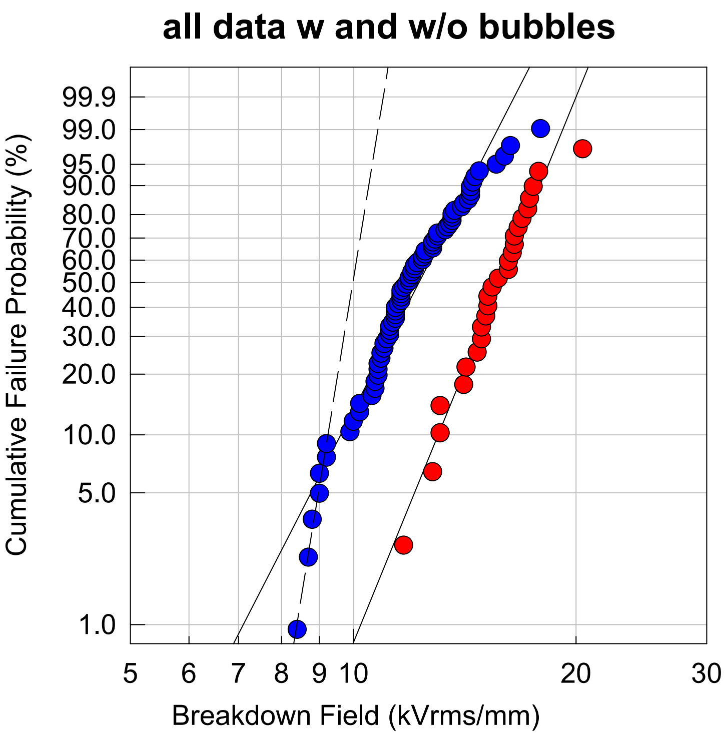
2 mm gap
0.5 mm capillary tube

- **Two experiments**
  - **Open bath LN**
  - **Pressurized cryostat**
- **Nitrogen gas provided by fused silica capillary tube**
- **Varied flow rates**
- **Parallel plane profiled SS electrodes**
- **BD strength of LN is ~5x the gas at 1 bar**

Important for FCL Recovery under Load

Effect of externally provided bubbles on LN Breakdown: AC breakdown





Liquid nitrogen at 1 bar

- Bubbles in LN lowers breakdown strength
- Change in slope at lower probability indicates change in BD mechanism

Summary

- Significant progress in understanding and impacts of:
  - RUL
    - Variables impacting RUL studied and understood
    - Worst case conditions at TIDD can be met
    - Impact of device design and cost under evaluation
  - LN_2 Dielectrics
    - Impact of bubbles on breakdown mechanism and dielectric strength
- Loss of cryogenic partner a setback, but not fatal
- Next step: Alpha detailed design

Thank You for your attention!

For more information:

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or

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