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Superconducting Fault Current Limiter Modules for Power Transmission / Distribution

Program Manager: Juan-Carlos H. Llambes, Ph.D.

Superconductivity for Electric Systems
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PHILIPS SuperPower, Inc. is a subsidiary of Royal Philips Electronics N.V.

Presentation outline

Program Outline & Objectives

FY09 Milestones

FY09 Accomplishments & Results

FY10 Planned Performance & Milestones

Technology Transfer, Collaborations & Partnerships

Summary

2009 Program focused on module development

- The current project purpose is focused on the development of second-generation (2G) high-temperature superconductor (HTS) based modules for a superconducting fault current limiter (SFCL) for operation at voltage levels up to transmission level. These modules can then be used in later proof-of-concept and alpha/beta prototypes

- The primary objectives for FY09 were:
  - to continue to improve our understanding of the impacts of recovery under load (RUL) on the module design
  - to continue to optimize the performance of the 2G HTS wire
  - to investigate the performance of more compact alternate ‘module’ concepts
  - to test FCL module components at rated voltage in a cryogenic environment

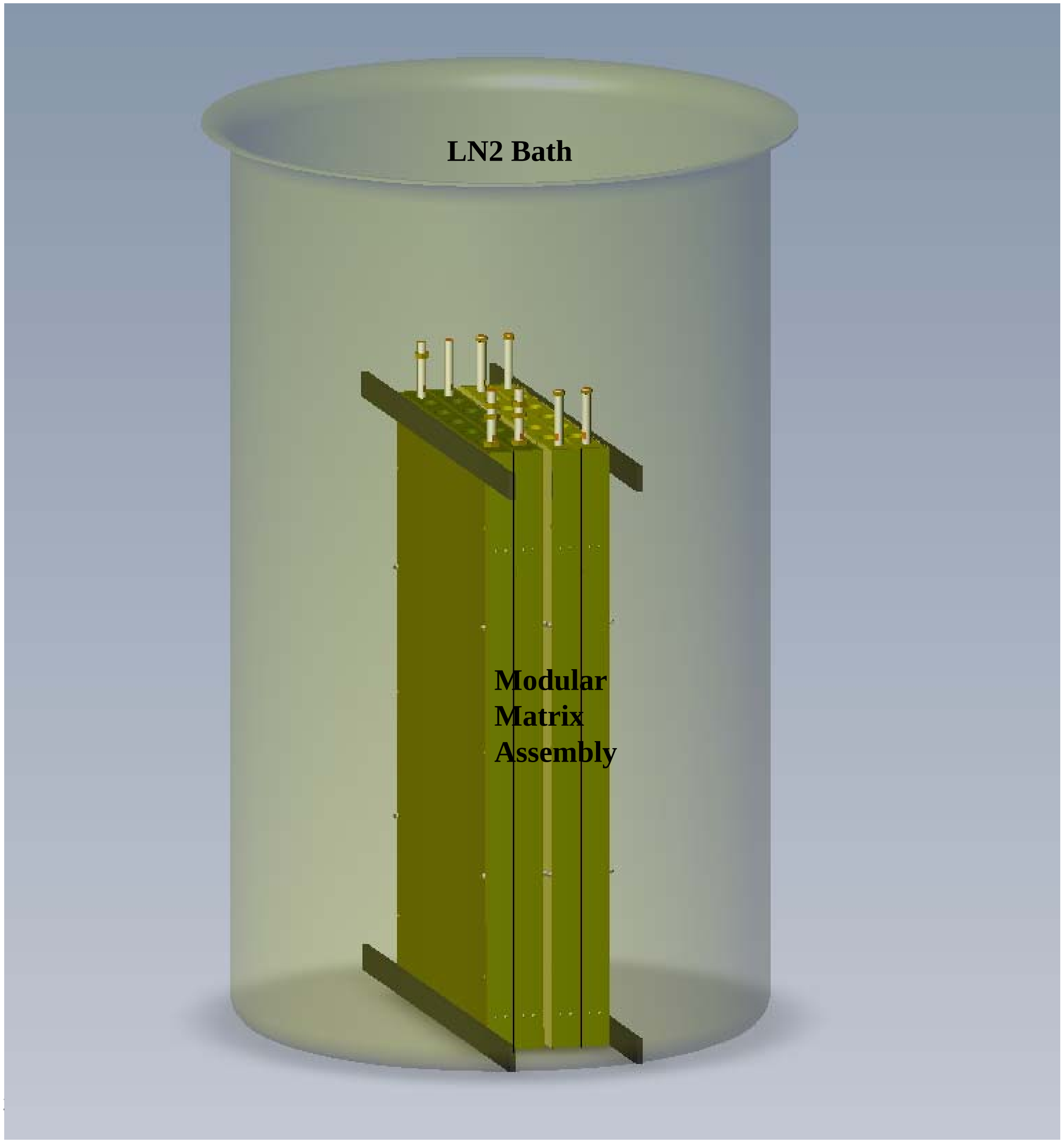
SFCL modular system design – components integration

Module Design Specification and criteria

- **2G tape** – Jc, J/cm/tape, RUL Arms/tape, mechanical, thermal and electrical properties
- **Shunt Coils** – Zsh = Rsh + jXsh, X/R ratio, EM force withstand, thermal and electrical properties, connectors, size, weight, over-banding, ease of assembly and manufacturablity
- **HTS assembly** – Tape per element, RUL per element, element energy capability, connectors, size, cooling orientation, failure mechanisms and mitigation, losses and their effects on cryogenics design
- **HV design** – LN2 and GN2 design stress criteria, spacing between tapes, elements and modules, stress shield dimensions, using solid barriers or not, bushings and assembly integration, assembly supporting structure (post insulators), overall assembly to cryostat spacing and integration
- **Cryogenics** - LN2 flow control, LN2 and GN2 interface, pressurizing, safety issues, thermal handling of fault and steady state losses

Complete Transmission / Distribution System Design Boundaries

- Instrumentation, control and condition monitoring of SFCL system
- **Systems issues** - SFCL device testing, systems study and utility interfaces



Generalized SFCL specification development

- Modular baseline design for transmission and distribution lines
  - Module current scalable in multiples of 500 A_{peak}
  - Module voltage scalable from 400 V - 1 kV_{peak}
  - Prospective fault currents scalable from 5 - 10 kA_{peak}
- This modular design allow us to scale up validated module voltages and currents in order to accomplish both Distribution and Transmission levels
- Therefore, both Distribution and Transmission level devices can be built using the same modular approach
- The number of modules used will be based on the voltage / current requirements of the application

Prior accomplishments

Proof-of-Concept demonstrated:

- MCP 2212 (2004)
- 2G YBCO (2006)
- Completed design and testing of HV bushings (ORNL, SEI, 2006)
- Weibull plots of ‘standard’ 2G failures (2006)
- Investigated several engineered 2G architectures for improved RUL (2008)
- Modify 2G conductor to improve performance for the FCL application (2008)
- Improve connector design (2008)
- Designed / tested shunt coils to withstand high fault transient loads (2008)
- Demonstrated Recovery Under Load (RUL) prove of concept and requirements (2008)
- Thermal simulation of RUL process (2008)
- Investigated LN2 dielectric properties (with ORNL, 2005-2008)
- Beta device testing specifications established (2008)
- Study of the Impact of bubbles on breakdown mechanism and LN2 dielectric strength (with ORNL 2008)

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FY09 Major milestones accomplished

- Increase compactness and reduced number of connections
- Designed Recovery Under Load (RUL) in the modular design
- Modified 2G conductor improving modular SFCL performance
- Simulated Shunt coil tests for modular RUL
- Experimental testing of the modular fault and RUL response
- Designed shunt coil and connector design for new modular configuration
- Designed Thermo and Electric dynamics of RUL for the modular design
- Tested High Voltage design of the modular SFCL
- Investigated LN2 dielectric properties of the modular SFCL

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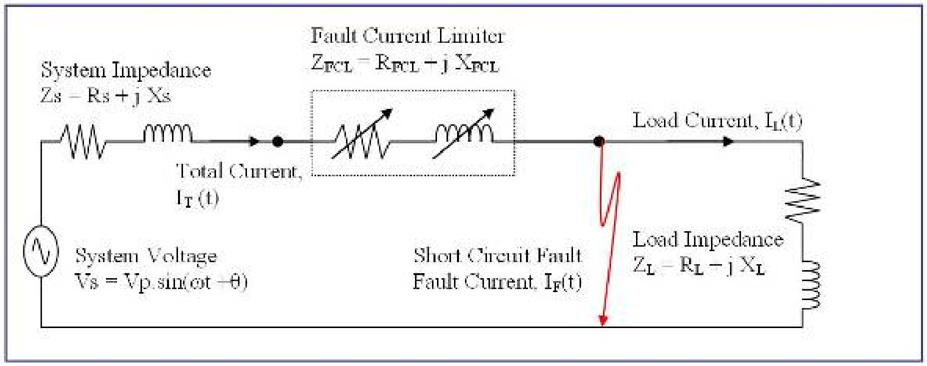
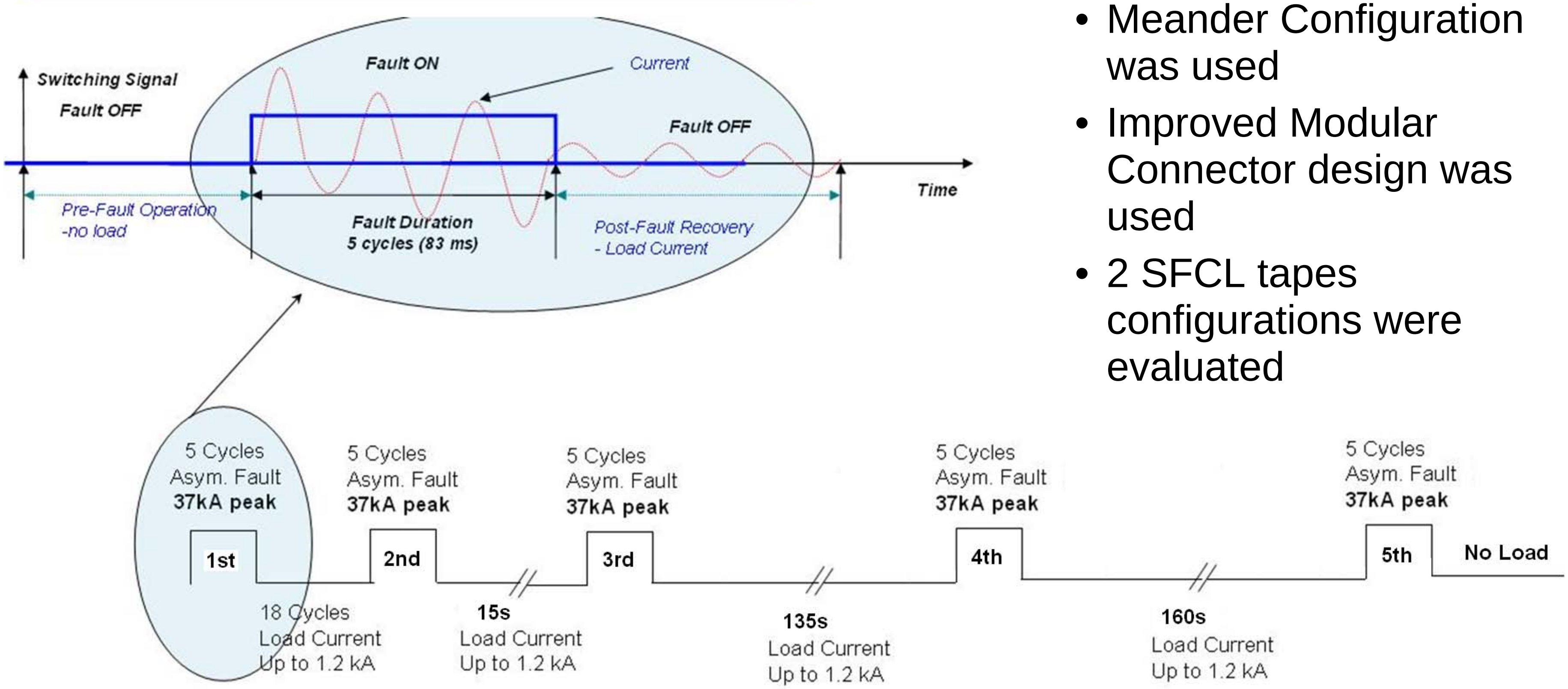
Power tests conducted at CAPS to validate module design





Typical AEP reclosure sequence

- Recent rounds of CAPS testing focused on critical AEP reclosure sequence for MODULAR SFCL Design
- Meander Configuration was used
- Improved Modular Connector design was used
- 2 SFCL tapes configurations were evaluated

2G Modular RUL capabilities tested at FSU-CAPS

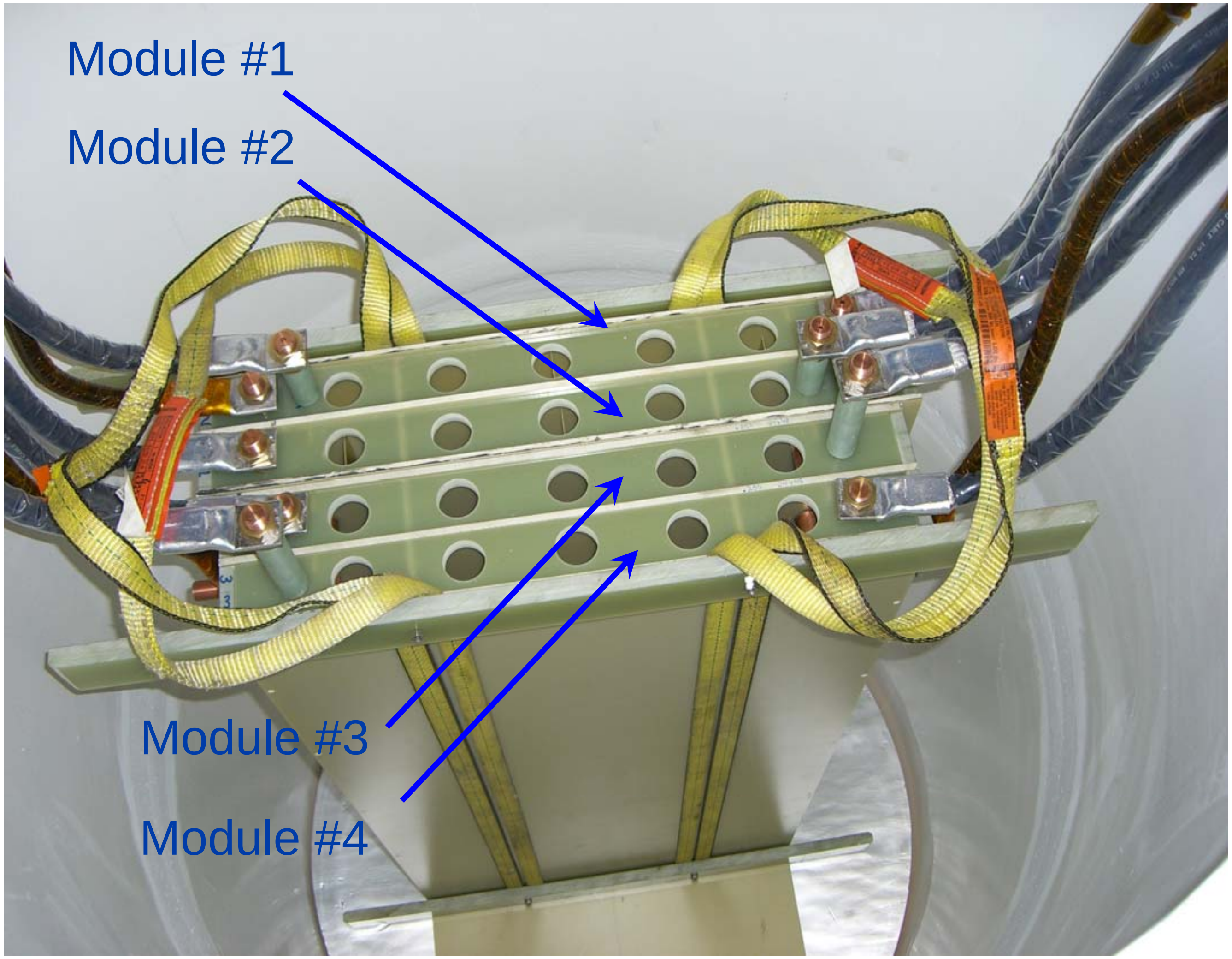
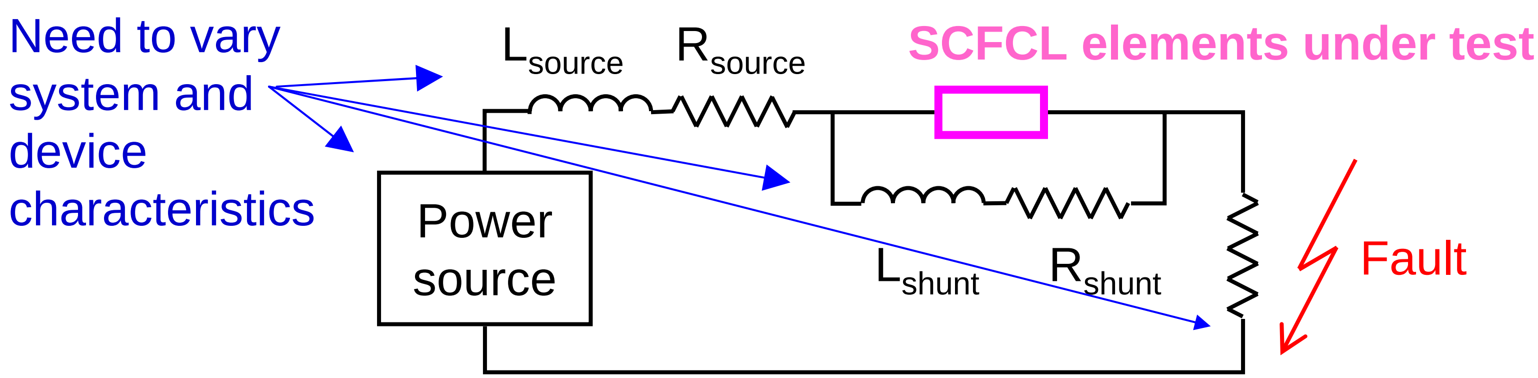


Photo of 4 modules in test dewar ready for test

- 2 SFCL tapes configurations were evaluated with 2 types of modules.
- Test conditions:
  - 5-10 kA Modular Prospective Fault
  - Follows AEP sequence
- Test variables:
  - Simulated Shunt impedance
  - Different parallel Modular circuits
  - System voltage (v/cm/tape)
  - Load Currents

Motivation for Power-Hardware-in-the-Loop (PHIL)

- Test of FCL modules/elements
  - under different grid conditions (1-ph or 3-ph faults)
  - system parameter uncertainties (variance in source impedance)
- Modification of FCL configuration/design (e.g. parallel shunt)



Possible difficulties with traditional hardware testing setups

- Flexible test envirronments are costly and setup is time intensive
- Several system conditions are difficult to reproduce (e.g.reclosing)

The optimal solution: Power-Hardware-in-the-Loop (PHIL) simulations

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Power-Hardware-in-the-Loop (PHIL) test facility at FSU-CAPS

Real Time Simulator RTDS

4.16 kV utility bus

AC Voltage feedback to RTDS

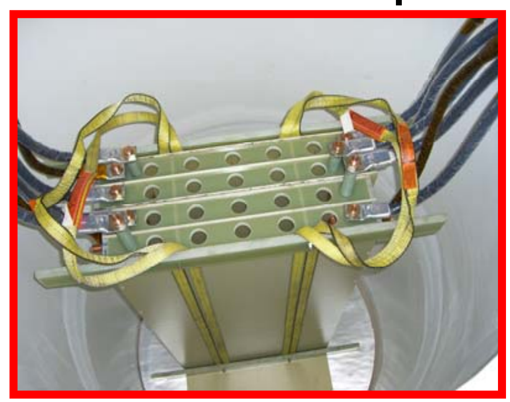
AC current reference from RTDS

0…4.16 kV / 5 MVA experimental bus

0-480 V / 1.5 MVA experimental **AC** bus

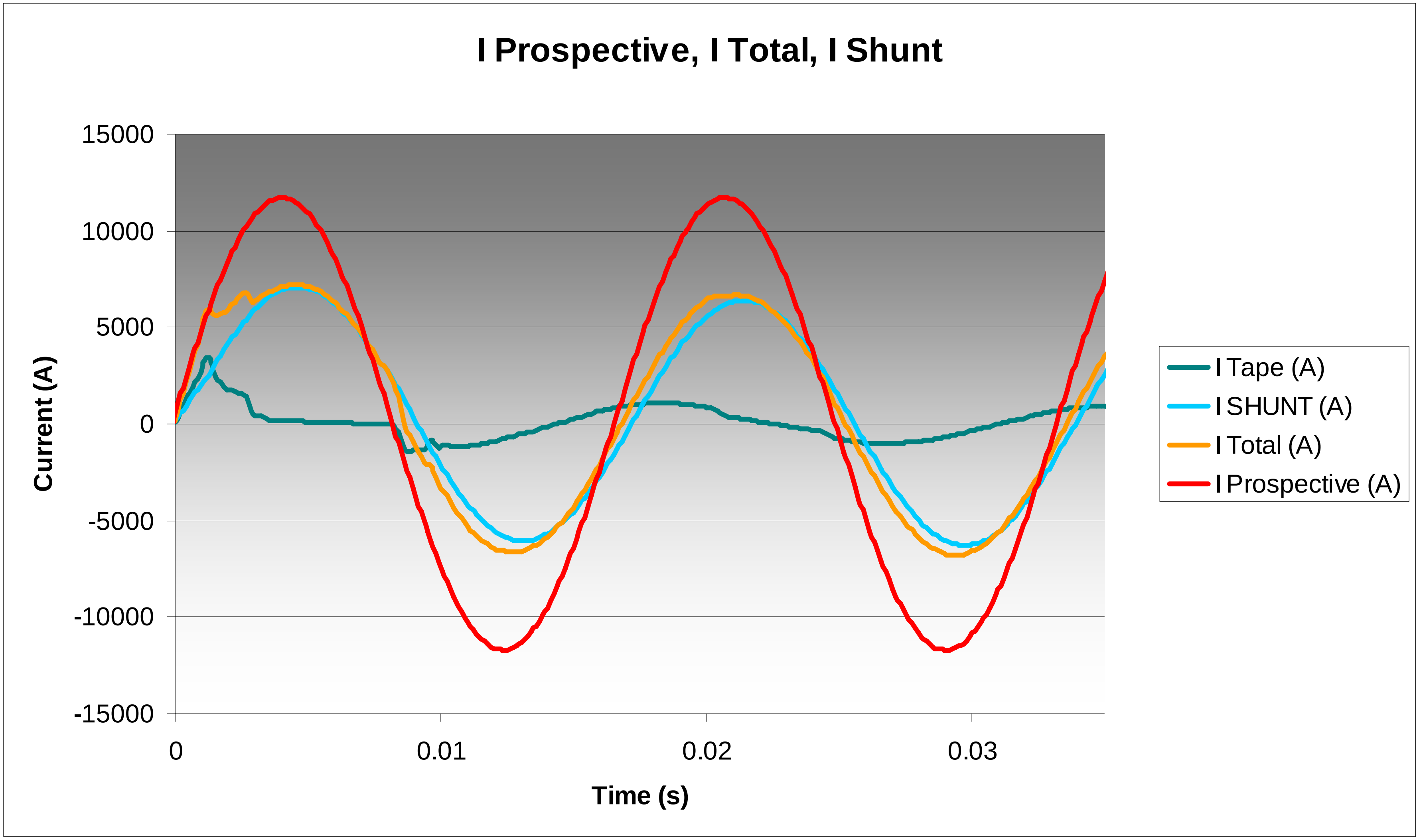
SFCL modules

5 MW Converter "Amplifier"



SFCL modules

Tape current vs. fault duration/occurrence



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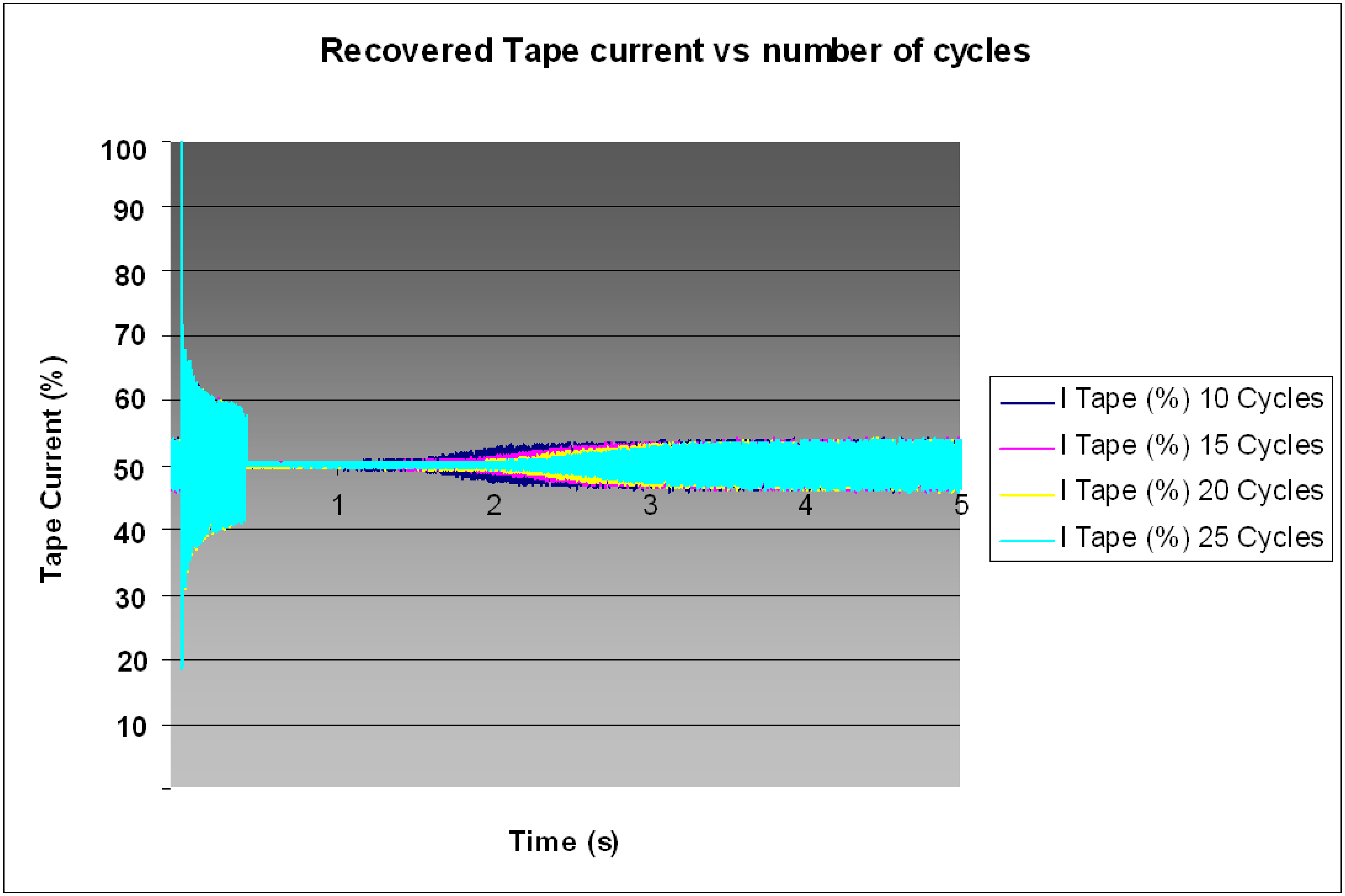

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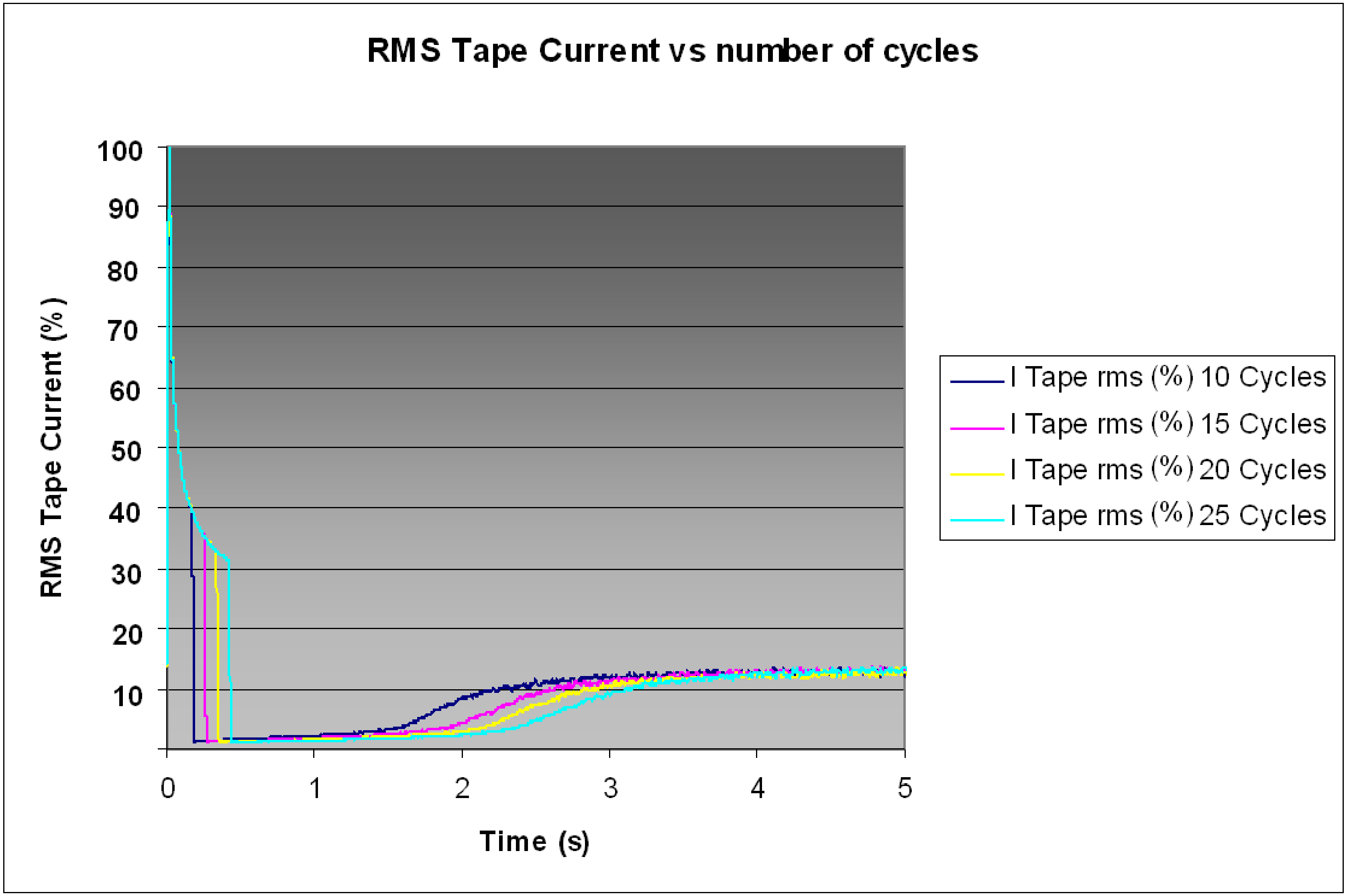
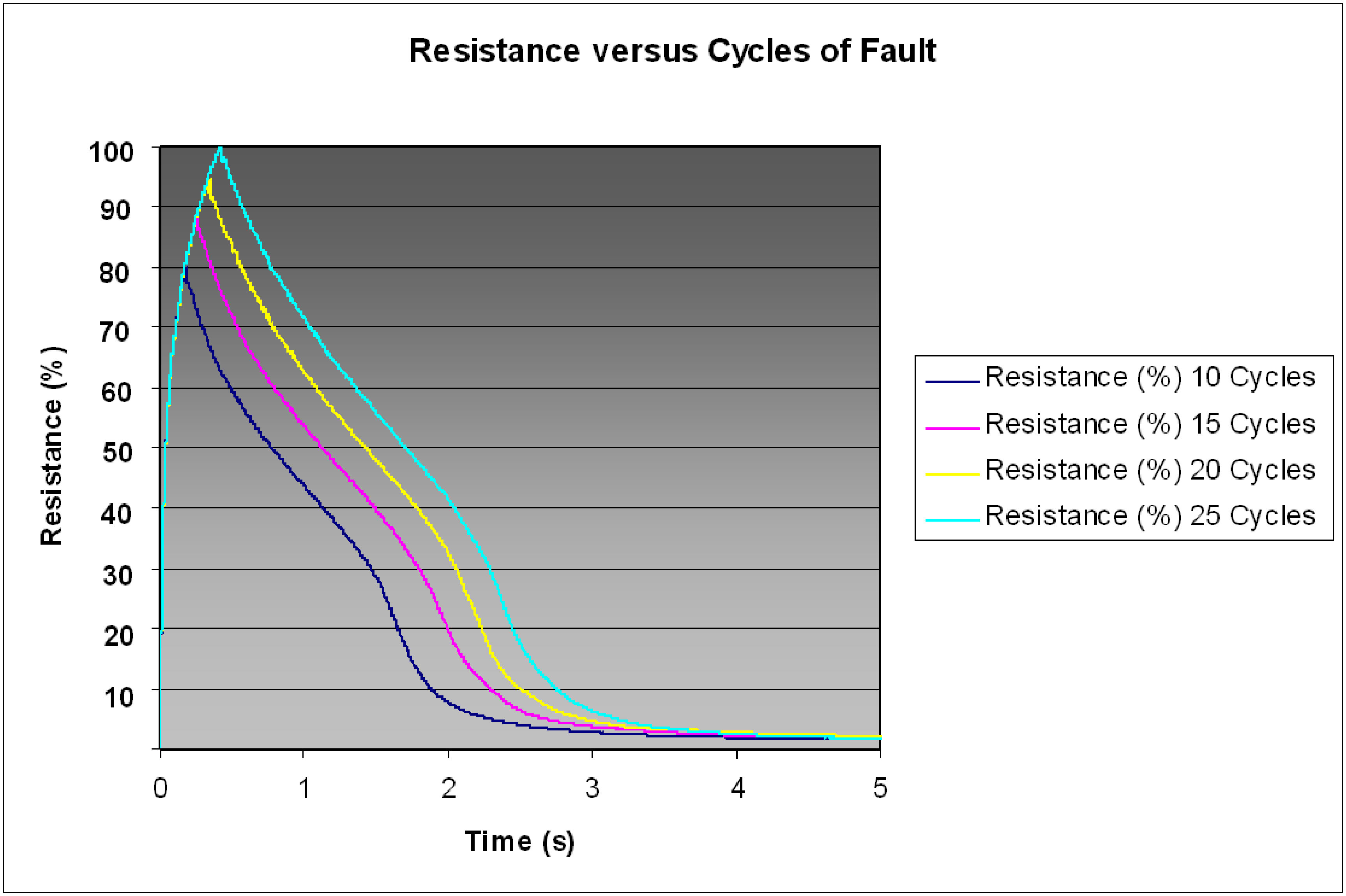
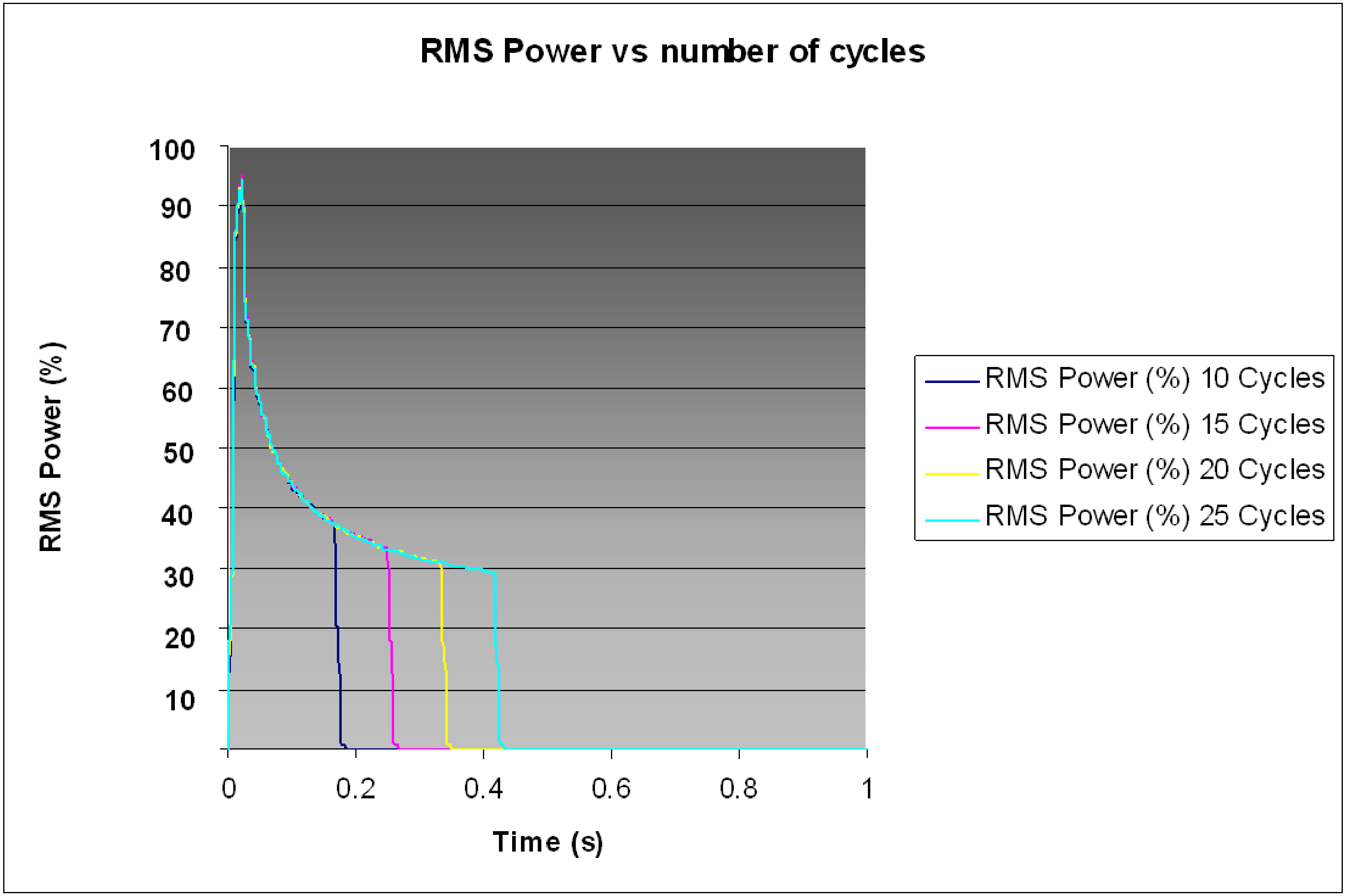


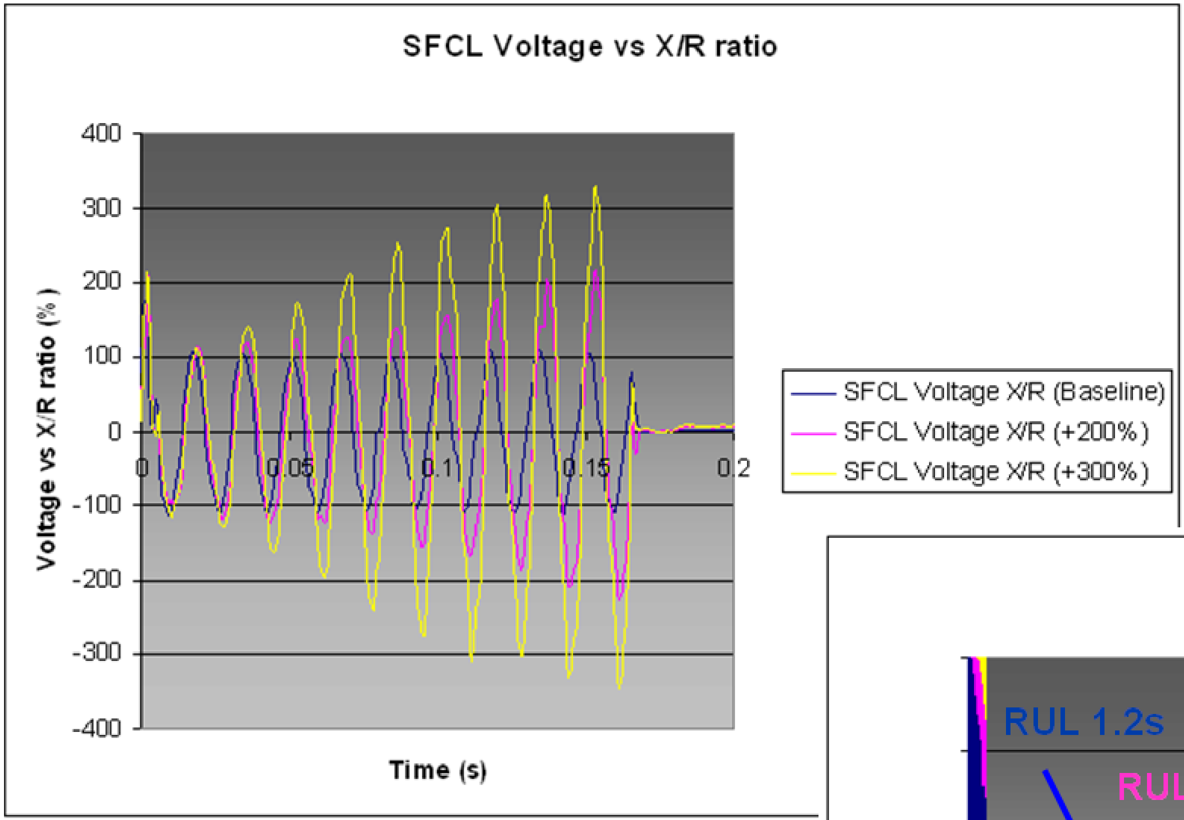
RUL resistance vs. fault duration/occurrence

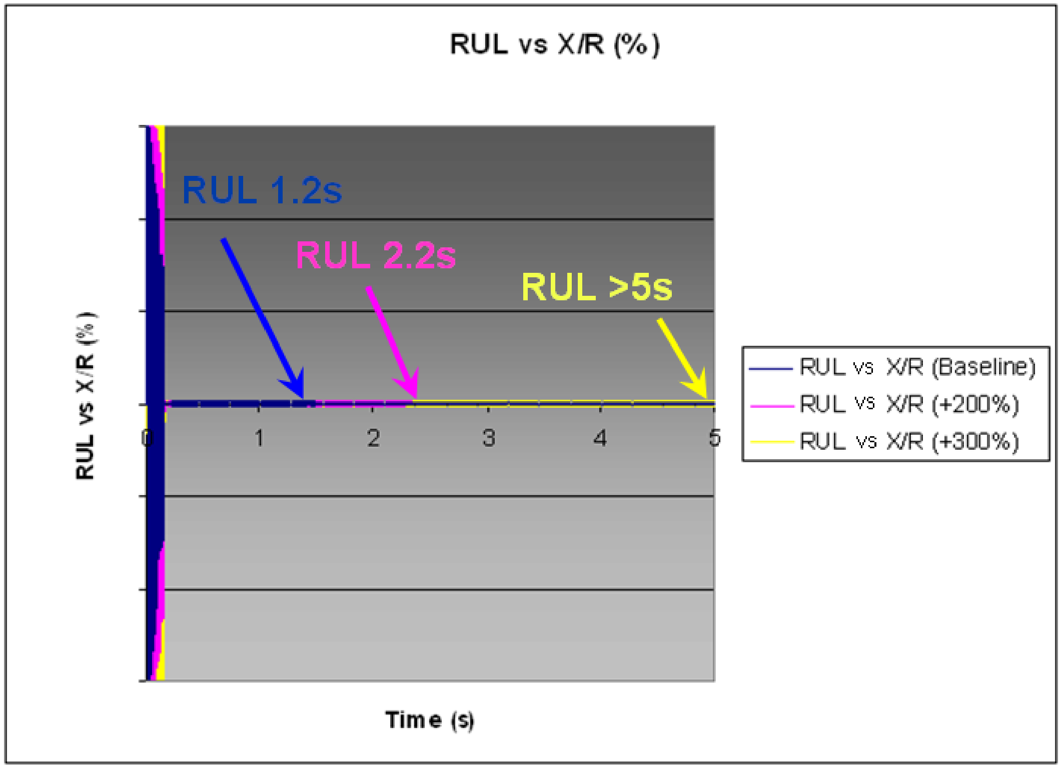


RMS power vs. fault duration/occurrence



RUL versus X/R ratio





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FY10 Plans

- Improve module performance in sub-cooled pressurized LN_2 environment
- Finalize configuration of ‘Engineered’ 2G conductor
- High Voltage insulation design for module
- Improve module RUL performance
- Improve module LN_2 dielectric performance

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Technology Transfer, Collaborations & Partnerships

- Majority of the work completed in the last year focused on SP tasks
- Strong ties remain in place with our partners who assist SuperPower with:
  - HV design (CAPS at FSU, ORNL, RPI, consultants)
  - Dielectrics (CAPS at FSU, ORNL)
  - 2G optimization and quench studies
- Papers published: 1 – Pulsed Power Conference
- Presentations: Several to prospective users of SFCL module technology

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- Focus on module development
- Significant progress in understanding and impacts of
  - RUL
    - Modular elements have been developed with RUL
    - Modular elements can meet worst case conditions
    - Impact of device design and cost has been determined
  - LN_2 dielectrics
    - Impact of bubbles on breakdown mechanism and dielectric strength has been evaluated for the modular elements