Organization(s):	**SuperPower, Nexans SuperConductors, American Electric Power, Oak Ridge National Laboratory, Los Alamos National Laboratory**
Project Title:	**Matrix Fault Current Limiter**
Presenter(s):	Leonard Kovalsky (SuperPower), Joachim Bock (Nexans), Isidor Sauers (ORNL)
FY 2005 Funding:	$2,650K (DOE to SuperPower & Nexans), $500K (DOE to ORNL)

Project Purpose and FY 2005 Objectives: The project purpose is to develop an HTS matrix fault current limiter (MFCL) for operation at the transmission voltage level. The milestone-driven program includes the fabrication of three prototypes: a proof-of-concept prototype, Alpha prototype, and Beta prototype. The first two prototypes are tested as single-phase units off the grid, and the Beta prototype is to be installed and operated as a three-phase unit in a host utility grid at the 138 kV level by early 2007. The low-voltage, single-phase, proof-of-concept prototype completed a successful test program in July 2004. This device was rated at 8.6 kV line to ground (15kV L-L), 800 A_{rms} continuous current, with first peak prospective fault currents up to 25.6 kA.

The primary FY 2005 objective was to scale the proof-of-concept design up to the 138-kV level and develop the design for the next prototype, the Alpha, to meet specific requirements for an actual utility application. This includes the supporting R&D to establish the dielectric performance of materials in a cryogenic environment at transmission level voltage.

FY 2005 Performance and FY 2006 Plans:

Summary of FY 2005 performance: A conceptual design for the Alpha prototype was completed in FY 2005. Within the concept design are options that still need to be evaluated before the detailed Alpha design is finalized. It was originally planned to have all Alpha design details complete by June 2005, but additional testing and evaluation of options will be required before the detailed design is complete. A summary of FY 2005 accomplishments include:

1) Established application requirements for Alpha and Beta prototype demonstrations.
2) Conducted high voltage testing to characterize the dielectric performance of LN2, GN2 and solid insulating materials in a cryogenic environment for 138-kV applications.
3) Completed Alpha high voltage conceptual design, with options on approach to bushing system.
4) Completed Alpha conceptual cryostat design.
5) Completed Alpha HTS conceptual matrix design, with selection of component values to be finalized in detailed design.
6) Implemented improvements and upgrades in Melt Cast Processed BSCCO 2212 HTS elements.

FY 2006 Plans:

1) Conduct additional testing and evaluation of options to finalize Alpha prototype detailed design by November 2005.
2) Complete assembly and test single-phase Alpha prototype at 138 kV by June 2006.

FY 2005 Results:

1) Alpha & Beta Prototype Requirements: AEP specified the application requirements that drive the 138-kV Alpha and Beta prototypes and include the steady state operating current, prospective fault current, and current limiting requirements. The requirements are selected to eliminate the need for a sequential breaker trip scheme presently used in normal operation to overcome the breaker over-duty problem at AEP's Sporn substation. A breaker re-close scheme is employed, and the MFCL will have to withstand periods of fault current followed by load current if the fault is persistent and the MFCL will have to recover back to a superconducting state while carrying load current. The high

voltage testing requirements such as impulse and ac withstand were established based on what is used for circuit breakers and transformers and current limiting reactors at 138kV.

2) High Voltage Characterization Tests: Tests at ORNL have resulted in an understanding of the basic dielectric characteristics of GN2 and LN2 for 138-kV applications and the development of design rules, including the effect of pressure on the insulating properties of GN2 and LN2. Basic geometries such as the sphere-plane, cylinder, and rod-plane electrodes were tested with different conductor and insulator interfaces and gap lengths. Using these test results, the preliminary transfer functions have been developed to predict breakdown voltages for the range of voltage, gap, and electrode geometries. Also, the insulating materials used in two commercial bushings have been qualified for operation in a cryogenic environment.
3) Concept High Voltage System Design: Using the design rules established above, a preliminary design of the MFCL internal and external insulation system was developed. One pending issue is the down-select between two options for the bushing system. The first option is a bushing system design developed for HTS cable termination applications, and the other is to use a conventional bushing customized for the specific MFCL application. The main tradeoff is the impact on the cryostat design, which is under evaluation.
4) Concept Cryostat Design: A design that achieves a stable pressurized sub-cooled environment has been selected.
5) Concept HTS Trigger Matrix: A series of short circuit tests were conducted at KEMA PowerTest on matrix mock-up assemblies using 20cm elements to qualify the performance of the elements under repetitive short circuits and to determine the best trigger circuit to enhance the uniform quench of the elements for the scale up to high voltage. Four different types of trigger circuits were evaluated and a design that meets the requirement to rapidly quench the elements and simplifies the overall high voltage design was selected. Further tests are planned to refine component values.
6) HTS Element Development: Improvements were made in the stabilization and connector design of the 20cm elements used in the pre-prototype tests. A design to combine two 20cm elements into one 40cm element was developed. Qualification tests of the elements to determine the energy handling capability are ongoing and will continue in FY2006.

Research Integration: There is a very high level of research integration on this project, both within the broad expertise of the project team, and in the forums that have been created to review the program progress. The project team consists of the following organizations and respective responsibilities:

1) **SuperPower, Inc**.: Program management, overall system integration, cryogenic system design, HTS matrix assembly, high voltage system design.
2) **Nexans SuperConductors GmbH**: Development and manufacture of Melt Cast Process (MCP) BSCCO 2212 tubes.
3) **American Electric Power**: Device requirements and utility host for Beta prototype demonstration.
4) **Oak Ridge National Laboratory**: High voltage R&D, material testing, and cryogenics.
5) **Los Alamos National Laboratory**: Support testing of HTS elements and assemblies.

There are two forums for review of project progress:

1) **Technical Advisory Board (TAB) –** The program team meets with the Board to formally review program progress with detailed presentations. The board consists of representatives of the two main sources of funding, DOE and EPRI as well as representatives of five utilities and academia. The DOE Readiness Reviews are also held concurrent with the TAB meetings. Two TAB meetings with embedded Readiness Reviews were held since June 2004.
2) **National Electric Energy Testing & Applications Center (NEETRAC)** at Georgia Tech: One of the projects funded by NEETRAC's utility members includes a periodic review of the MFCL program progress and to provide guidance to steer the operating performance and test requirements. Five utilities are involved in this project and five teleconferences were held with the NEETRAC members since June 2004.