Project Title:	**HTS Transformer: Waukesha/SuperPower Superconductivity Partnerships with Industry Project**
Organization(s):	**Oak Ridge National Laboratory**
Presenters:	S. W. Schwenterly
FY 2003 Funding:	$555 K (DOE to ORNL)

Project Purpose and FY 2003 Objectives: The objective of the current Phase II Superconductivity Partnerships with Industry (SPI) project with Waukesha Electric Systems (WES), SuperPower (SP), and Energy East (EE, formerly Rochester Gas & Electric) is to demonstrate the technical and economic feasibility of HTS transformers of medium (30 MVA) to larger ratings. An alpha-prototype, 5/10 MVA, 3-phase, HTS transformer, with primary /secondary voltage ratings of 24.9/4.2 kV and a 150-kV BIL requirement has been designed, fabricated, and is being tested. This unit will later be operated long-term, supplying power from the local utility grid to WES's main manufacturing plant in Waukesha, Wisconsin. ORNL's FY 2003 objectives are to:

1. Participate in the assembly, commissioning, and testing of the 5/10-MVA transformer at WES.
2. Complete design of the MLI blankets for the 5/10-MVA HTS coil set.
3. Refine cryogenic and high-voltage insulation designs for commercial 30-MVA transformers.
4. Carry out ac loss and critical current tests on further sample coils for the 30-MVA transformer.
5. Continue high-voltage insulation tests, with focus on 550-kV BIL applications for 30-MVA transformers.
6. Investigate fault-current-limiting transformer designs.
7. Carry out any other required materials testing as necessary and appropriate for ORNL facilities.

FY 2003 Performance and FY 2004 Plans: Project activities focused on final assembly and testing of the 5/10-MVA transformer, as described below. Tasks 3 and 6 above were deferred so that ORNL could complete the MLI blanket design and take over procurement of the LN tank module as requested by the industrial partners. No further ac loss sample coils were received for Task 4 in 2003. Electrical insulation tests continued on solid materials and epoxies. Heat capacity measurements were also made on Stycast epoxy. Following completion of the Phase II SPI in FY 2003, a new proposal for follow-on work in FY 2004-05 may be submitted. This two-year interim project will supply further R&D data required for design of the Phase-III prototype commercial 30-MVA transformer. Plans for this phase include:

1. Critique and provide technical input to the 30-MVA transformer reference design.
2. Continue measurements of dielectric, thermal, and mechanical properties of candidate cryogenic electrical insulation materials for transformer design ratings of 30 MVA and above. Topics would include partial discharge, ac and impulse breakdown strength, tan delta, thermal shock resistance, thermal conductivity, and heat capacity.
3. Perform cryogenic tests on specific dielectric components for the 30-MVA reference design.
4. Investigate the incorporation of second-generation YBCO materials into the 30-MVA reference design, including ac loss, over-current capability, and fault current limiting issues.
5. Investigate the utilization of pulse-tube cryocoolers in the 30-MVA reference design.

FY 2003 Results: ORNL personnel participated in partial discharge tests on the first and third phase coil sets for the 5/10-MVA transformer. The first set was cooled down with liquid nitrogen and brought in stages to 17 kV without failure. The test yielded valuable experience for the cool-down of the completed transformer. The third phase was later inspected and tested for partial discharge at room temperature, in preparation for its final assembly. A few adjustments were made to help improve high voltage performance as a result of these inspections. Design work on the MLI blankets for the 5/10-MVA transformer coil assembly was completed, and final drawings were transmitted to SuperPower and WES. ORNL also supervised procurement of the LN tank module, which was shipped to WES in mid-December. ORNL personnel visited WES three times to participate in final assembly and cooldown of the 5/10-MVA transformer. Activities included installation of the LN tank module and related instrumentation, and installation of the coil cooling module designed and procured by ORNL in FY2002.

The aluminized mylar MLI blankets were installed on the phase set assembly, with great care to prevent electrical shorts between adjacent blankets. The cryocooler compressors, LN hoses, vacuum system, and helium supply manifolds were installed on the transformer tank. After final leak and instrumentation checks were made, the tank was evacuated and all piping was pumped and backfilled with dry helium. Cooldown began with a slow manual transfer of LN into the LN tank. Soon afterward, the three cryocoolers were started. The coils cooled smoothly at about 2 K/hr, while LN flow into the tank was controlled to maintain a few inches of liquid in the bottom. After about 10 days, the coils reached 28 K, the shields reached 75-80 K and filled with LN, and the whole system was put into automatic closed-cycle mode. At this writing the transformer is ready for preliminary electrical tests, which should be under way by the time of the Peer Review.

Materials testing included measurements of the heat capacity of Stycast 2850FT above 100 K, which were required for estimates of the cool-down time of the transformer. Cured samples of the same Stycast used in the transformer coils were obtained from Superpower and mounted in a cryocooled cryostat. The heat capacity data obtained were consistent with published low-temperature values. Partial discharge studies have been conducted on solid samples with intentionally placed defects (such as bubbles or voids) with the ability to vary the pressure inside the defect. Preliminary data shows that PD inception can occur at voltages as low as 600 V at low pressures. The onset and extinction voltages generally follows the shape of the Paschen curve (which governs uniform field gas breakdown) as a function of pressure, but the voltages are higher.

ORNL personnel participated in inspection and partial discharge (PD) testing on the first two phase coils for the 5/10-MVA HTS Transformer, in preparation for final assembly of the coil sets. The tests were performed at SP and WES using the ORNL digital PD system. PD tests were conducted on a coil set before and following a test cool-down and the second coil was tested at room temperature. Lower than expected PD onset was observed in both cases, the cause of which is still being investigated. Several small model samples of various practical electrode designs were also studied.

Research Integration: ORNL team members visited SP and WES on seven occasions to carry out assembly and testing on the 5/10-MVA transformer. Several of these visits extended to as much as two weeks. Collaboration within the team continued to proceed smoothly, with each member contributing in its particular area of expertise as shown below:

- Waukesha Electric Systems - Project management, conventional component engineering and procurement, market assessment, and benefit analysis.
- SuperPower - HTS conductor development and manufacturing, coil winding development and fabrication, cryogenic and electrical transformer design.
- Oak Ridge National Laboratory - Cryogenic design and analysis, transformer and systems analysis, component design and procurement, HTS conductor dc/ac testing, and dielectric testing.
- Energy East - Transformer applications engineering, market evaluation, and technology benefits.

A presentation on test results for the 5/10-MVA cooling module was given at the 2002 Applied Superconductivity Conference. A paper on the 5/10-MVA cooling module design has been submitted and accepted for the 2003 CEC/ICMC Conference. Two papers (one on solid dielectric breakdown and the other on vacuum flashover) were presented at the Conference on Electrical Insulation and Dielectric Phenomena in October 2002. Also a paper was published on cryogenic dielectrics in a special issue of the IEEE Trans. on Dielectrics and Electrical Insulation in December 2002.