Organization:	**Oak Ridge National Laboratory**
Project Title:	**HTS Transformer: Waukesha/IGC-SuperPower Superconductivity Partnership Initiative Project**
Presenter(s):	**S. W. Schwenterly (ORNL)**
FY 2002 Funding:	**$600K (DOE to ORNL)**

Project Purpose and FY 2002 Objectives: The objective of the current Superconductivity Partnership Initiative (SPI) project with Waukesha Electric Systems (WES), IGC-SuperPower (IGC-SP), and Rochester Gas & Electric (RGE) 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 100-kV BIL is being designed and fabricated. This will be operated long-term, supplying power from the local utility grid to WES's main manufacturing plant in Waukesha, Wisconsin. ORNL's FY 2002 objectives are to:

1. Fabricate, assemble and conduct performance tests (with a dummy load) on the cryogenic cooling system for the 5/10-MVA transformer and help with its subsequent installation in the transformer.
2. Participate in the assembly, commissioning, and testing of the 5/10-MVA transformer at WES.
3. Carry out ac loss and critical current tests on YBCO coils as they become available.
4. Continue high-voltage breakdown and partial-discharge experiments for composite dielectric materials in practical electrode geometries applicable to the 30-MVA HTS transformer design.
5. Carry out 10x fault current tests on sample windings provided by IGC-SP.

FY 2002 Performance and FY 2003 Plans: Work continued on the Phase II SPI project that was approved in FY 1998. Fabrication and assembly work on the 5/10-MVA transformer cryogenic cooling module was completed by outside shops at Oak Ridge, and the unit was tested successfully at the WES site. A multi-layer insulation (MLI) design task was undertaken. The fourth ac loss sample from IGC-SP was tested extensively in the cryocooled ac-loss test cryostat. Electrical insulation tests continued on solid materials and epoxies in order to verify materials and designs for the 5/10-MVA and 30-MVA transformers. Tasks 3 and 5 have been deferred toward the end of FY2002 due to higher priority tasks. ORNL's FY 2003 plans include:

1. Continued participation in assembly and testing of the 5/10-MVA transformer at WES.
2. Verification testing of YBCO coated conductor samples from IGC-SP.
3. Continued high-voltage breakdown, partial-discharge, and lifetime measurements on various dielectric materials in practical electrode geometries, at BIL and operating voltage levels appropriate for 30-MVA HTS transformer designs.
4. Investigation of the feasibility of individual metallic transformer phase cryostats with insulating breaks, so that the core need not be in vacuum.

FY 2002 Results: Fabrication and assembly of the ORNL-designed cooling module for the 5/10-MVA transformer was completed in commercial shops near Oak Ridge. The unit was shipped to Waukesha without damage and installed in their large vacuum test tank. The tests confirmed that the rated power of the cryocoolers could be extracted from the load at 20-50 K with acceptable temperature differentials.

More detailed calorimetric ac loss tests were carried out in the cryocooled test cryostat on the fourth HTS model coil from IGC-SP. This coil uses the actual tape conductor to be installed in the 5/10-MVA transformer and incorporates fault current handling features to provide a more realistic simulation of the windings. The cryostat and data system were upgraded to allow monitoring of the many extra sensors that were installed in this coil. Analysis of the data gave a more detailed profile of ac losses vs. turn position in the coil. The losses are acceptable and comparable to those measured previously.

A new task for FY 2002 was design of the MLI blankets that surround the phase coil sets in the 5/10-MVA transformer. This was undertaken in return for a harmonic analysis by IGC-SP on the cryogenic suspension of the ORNL cooling module. This trade-off was made to achieve a better match to the capabilities at both organizations. Shop drawings were prepared for all the blankets, and full-size patterns were sent to WES to check the fit to the coil sets. The blankets are now being fabricated by a commercial supplier.

Studies continued on dielectric materials at room and cryogenic temperatures, including ac breakdown and withstand, impulse breakdown (BIL), partial discharge and aging, tan delta, and thermal shock. Materials studied include filled and unfilled epoxies, liquid nitrogen, vacuum, and manufactured components that have not been previously tested at both high voltage and liquid nitrogen temperatures.

Additional statistical data were obtained for the epoxy selected for various applications in the 5/10-MVA unit. In total, 13 samples were run at room temperature and 24 samples were run at liquid nitrogen temperature. AC breakdown data for these samples were found to follow Weibull statistics, which apply to a weakest link model, due to the presence of random voids in the sample. Hence reduction of voids will maintain the high strength of the material under the application of high electrical stresses.

Partial discharge (PD) studies on intentionally-placed voids in a visually transparent epoxy showed that significantly more PD was observed in samples with a known void than for samples without. The PD pattern was observed to change at liquid nitrogen temperature from that observed at room temperature, indicating the potential for using PD analyses for identifying voids in equipment. Other samples have been made with voids contacting one of the electrodes and with multiple voids, and these samples are currently under investigation.

Breakdown studies on new epoxies have identified a material with significantly increased breakdown strength in liquid nitrogen over room temperature. A practical cylindrical geometry test has been performed and further testing with this geometry is planned. These tests are directed toward meeting the 550 BIL requirement for 30-MVA, 138kV class equipment.

Technology Integration: ORNL team members met with IGC-SuperPower and WES personnel on three occasions to review progress on the 5/10-MVA transformer. Another extended two-week visit was made to WES for testing of the transformer cooling module. Collaboration within the team continued to proceed smoothly, with each member contributing in its particular area of expertise. The original division of efforts between the members has worked well and will continue:

- Waukesha Electric Systems - Conventional component engineering, market assessment, benefit analysis.
- IGC-SuperPower - HTS conductor development and manufacturing, coil winding development and fabrication, cryogenic and electrical transformer design.
- Oak Ridge National Laboratory - Cryogenic design, analysis, and testing, transformer and systems analysis, HTS conductor dc/ac testing, dielectric testing.
- Rochester Gas & Electric Company - Transformer applications engineering, market evaluation, technology benefits.

Presentations on “Development of HTS Power Transformers” were made by C.T. Reis (IGC-SP) et al. at the 2002 IEEE Winter Power Meeting, and by S. W. Schwenterly (ORNL) et al. at the 10th US-Japan Workshop on High-T_c Superconductors (published in Physica C). A paper on the 5/10-MVA cooling module tests has been submitted and accepted for the 2002 Applied Superconductivity Conference.