Organization: Oak Ridge National Laboratory

Project Title: HTS Transformer: Waukesha/IGC-SuperPower Superconductivity Partnership Initiative Project

Presenters: S. W. Schwenterly (ORNL)

FY 2001 Funding: $770K (DOE to ORNL)

Project Purpose and FY 2001 Objectives: The objective of the current Superconductivity Partnership Initiative (SPI) 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 kVac and 100-kV BIL is being designed and fabricated. This will be operated long-term, supplying power from the local utility grid to Waukesha Electric Systems' (WES's) main plant in Waukesha, Wisconsin. FY 2001 objectives are to:

1. Contribute to engineering and design work on the 5/10-MVA and 30-MVA transformers;
2. Carry out ac loss tests on model HTS coils provided by IGC-SuperPower;
3. Contribute to development of high voltage bushing/downlead systems;
4. Conduct materials evaluation and sub-scale model tests on high-voltage dielectrics;
5. Design and fabricate the cryogenic cooling system for the 5/10-MVA transformer.

FY 2001 Performance and FY 2002 Plans: Work continued on the Phase II Superconductivity Partnership Initiative (SPI) project that was approved in FY 1998. A fourth sample coil was received from IGC-SuperPower and tested in the cryocooled ac loss test cryostat. ORNL team members met five times with the other team members to develop the preliminary design and detailed analysis of the 5/10-MVA transformer, which is a scale-down of the final 30-MVA design. Engineering analysis and design work on the 5/10-MVA transformer cryogenic cooling system was completed and fabrication is under way. Tests of the cooling system with a dummy heat load will be carried out in the late summer of 2001 at WES. Electrical insulation tests continued on solid materials and epoxies in order to verify materials and designs for the 5/10-MVA transformer. Several commercial high voltage components were tested for vacuum compatibility. ORNL's FY 2002 plans include:

1. Complete system level tests on the 5/10-MVA transformer cryogenic cooling system and supervise its subsequent installation in the transformer.
2. Carry out 10x fault current tests on a sample winding in the cryocooled cryostat.
3. Continue high-voltage breakdown and partial-discharge experiments for composite dielectric materials in practical electrode geometries applicable to the 30-MVA HTS transformer design. Tan delta measurements will also be made.
4. Carry out tests on a high-voltage winding cryogenic downlead mockup.
6. Participate in the preliminary design of the 30-MVA transformer.

FY 2001 Results: Model coils were suspended in vacuum in a special ac loss cryostat and conductively cooled by a Cryomech GB-37 cryocooler using flexible copper straps and heat sinks on the current leads. Minimum temperatures below 20 K were routinely achieved, with temperature stability below 0.1 K. A fourth HTS model coil incorporating various ac loss reduction features was received from IGC-SuperPower. This coil used the actual tape conductor

to be installed in the 5/10-MVA transformer and incorporated fault handling features to provide a more realistic simulation of the windings. The coil was about 13-cm diameter by 12-cm height, similar to those tested earlier. It was instrumented with many voltage taps and temperature sensors for critical current and calorimetric ac loss measurements. By using short, few-second pulses of ac current, ac losses could easily be resolved for individual turns. The measurements were calibrated by comparison of the ac heating rates with those for known dc heat inputs with an installed heater. For sample coils of this size, the minimum loss sensitivity is about 0.1 W. Analysis of the data indicated that the losses are acceptable and comparable to those measured on earlier coils.

Studies continued on dielectric materials at room and cryogenic temperatures in order to establish a database of the desirable physical properties including high dielectric strength, low partial discharge, low dissipation factor, thermally compatible with other materials, high mechanical strength, and good thermal conduction. Measurements included 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. Tests were performed on both pure and composite materials under the application of uniform electric field to determine intrinsic breakdown strength of the pure materials, and at relevant practical electrode geometry to assess the potential degradation of dielectric strength due to mismatch of permittivities and interfaces. Epoxy materials examined thus far have been shown to have high dielectric strength at cryogenic temperatures. Two samples have been made with practical geometries, one in which the electrodes were terminated by corona rings and one where the electrode ends were rounded instead. Both samples performed well in the bulk material while differences were observed that correlated well with intensification of the electric field at the ends. Tan delta measurements performed on certain selected filled epoxies and fiber reinforced plastic showed in general a 10-fold lowering of tan delta at liquid nitrogen temperature compared to room temperature. High voltage tests were also performed on other commercial components including fluid transfer components and thermal sensors that will have to perform in a high electric field. In addition to the electrical measurement, outgassing tests have also been performed on commercial manufactured components, since excessive outgassing can degrade the high voltage hold-off capability.

ORNL team members met with IGC-SuperPower and WES personnel on five occasions to complete the detailed engineering design for the 5/10-MVA transformer. The 5/10-MVA unit will use newly developed, high-capacity, single-stage cryocoolers. It will incorporate several features of the commercial 30-MVA design to provide extended operation at twice rating, and to remain superconducting through a 10x fault current.

Technology Integration: 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.
- Rensselaer Polytechnic Institute - Dielectric performance, field calculations, dynamic transformer response modeling.
- Rochester Gas & Electric Company - Transformer applications engineering, market evaluation, technology benefits.

A presentation was made at the *Applied Superconductivity Conference* in September 2000 on AAC Loss Measurements with a Cryocooled system@ by S. W. Schwenterly et al. Team members also made a presentation on the project at the *IEEE Winter Power Meeting* in Columbus, Ohio, in January 2001.