Project Title:	**HTS Transformer R&D: Waukesha Electric Systems/ORNL**
Organization:	Waukesha Electric Systems and Oak Ridge National Laboratory
Presenters:	S.W. Schwenterly (ORNL), E.F. Pleva (WES)
FY 2010 Funding:	$450 K (DOE to ORNL)

Overall Project Purpose and Objectives:

The objective of the project is to demonstrate the technical and economic feasibility and benefits of HTS transformers in ratings of 10 MVA and above. Building on experience gained in a preceding Phase II Superconductivity Partnership Initiative (SPI) HTS transformer project, ORNL and Waukesha Electric Systems (WES) are pursuing a joint follow-on effort of about 1 MY at each location in FY 2010. The ultimate goal is to fabricate and test a pre-commercial prototype HTS transformer operating at transmission level voltages in the 138-kV class. Important objectives are to optimize the conceptual design using second-generation YBCO conductor, and to provide increased simplicity, manufacturability, and reliability. To speed the addition of HTS transformers to WES's product line, we intend to use as much of WES's conventional transformer manufacturing technology as possible. The project supports DOE's mission to develop revolutionary power equipment using HTS wires. During FY 2010, ORNL teamed with WES, SuperPower (SP), and Southern California Edison (SCE) to submit a proposal for development of a 28-MVA, 69-kV fault-current-limiting (FCL) HTS transformer for the DOE Smart Grid Initiative. Cost-sharing for a three-year project to accomplish this has been approved by DOE. Final project definitization negotiations between DOE, WES, and SP are nearly complete.

2010 Approach and Results:

In support of the above objectives, work in FY 2010 has focused on measurement of ac loss, development of composite dewar vessels, and high-voltage insulation testing. At the beginning of the year our goal was to design, build, and test a single-phase device that would represent one phase of a 25-kV-class demonstration unit that would replace one of the 5/7-MVA transformers in WES's plant substation. After winning the Smart Grid Regional Demonstration award at mid-year, the focus shifted to preparations for the 28-MVA unit design effort. The experimental R&D program continued unchanged, since it was equally relevant to both goals.

Composite Dewar Outgassing Tests– Since the dewars around the HTS transformer coils cannot form a shorted turn, it is necessary to determine pumping requirements for a non-conducting composite dewar vessel to maintain vacuum near 10^{-4} torr. In FY 2009 a small open-top composite dewar was fabricated in a stepwise development program with a commercial manufacturer. A small commercial, oil-free, molecular drag pumping package was connected to the vacuum jacket which easily maintained the desired vacuum. During FY 2010, a long term test was carried out on the dewar to verify that a good vacuum could be maintained without buildup of outgassed material on the cold inner wall. The dewar was refilled with liquid nitrogen (LN) once a week for 4 months. The boil-off rate went up a little from 0.14 liters/hr to 0.16 liters/hr in the first week but then stayed constant over the rest of the four months. Thus, over 4 months there was no long-term buildup of condensate on the cold inner wall that could lead to a high vapor pressure and contaminate the vacuum. We could also valve the drag pump off from the dewar for 8 hours with no observable boil-off increase, but the boil-off went up to about 0.20 liters/hr if we left it valved off for a week. We could recover the 0.16 liter/hr rate when we opened the valve to the pump. In a final test, the drag unit was unplugged to simulate a power outage. The internal valves closed and protected the vacuum, as claimed by the manufacturer. These results can be scaled to show that a full-size composite dewar is feasible and will not require excessive pumping hardware to maintain a good vacuum.

AC loss test coils– The electrical ac loss measurement apparatus was improved by addition of an external toroidal air-core transformer with a voltage divider, to provide an adjustable inductive signal to buck out the inductive component of the test coil voltage. This was done because the earlier method of sliding a pickup coil in and out of the test coil appeared to be affecting the losses in the coil itself. A new test fixture was also fabricated to mount ac loss sample coils in the composite dewar described above. Since this dewar has a sealed top plate, the LN bath could be pumped down to allow loss measurements at reduced temperatures, without any effects from nearby metallic vessel walls. Three test coils wound by WES have been tested so far. Each had 50 m of conductor, wound continuously in 26 6-turn discs on a G10 composite former, with Lexan™ disc spacers. The 4-mm HTS tape was produced by AMSC and had a self-field dc I_c of about 75 A at 77 K. Voltage tap pairs were soldered across each set of two single pancake coils so that a total of 13 separate voltage measurements could be made across the entire length of the coil. In the first two coils, the HTS tape was respectively co-wound with a 5-mm copper and a 5-mm stainless steel strip, to assess the effect of a parallel fault conductor. The third coil had only the copper strip and was used to calibrate our loss setup. Loss measurements with this coil at both room temperature and 77 K agreed well with calculations using literature values of copper resistivity. The HTS coils showed good agreement between the end-to-end loss measurements and the sum of the individual coil sections. Measurements were also made at various temperatures and frequencies. The overall 60-Hz losses were within our target range of 40-60 mW/m.

650-kV BIL test coil– A new test coil rated at 650 kV BIL was fabricated by WES. The coil had simulated high-voltage and low-voltage windings of dummy copper conductor, insulated with WES's proprietary polymer material. Standard WES design procedure was used for the structure and material selection in the coil, as this has previously been found to be adequate for operation in LN. So far, the coil has successfully passed three impulse shots at both negative and positive 500 kV, as well as a 1-min ac withstand test at 200 kV rms. Further tests to 650-kV impulse voltages are planned. The new epoxy-resin bushing that was ordered in FY 2009 was used for these tests, and has performed well.

2011 Plans and Expectations:

Design and development work will continue for the 28-MVA Smart Grid unit. Major tasks include completion of the conceptual design, engineering analysis on mechanical, cryogenic, and electrical issues, and carrying out a survey of utilities. An important short-term goal is development by SP of a process to laminate their HTS tape for a high-resistance fault-limiting conductor. Several more sample coils will be fabricated as soon as conductor is available from SP. Long-term tests will be carried out on a sample epoxy-resin bushing. Detailed design work will begin on a prototype Alpha unit to simulate a single phase of the 28-MVA unit.

Technology Transfer, Collaboration, Partnerships:

Collaboration within the team continued to proceed smoothly, with each member contributing in their particular areas of expertise. ORNL teamed with WES, SP, and SCE in a successful proposal to DOE for development of a 28-MVA HTS transformer to be demonstrated at SCE's Smart Grid site. Team meetings on the project were held at both WES and SP, in addition to two visits by WES to ORNL.