

**2010 Advanced Cables and Conductors Peer Review
Project Summary**

Project Title:	Understanding and Minimizing AC Losses
Organization:	Los Alamos National Laboratory
Presenters:	Doan Nguyen and Steve Ashworth
FY 2010 Funding:	\$200 K

Overall Project Purpose and Objectives:

The overall purpose of this project is to develop and employ advanced measurements and numerical simulations for predicting and minimizing the ac loss in conductors and superconducting power devices. Our intention in this project is to develop the techniques to support the various HTS power application projects. In this year, we have focused on the ac loss in YBCO cables. The key objectives have been:

- Develop experimental techniques and numerical models to predict AC loss in three-phase cables
- Understand the effect of the design parameters (cable radii, gap between the tape, orientation of RABiTS tapes...) on ac loss in HTS cables
- Predict and measure current sharing in multilayer cables

2010 Approach and Accomplishments

We enhance our ‘core’ ac loss research program at LANL by developing experimental techniques and numerical models applicable to the increasingly complex ‘real ‘world geometries and designs being utilized by our partners. These tools are then used to generate confidential ac loss results for CRADA or other projects.

Perhaps the most complex HTS device from an electromagnetic viewpoint is the three phase tri-axial cable utilizing 2G RABiTS conductor. This design has been used by Southwire in the Bixby installation using simpler 1G material, and is planned to be used in the Entergy and the DHS ‘Hydra’ cables. In three-phase tri-axial cables, we need the sensitivity of electrical measurements to understand the loss mechanisms, this is very challenging because of the strong magnetic interaction between the phases. We developed the theoretical background showing that three-phase AC loss measurements by the electromagnetic method are, in principle, possible. This theory was then implemented in practical measurements using cable samples from, and in support of, the DHS ‘Hydra’ project. We believe these data represent the first electromagnetic multi-phase AC loss measurements. The technique is applicable to HTS devices in general, not just cables, with arbitrary phase differences between currents and / or magnetic fields, not just balanced three phase systems.

AC loss in a cable may be controlled by several parameters, such as the cable radius, the gap between the tapes or orientations of RABiTS tapes. Thus, it is critical to understand how these parameters impact ac losses in order to design low loss HTS cables. In order to answer this question, it is necessary to fabricate and measure ac loss in several cables with only one parameter changing. We produced short (<1m) solenoid-like cables wound using only one YBCO tape (either IBAD or RABiTS tape). The single-layer, single-tape design allows us to fabricate cables with very uniform gap and avoid the unbalanced current distributions. We have made six solenoid-like cables (3 IBAD and 3 RABiTS) in order to have a thorough understanding of the relation between the design parameters and cable loss.

Numerical models were refined and used extensively to predict ac loss in cables and coils. We also developed a numerical model to predict current sharing in a multilayer cable that is capable of taking the contact resistance and the presence of ferromagnetic substrate into account.

We have published 4 papers in peer reviewed literature, with 3 further papers presently submitted and have delivered 2 presentation at 2009 EUCAS conference. Three other presentations will be given at the upcoming ASC conference.

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2011 Plans and Expectations:

Our plans and expectations for FY 2011 include:

1. 3D simulation for cable is necessary to take the twist parameters into account, but it is still very challenging. We plan to continue our collaboration with outside numerical experts (Prof. Frederic Sirois' group at École Polytechnique de Montréal) to overcome this challenge. Our final goal is a complete 3D model to calculate ac loss and current distributions for multilayer, multiphase cables.
2. Understanding and minimizing ac loss in inductive coils would be another focus to support for other HTS power applications (such as generators for wind turbine, transformers...). We will improve and develop simulation models and experimental setup to study ac loss in magnet coils with different geometries.
3. We plan to develop measurements and simulations to study ac loss caused by ac ripple in DC cables; there is very limited knowledge on this issue.
4. We continue using our advanced simulation and experiments facilities to support partners in searching for low ac loss conductors and devices.

Technology Transfer, Collaboration, Partnerships:

To better coordinate the DOE funded ac loss work, LANL and ORNL have arranged a series of collaborative exchanges. The first of these exchanges involved Robert Duckworth from ORNL visiting LANL to discuss and participate in measurements of losses on single-phase, two-layer 2G cables. The primary aim was not particularly to obtain data on the cable in question but to establish a working knowledge of each other's measurement techniques and to transfer 'best practices'. LANL workers also visited ORNL in a reciprocal visit. AMSC also attended part of the time. Several teleconferences were set-up after the visits to maintain regular contact.

Our advanced experimental and simulation tools developed by this core program have been used extensively for other CRADA or DHS projects.

We have continued our fruitful collaborations with Prof. Frederic Sirois' group at École Polytechnique de Montréal. Prof. Sirois' group has developed a new simulation technique that is capable of taking the twisting of conductors in a cable into account. We built experiments to validate the model and used the model for further study of the ac loss characteristics in cables.