



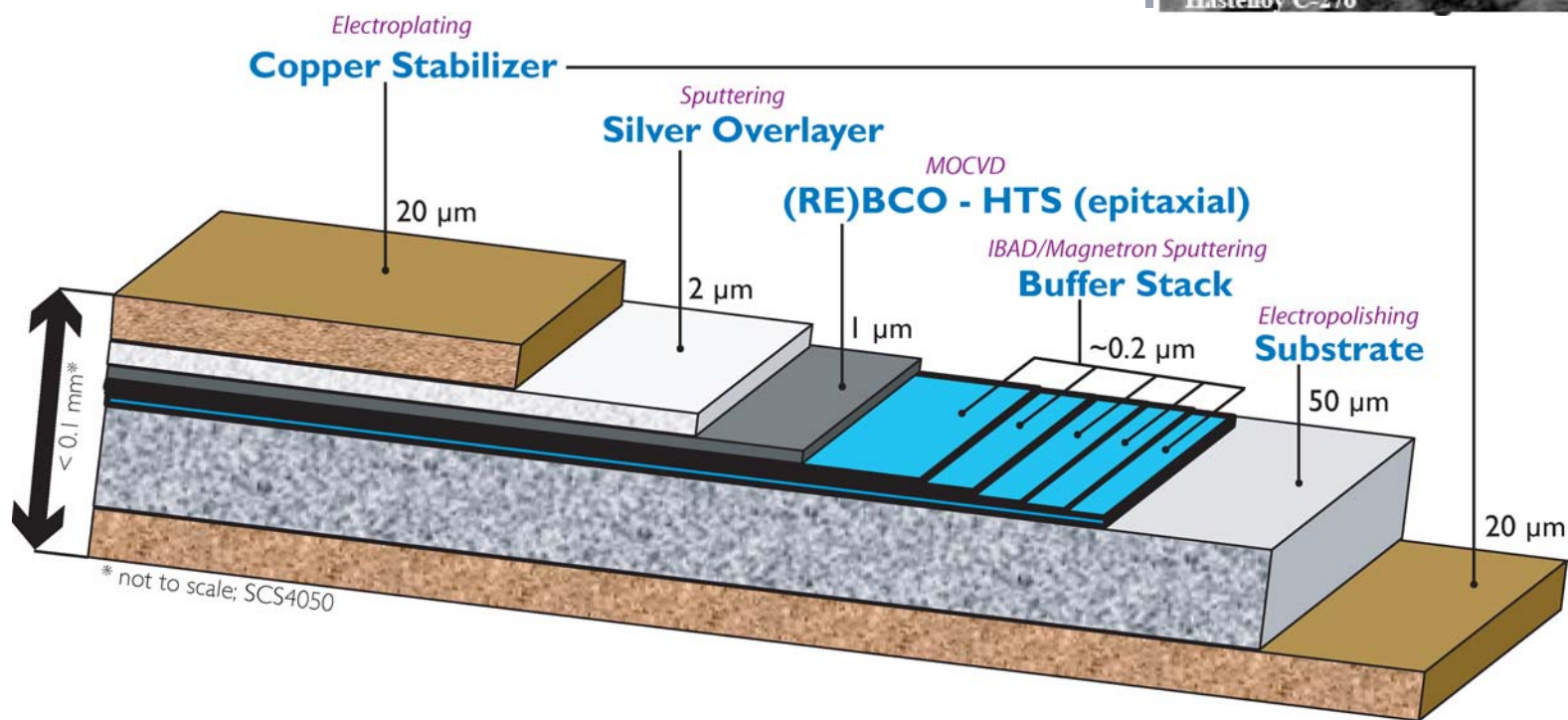
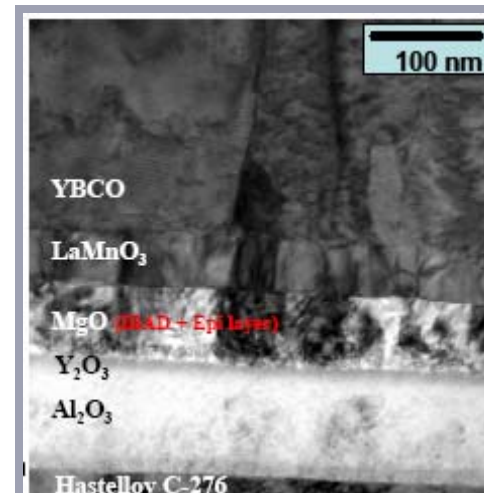
superior performance.
powerful technology.

Applications Using SuperPower 2G HTS Conductor

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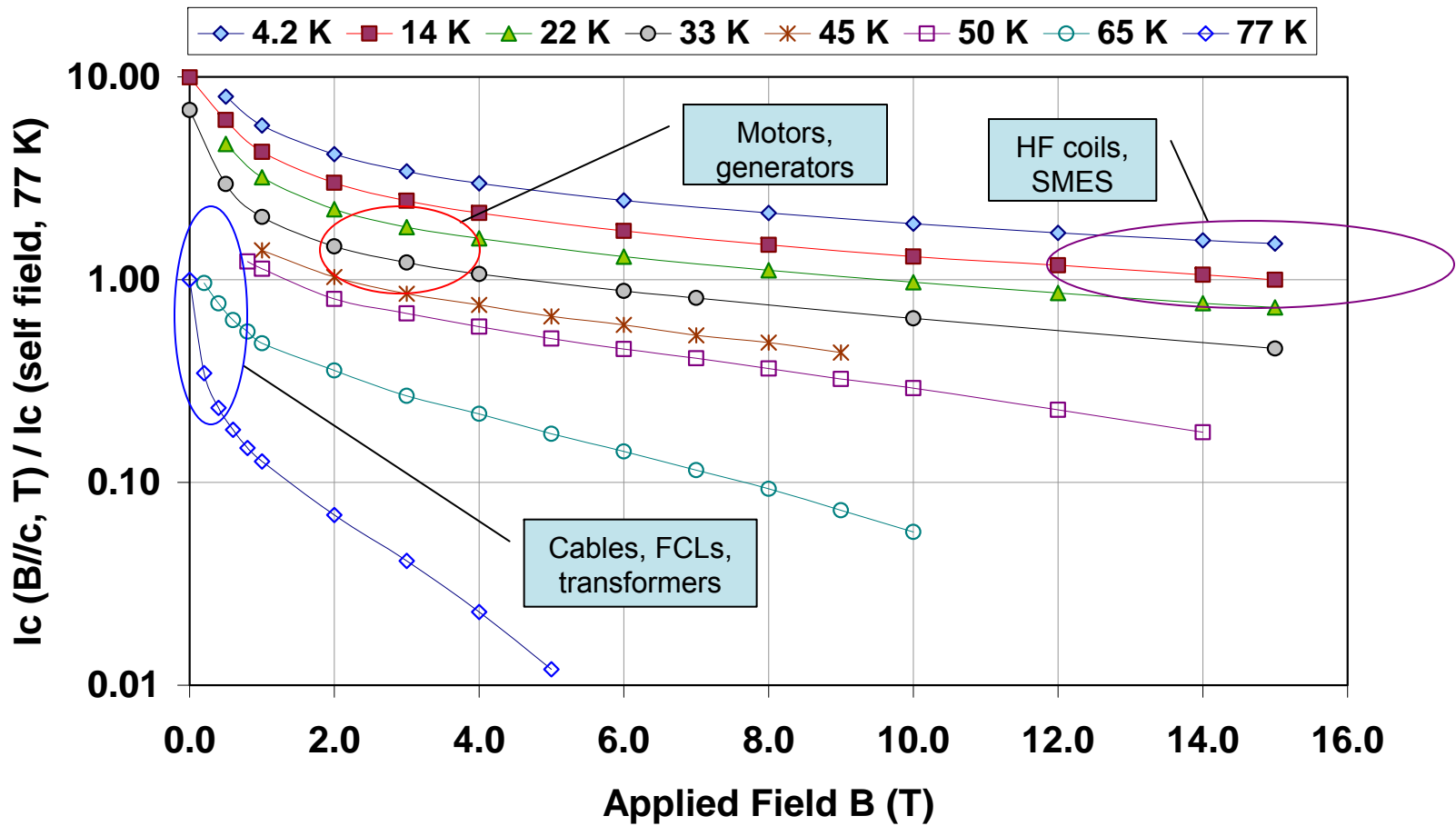
2011 CEC/ICMC Conference
June 16, 2011 ▪ Spokane, WA

SuperPower 2G HTS architecture

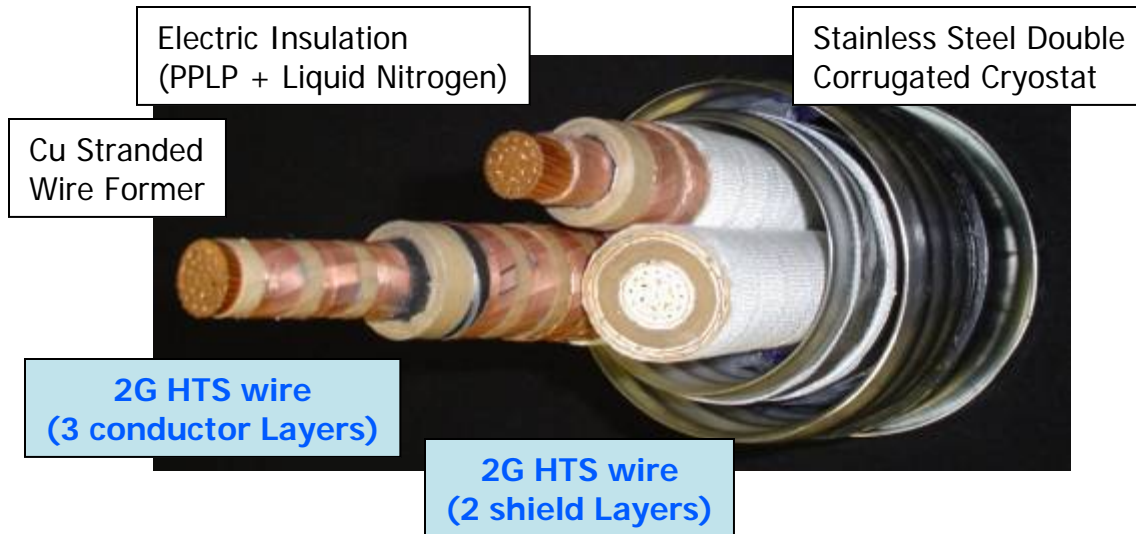


2G HTS offers excellent performance for all electrical device operating ranges

Normalized I_c vs. Applied Field I_c



Demonstration of the world's first system made with 2G HTS conductor in a live power grid



Installation at Albany Cable site (Aug. 5, 2007)

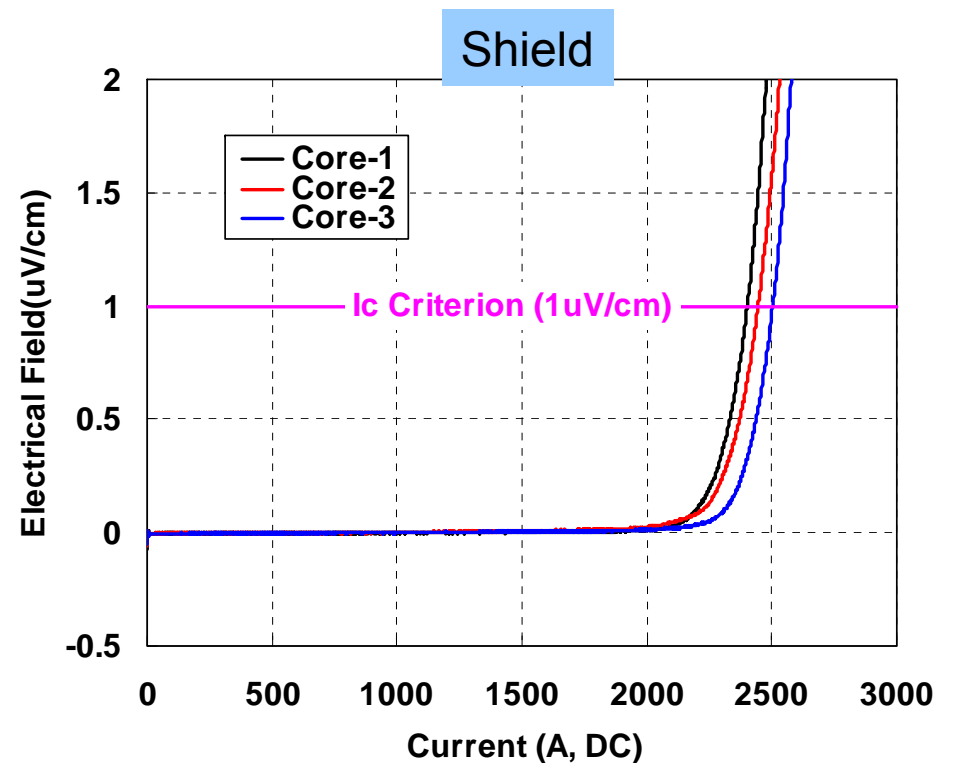
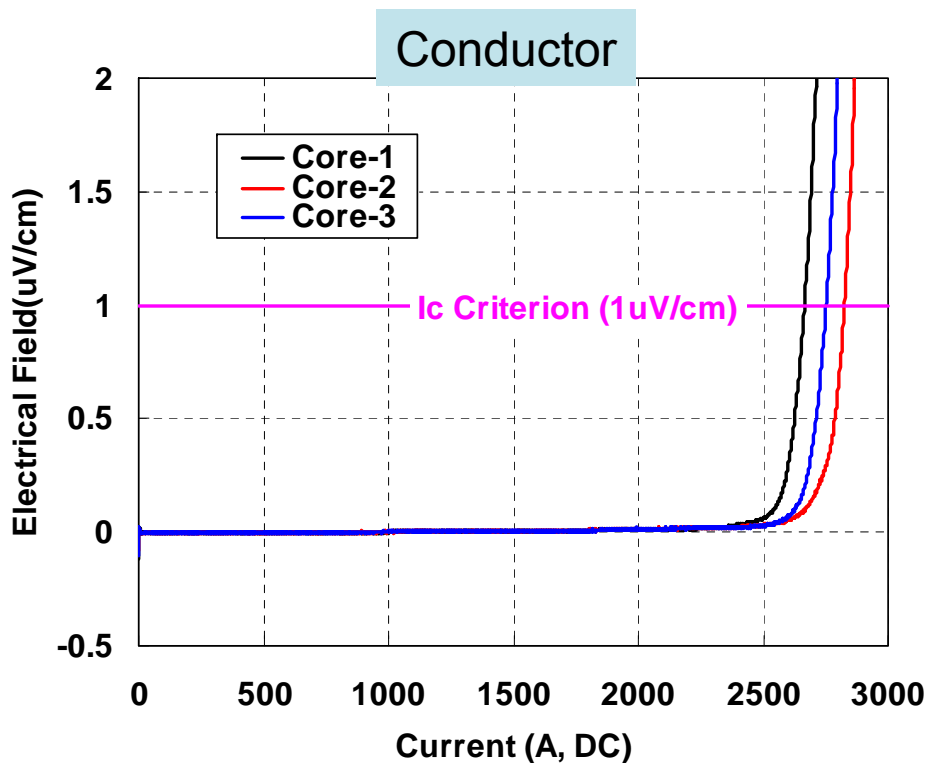


350 m cable made with 30 m segment of 2G HTS thin film tape was energized in the grid in January 2008 & supplied power to 25,000 households in Albany, NY

YBCO Cable - critical current measurement

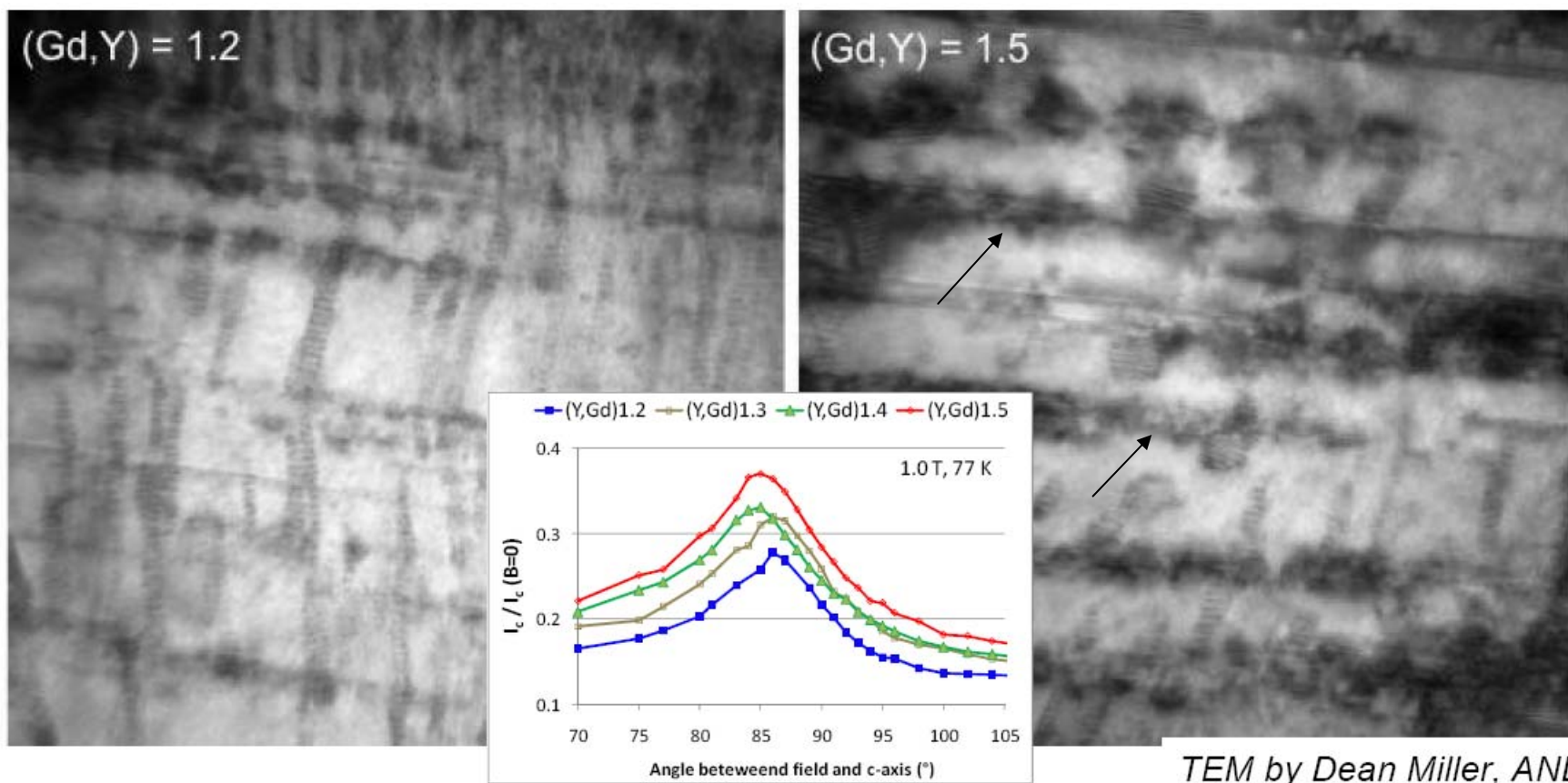
Sample: 3 meter 3-Core

- I_c (Conductor) = Approx. 2660 – 2820A (DC, 77K, 1uV/cm)
- I_c (Shield) = Approx. 2400 – 2500A (DC, 77K, 1uV/cm)



Very good match between test results and design values

(RE)BCO Composition modified for optimum cable performance

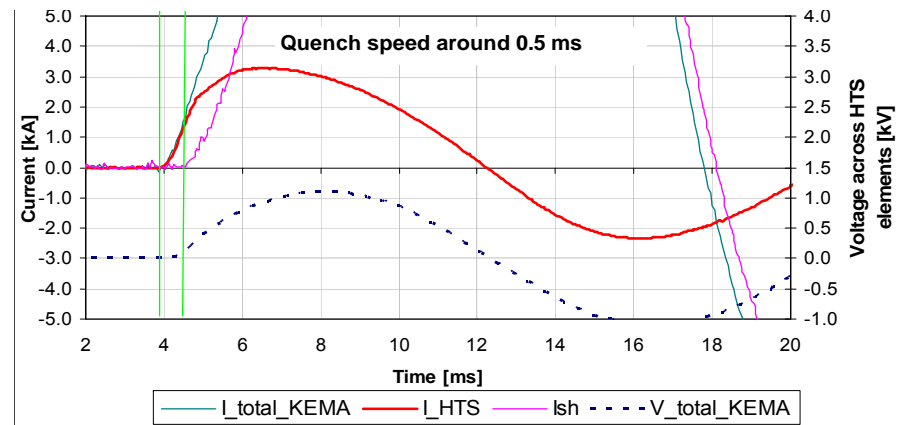
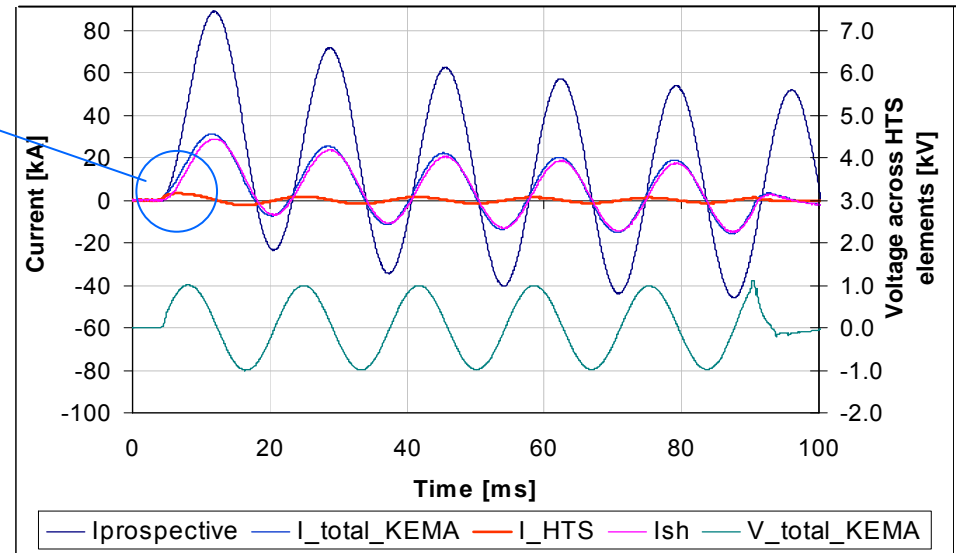


Thicker $(Gd,Y)_2O_3$ precipitates along a,b plane with higher Gd, Y content

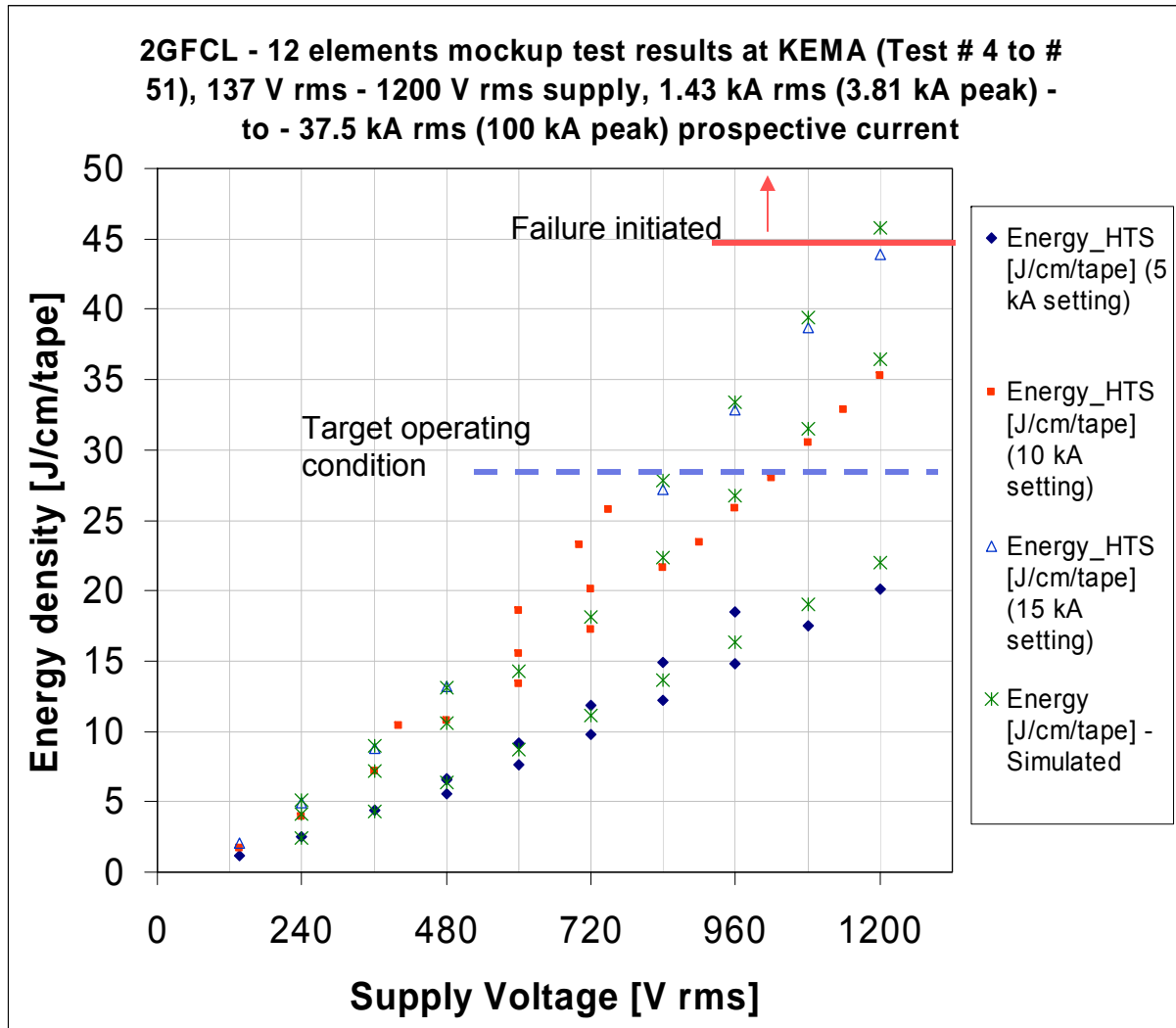
2G HTS conductor for SFCL shows consistent, excellent performance

Fast response time

High-power SFCL test	2G
Prospective current	90 kA*
Limited current	32 kA
Peak current through element	3 kA
Response time	< 1 ms
Element quality range	Narrow



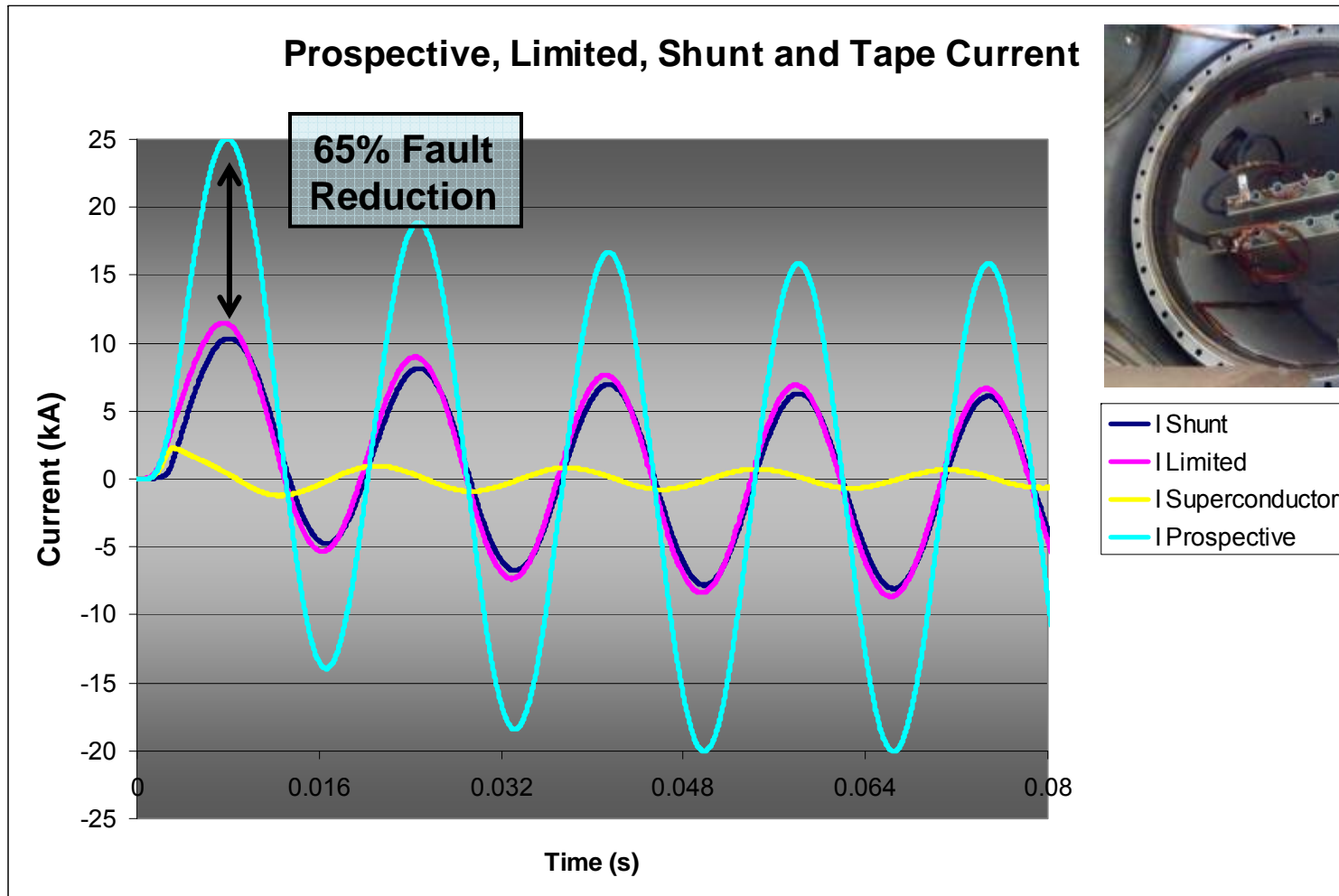
KEMA test results – Energy limit in 2G FCL elements



Test Results – Energy dissipation

- 2GFCL elements tested to 37.5 kA rms (100 kA peak) prospective fault current at 1200 V rms supply
- 2G tapes performed well up to 38 J/cm/tape and start failure at 43.91 J/cm/tape
- Design limit around 25 J/cm/tape – around 65% of failure value => need to establish probability of failure at variable energy level (Weibull distribution)
- Excellent current limiting performance
- Excellent agreement between simulation and test results – performance predictability is critical to success

Limited current in a two module SFCL test



65% Fault reduction at 1st peak with 2 tape circuit with a prospective current of 26kA

New FCL transformer under development

- FCL transformer being designed and constructed in a \$21.2 M Smart Grid program
- Partners:
 - Waukesha Electric Systems
 - SuperPower
 - University of Houston
 - Oak Ridge National Laboratory
- To be installed Southern California Edison grid by early 2014 (MacArthur Substation)
- 28 MVA (69 kV: 13 kV, 40 MVA overload capability)
- Fault current limiting capability ~ 40 to 50%



The 2G HTS windings will be similar to Waukesha's conventional design

- HV – Continuous disc winding; 8-12 turns/disc
- LV – Screw winding; 8-15 conductors in parallel.
 - Roebel cable is another option
- Exact number of disc turns or parallel conductors is determined by unit power ratings and tape I_c
- Windings will contain several individually-tested modules to limit amount of conductor at risk in a test failure
- Conductor transpositions will be at module junctions
- Need laminated or thick plated HTS tape to handle:
 - High speed insulating process
 - High stresses during fault
 - FCL function

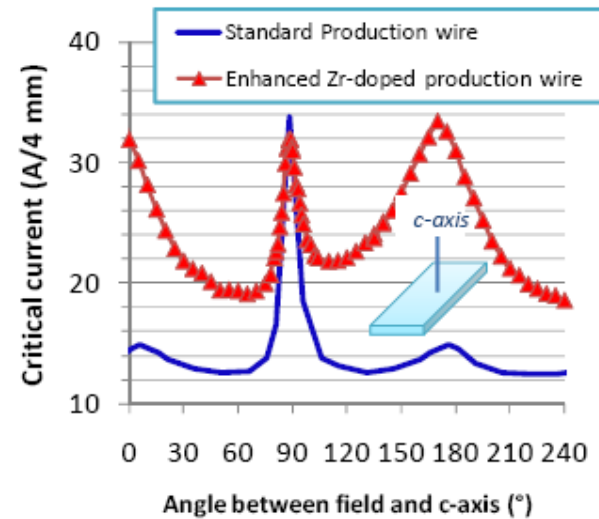
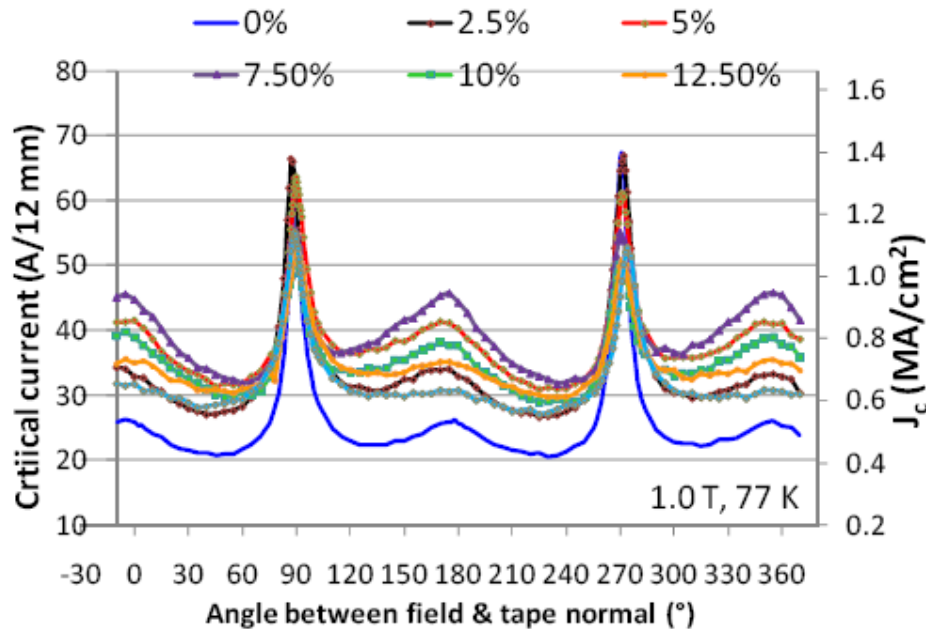


**HTS w/
Insulation**

Advantages of SuperPower 2G HTS in moderate to high field magnet applications

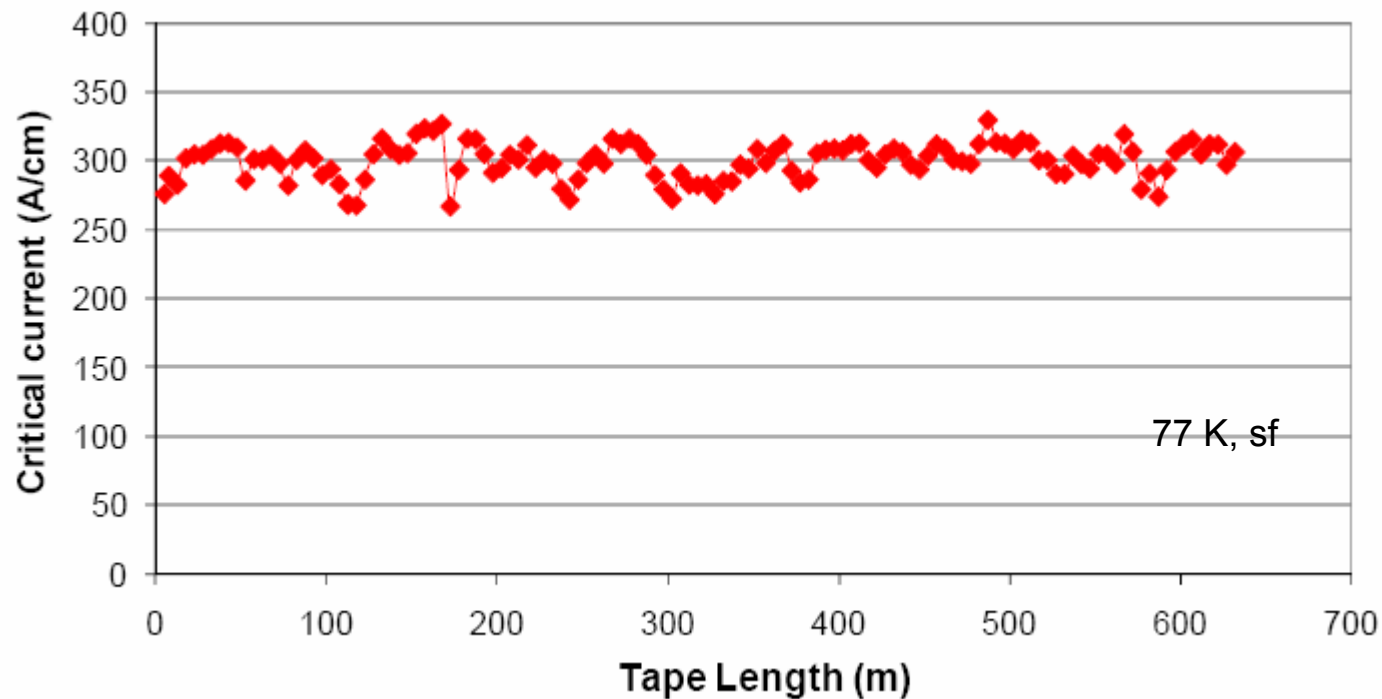
- High critical currents with excellent high field performance
 - (RE)BCO layer can be readily doped using MOCVD for added performance advantage
- High current density available in thin tape form
 - Standard thickness ~ 0.1 mm
 - (RE)BCO layer small fraction of total cross-section
- High mechanical strength
 - Strong Hastelloy® C276 substrate

Improved pinning by Zr doping of MOCVD (RE)BCO layer



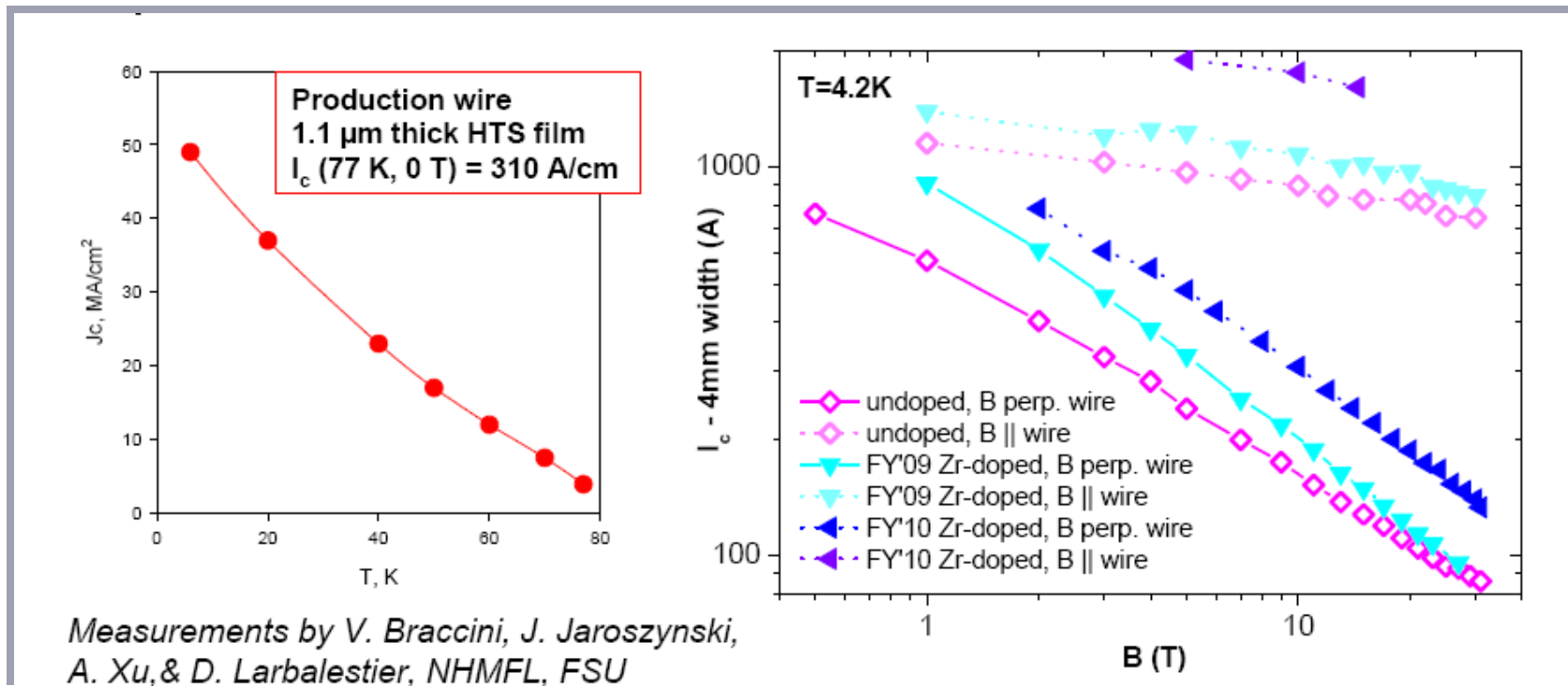
- Systematic study of improved pinning by Zr addition in MOCVD films at Univ. of Houston
- Process “know how” transitioned to SuperPower manufacturing

Routine manufacturing of Zr-doped tapes in long length initiated



Long tapes with Zr-doping exhibit critical currents of >250 A/cm in tapes run through the manufacturing facility

I_c improvement by pinning extends to higher fields



Advances with Zr-doping locked into production

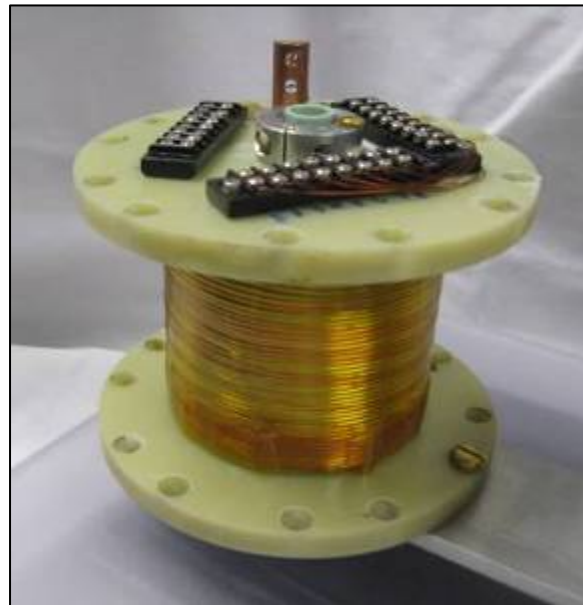
HTS coils for motors and generators

- Distinct Advantages:
 - Improved efficiency
 - 50% reduction in full load losses
 - Improved power quality enabling faster switching speeds
 - 30% - 50% smaller and lighter
 - Higher magnetic fields – greater power density
- Industrial Applications
 - Wind and hydro-electric generators
 - Petroleum refining
 - Specialized machine tool operation
- Military Applications
 - **Navy:** all electric ship
 - **Air Force:** electrically-driven power aboard military aircraft, airborne active denial systems, self-protect systems, directed energy weapons



Coil applications: World record performance achieved in high field coils constructed with SP 2G HTS wire

- 2009: 27.4 Tesla at 4.2K in 19.9 Tesla background field (SP)
10.4 Tesla at 4.2K (self field)
- 2008: 33.8 Tesla at 4.2K in 31 Tesla background field (NHMFL)
- 2007: 26.8 Tesla at 4.2K in 19 Tesla background field (SP)
- 2006: 2.4 Tesla at 64K in self field (SP)



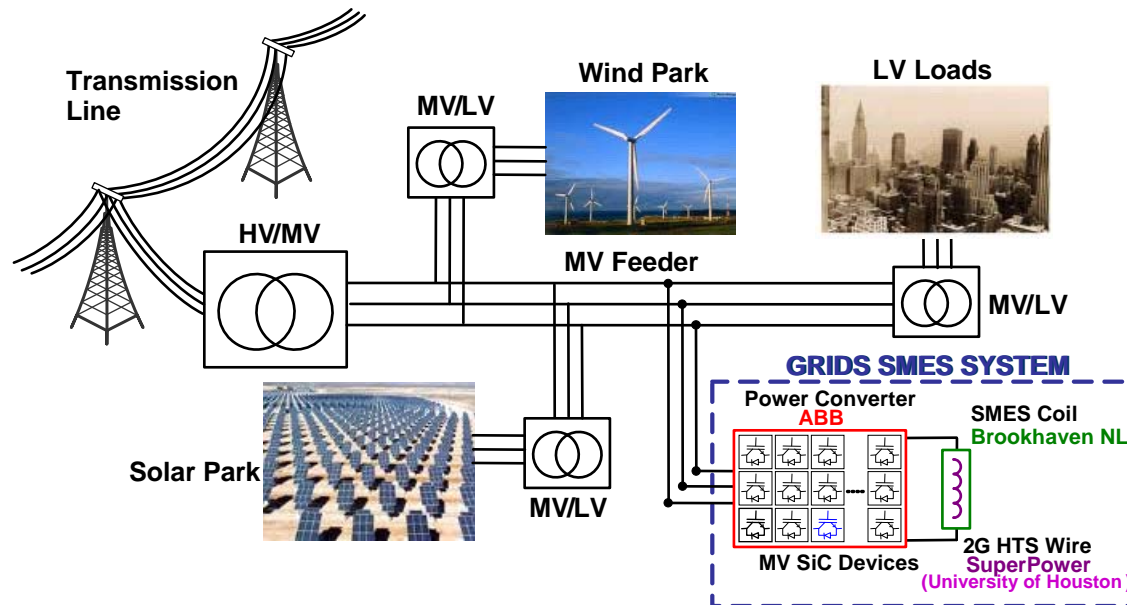
2009 Insert Coil

New Superconducting Magnetic Energy Storage (SMES) project initiated

- ARPA-E funded proof-of-concept project recently awarded (\$5.2M/3yr)
- Project Participants
 - ABB (lead; power electronics / system integration)
 - Brookhaven National Laboratory (high field coil design; fabrication)
 - SuperPower (2G HTS; coil design support)
 - Univ. of Houston (enhanced 2G HTS fabrication)
- Storage capability (~2.5 MJ / 20 kwh)
 - 25 Tesla coil
 - Enhanced power electronics
 - >80% round trip efficiency

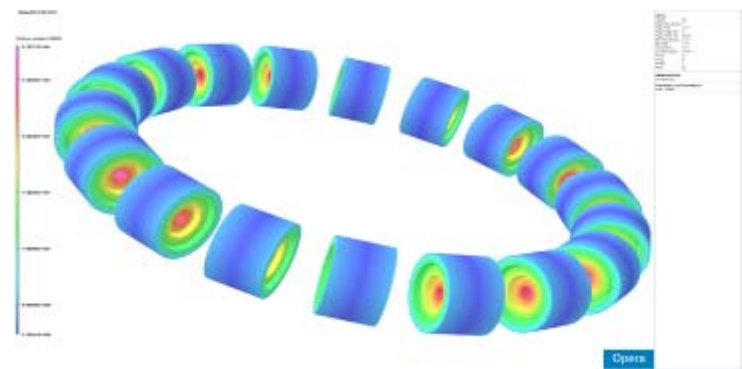
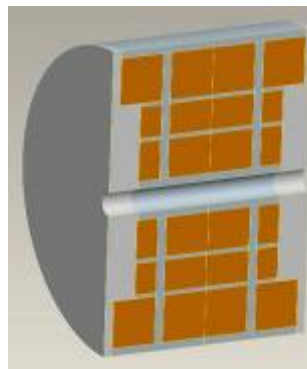
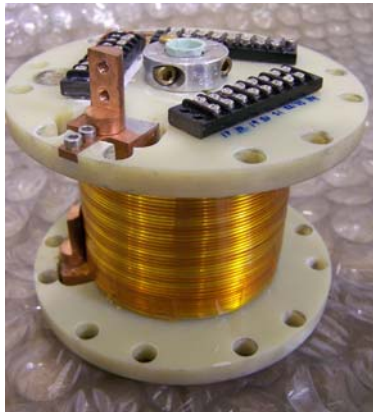
SMES usage

- SMES is currently used for short duration (secs) energy storage for improving power quality
- In a utility situation, SMES could be used for either:
 - medium term storage (secs - minutes) to level out variations in renewable (solar, wind) generation
 - diurnal storage (hours), charged from baseload power at night and meeting peak loads during the day



Why high field HTS SMES?

- Energy stored scales as $B^2 * r^3$, while losses scale as r^2
- 2G HTS enables high field operation for a compact, high energy density system
- Toroidal geometry lessens the external magnetic forces, reducing the size of mechanical support needed
- Fields in a toroidal SMES are mainly axial ($\parallel a, b$), maximizing the use of 2G HTS
- Due to the low external magnetic field, toroidal SMES can be located near a utility or customer load



Challenges

- High fields equate to high stresses
 - mainly hoop stress << SP 2G HTS can handle up to 700 MPA hoop stress
- High performance conductor required for economics to be competitive with advanced batteries (need to be in the \$50/kAm range)
- Persistent current joints / switches highly desirable to reach loss targets
- Long lengths will be required to minimize / eliminate splices / joints (each splice is a loss source)

Summary

- SuperPower 2G HTS is available in multiple configurations suitable for a wide range of applications
- The conductor can be tailored for specific application requirements
- Ongoing improvements in the price : performance of the 2G HTS enable broader adoption of the conductor into the marketplace



Questions?

Thank you for your interest!

For further information about SuperPower,
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