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Applications Using SuperPower 2G HTS Conductor

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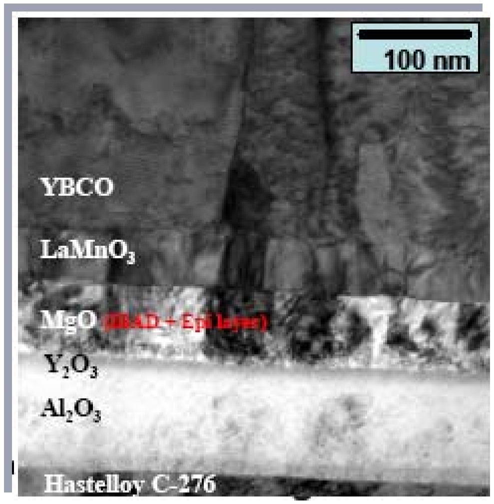
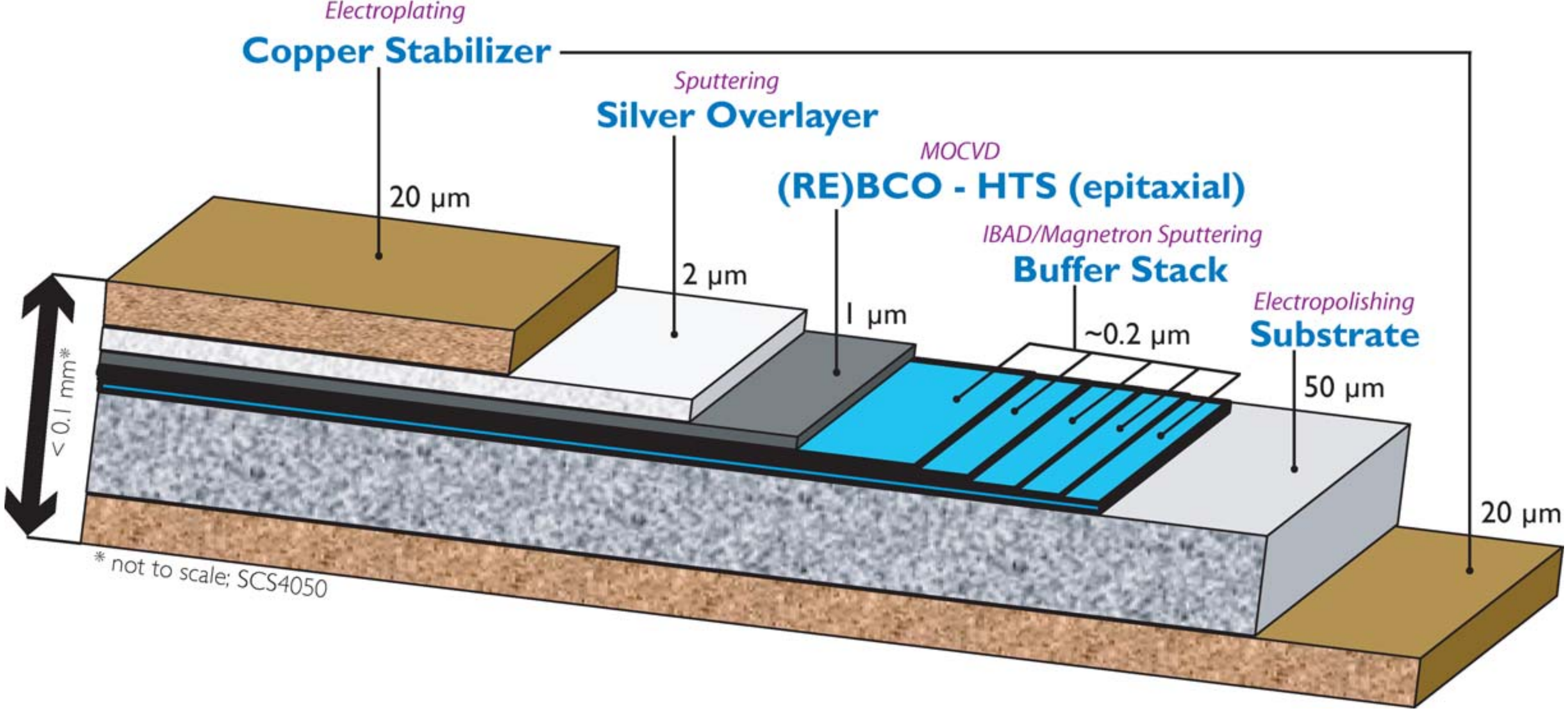
SuperPower 2G HTS architecture





Electroplating
Copper Stabilizer
20 µm

Sputtering
Silver Overlayer
2 µm

MOCVD
(RE)BCO - HTS (epitaxial)
1 µm

IBAD/Magnetron Sputtering
Buffer Stack
~0.2 µm

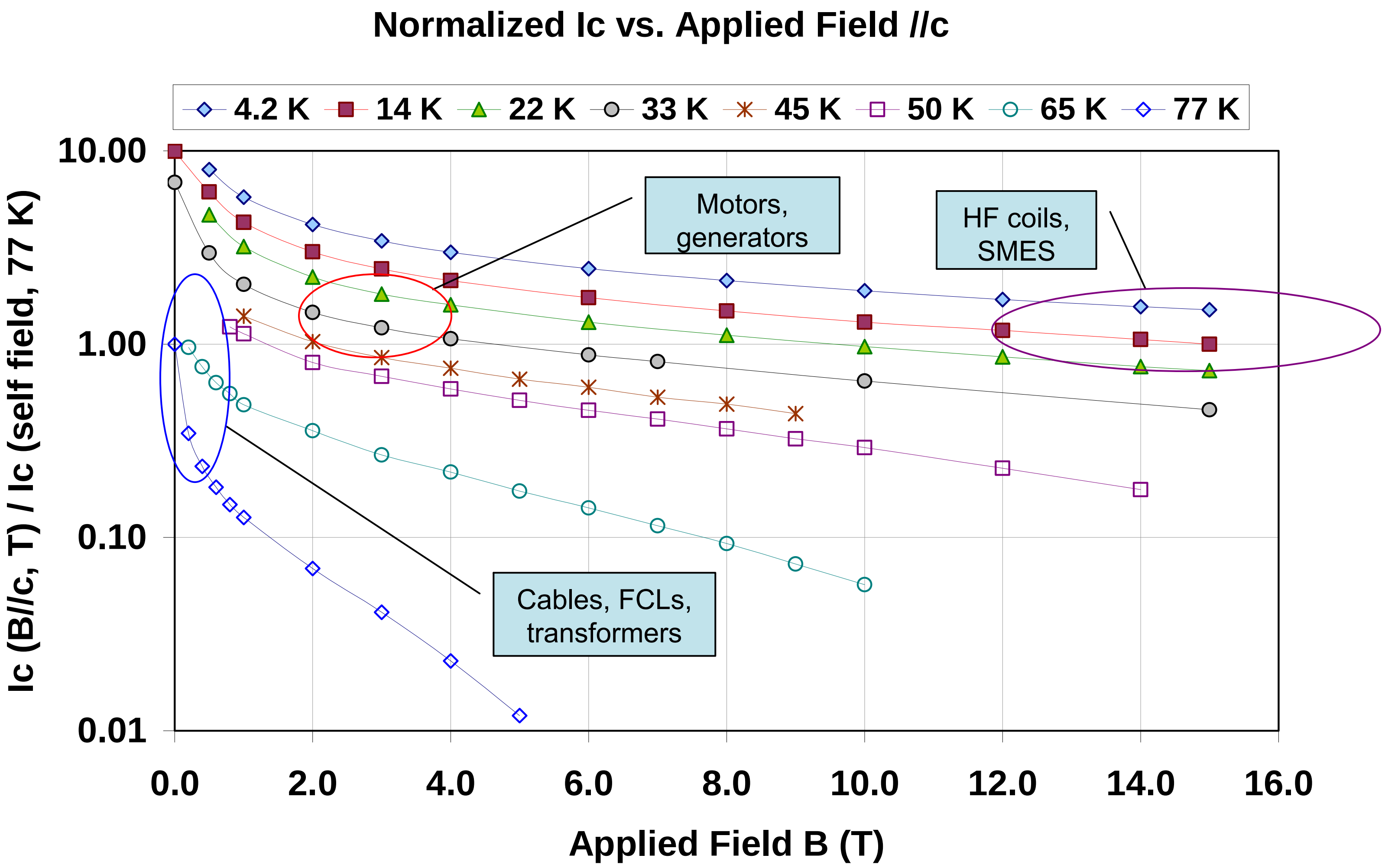
Electropolishing
Substrate
50 µm

20 µm

< 0.1 mm*

* not to scale; SCS4050

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

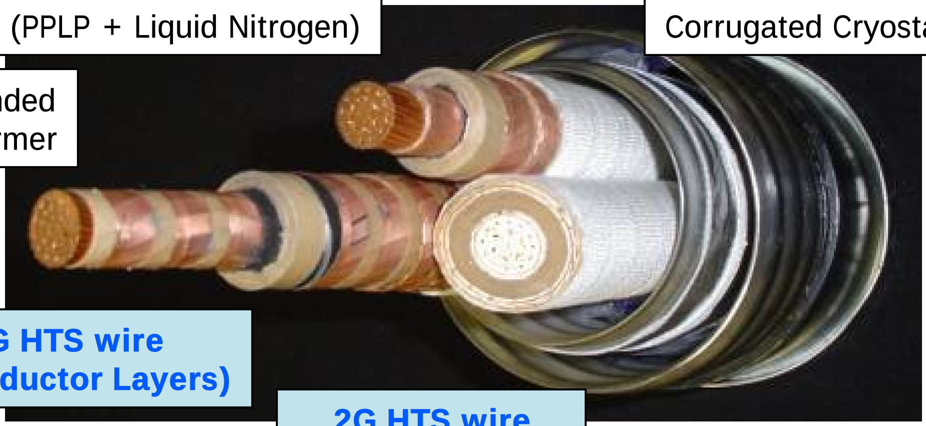


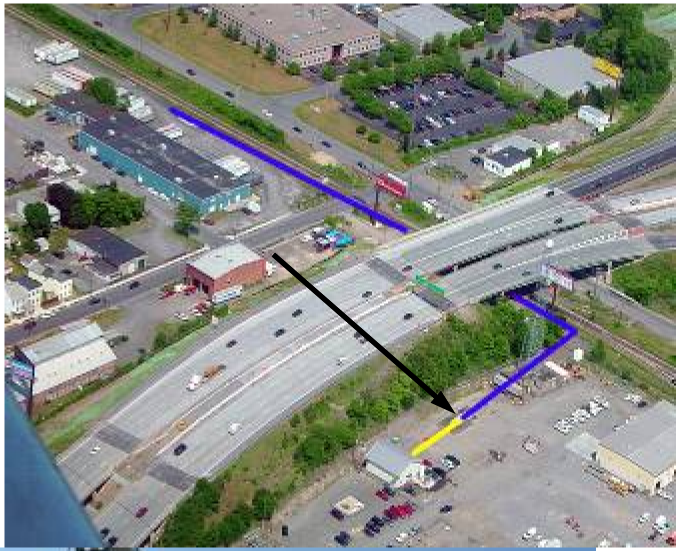
Motors, generators

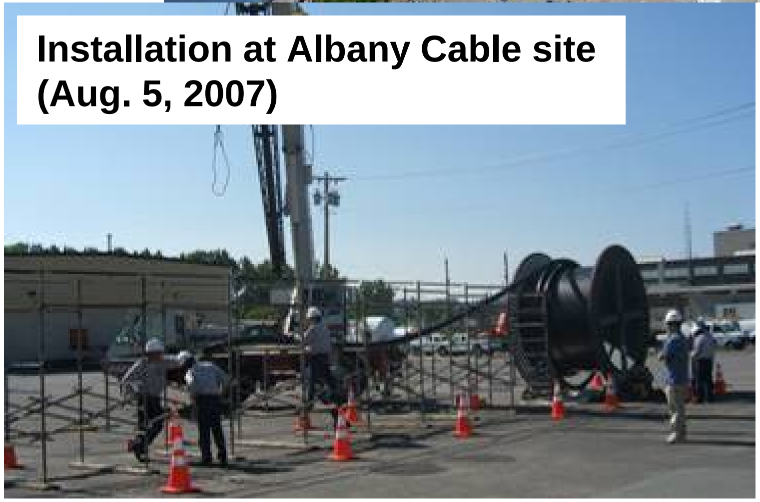
HF coils, SMES

Cables, FCLs, transformers

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

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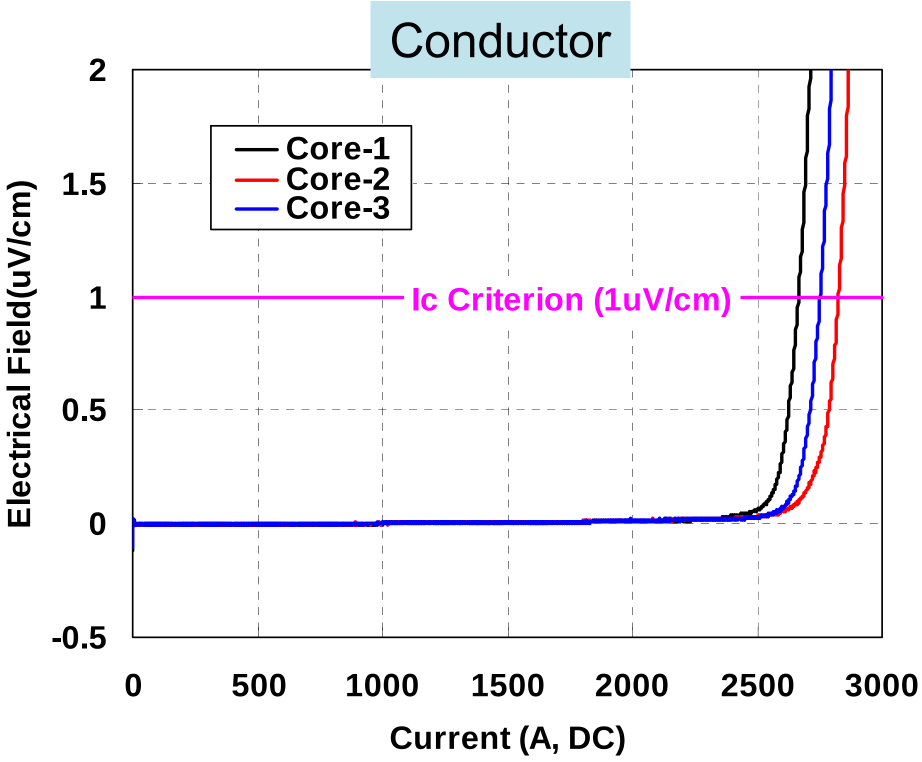
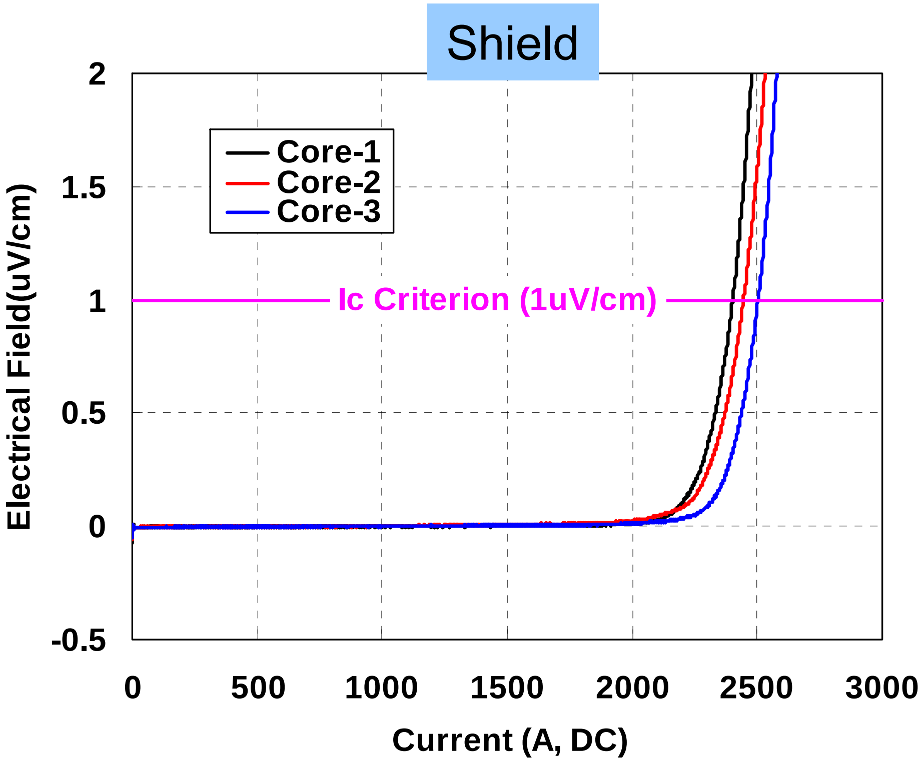
YBCO Cable - critical current measurement

Sample: 3 meter 3-Core

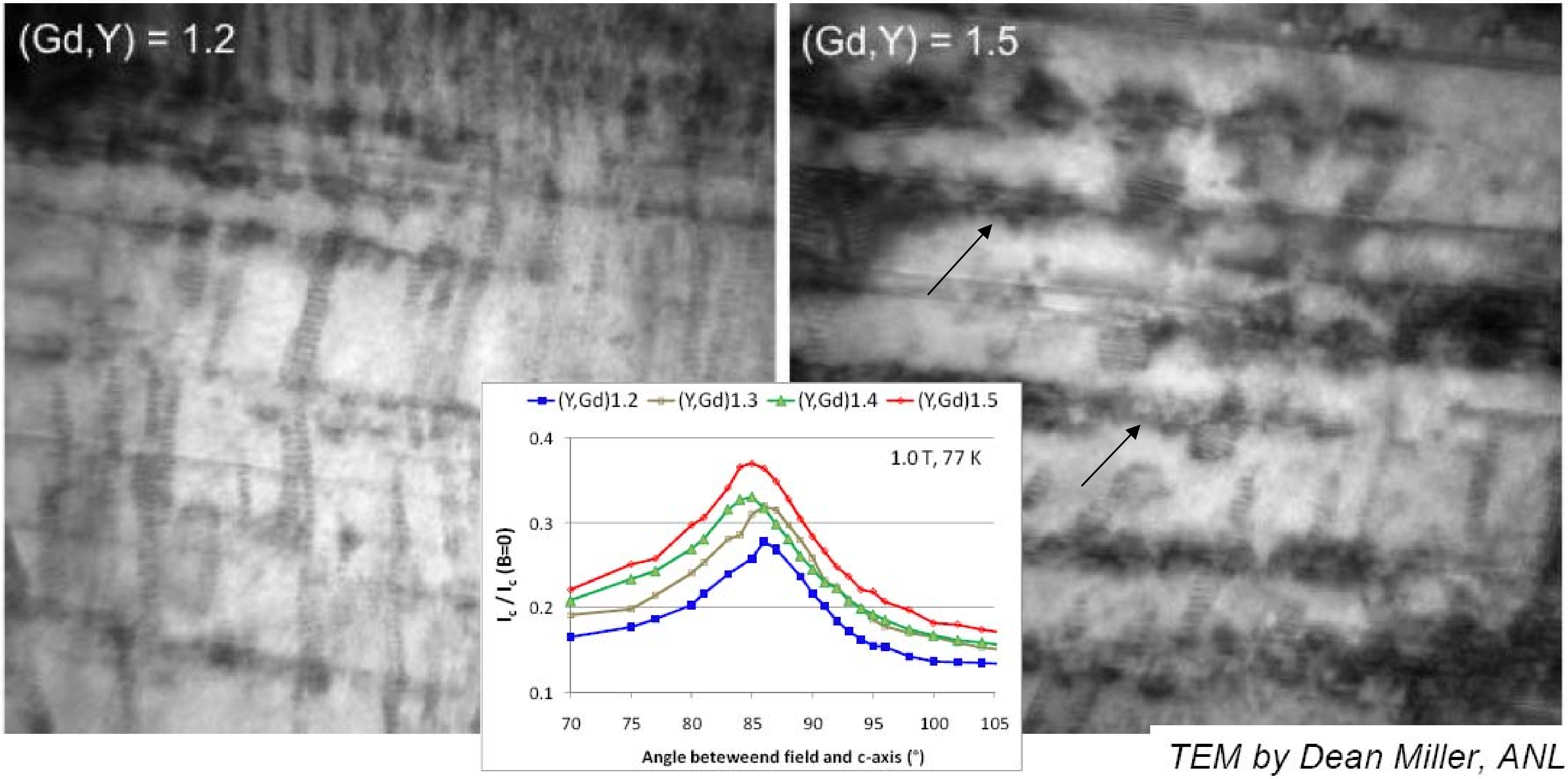
- **Ic (Conductor) = Approx. 2660 – 2820A (DC, 77K, 1uV/cm)**
- **Ic (Shield) = Approx. 2400 – 2500A (DC, 77K, 1uV/cm)**





Very good match between test results and design values

(RE)BCO Composition modified for optimum cable performance

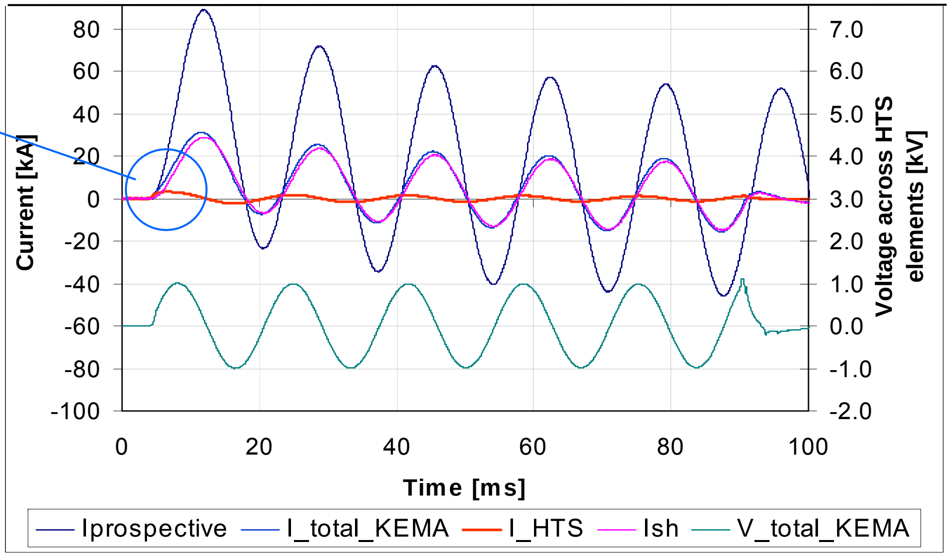


TEM by Dean Miller, ANL

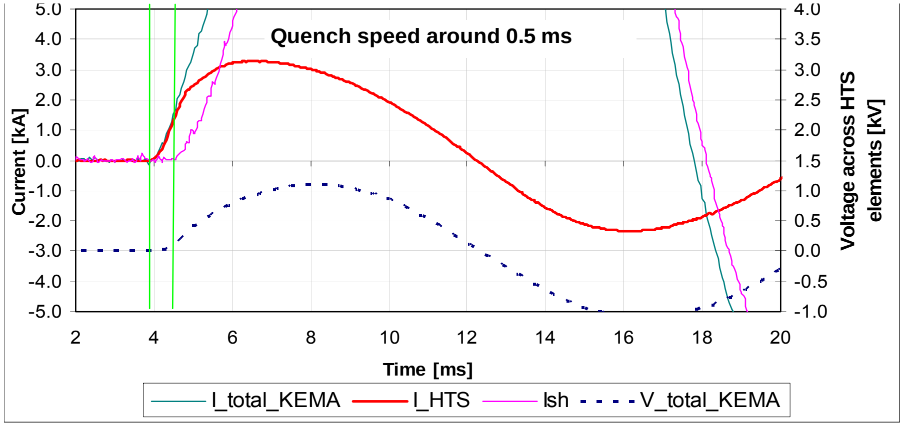
Thicker $(Gd,Y)_2O_3$ precipitates along a,b plane with higher Gd, Y content

2G HTS conductor for SFCL shows consistent, excellent performance

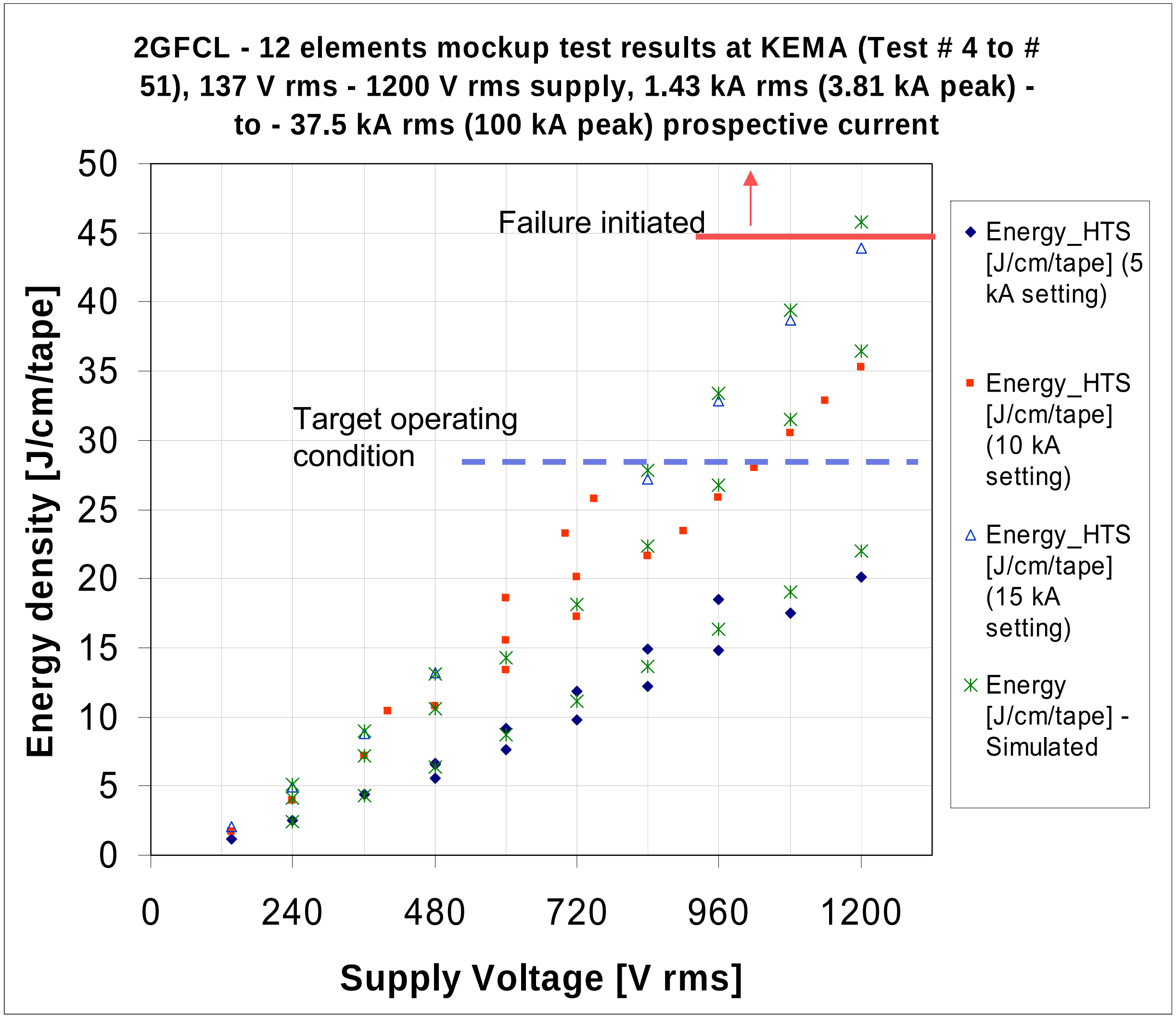
Fast response time



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



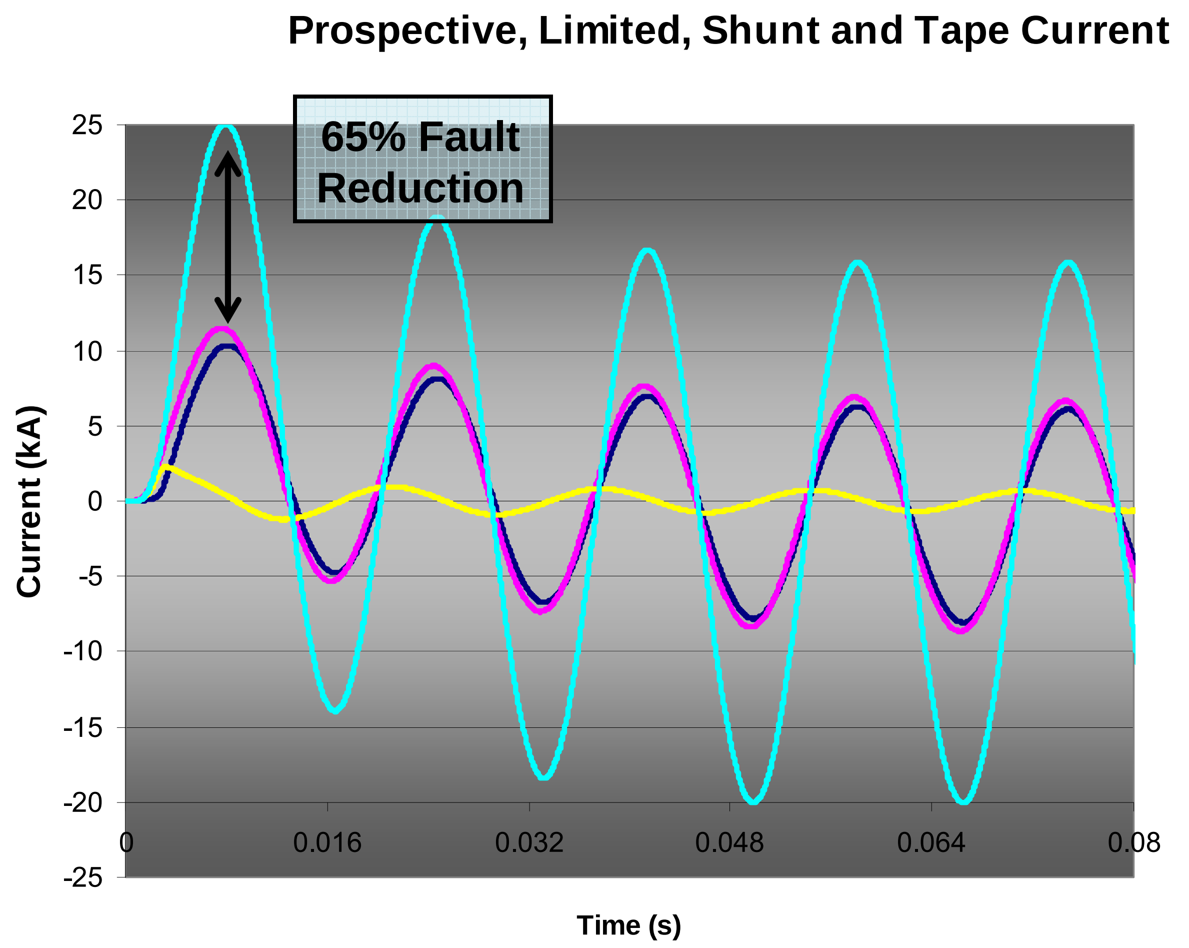
KEMA test results – Energy limit in 2G FCL elements

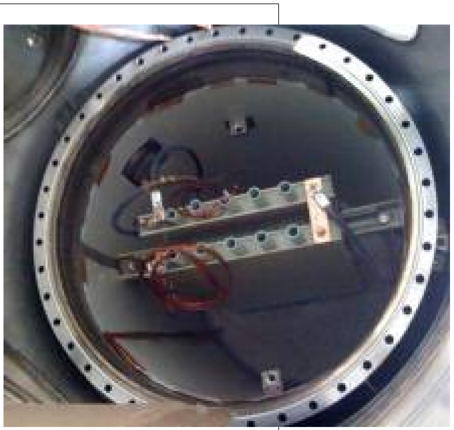


Test Results – Energy dissipation

- 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





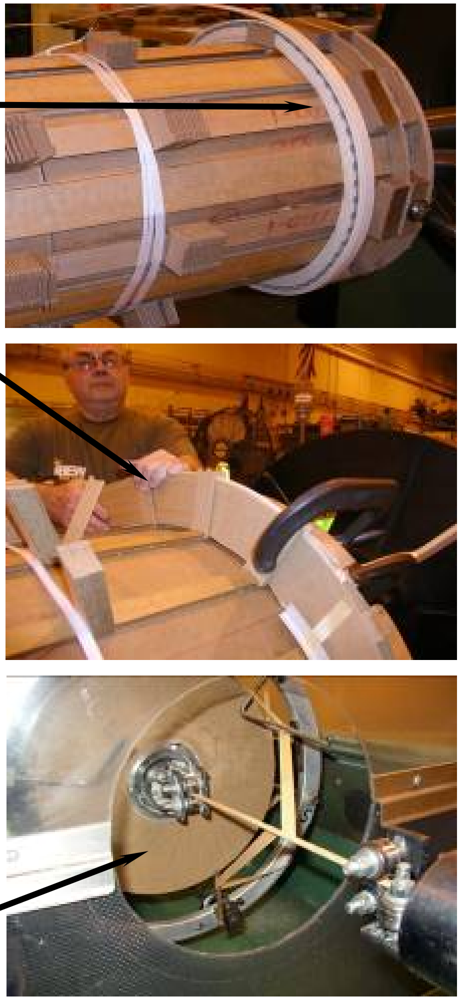
65% Fault reduction at 1st peak with 2 tape circuit with a prospective current of 26kA

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 Ic
- 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

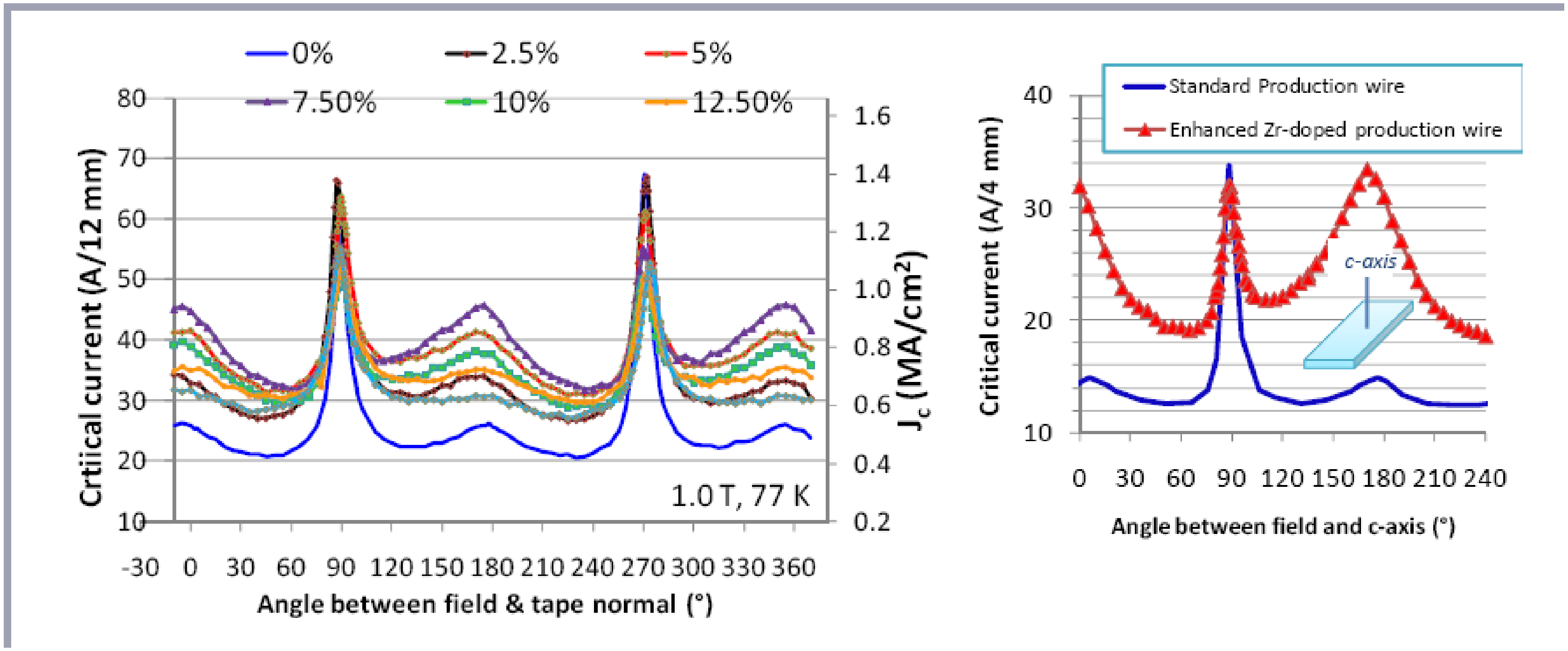


HTS w/ Insulation

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

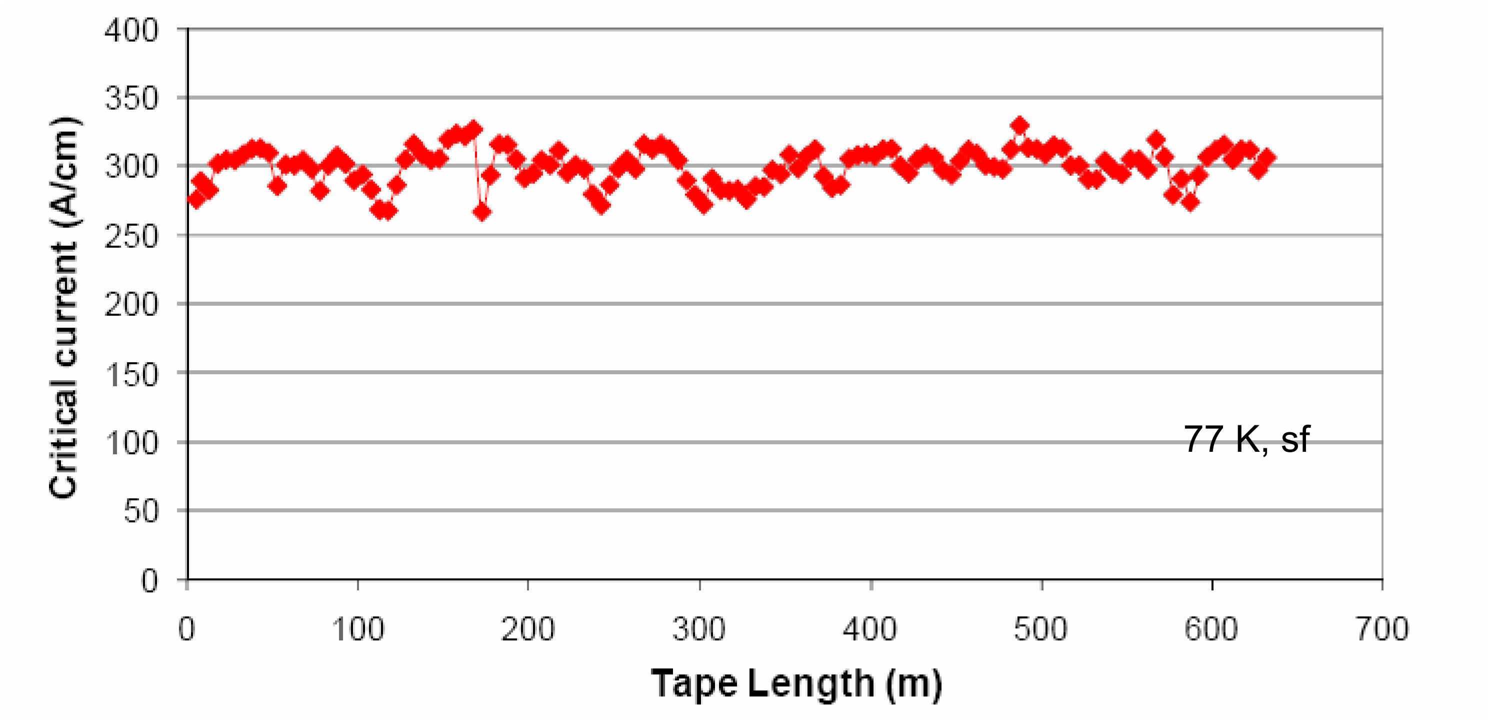
- High critical currents with excellent high field performance
  - (RE)BCO layer can be readily doped using MOCVD for added performance advantage
- High current density available in thin tape form
  - Standard thickness ~ 0.1 mm
  - (RE)BCO layer small fraction of total cross-section
- High mechanical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

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



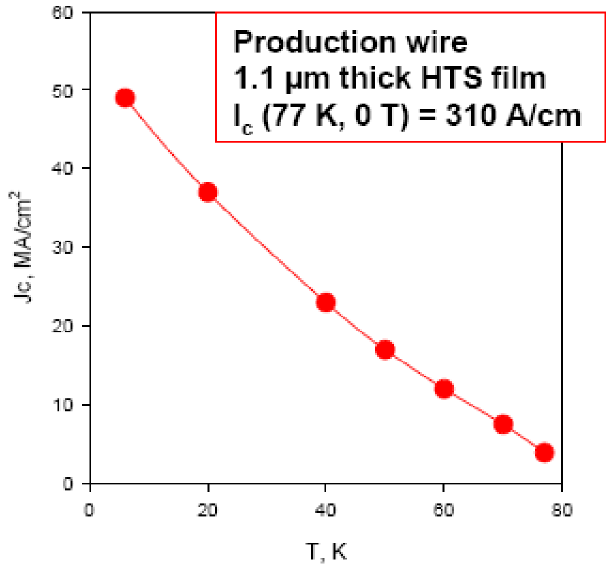
- Systematic study of improved pinning by Zr addition in MOCVD films at Univ. of Houston
- Process “know how” transitioned to SuperPower manufacturing

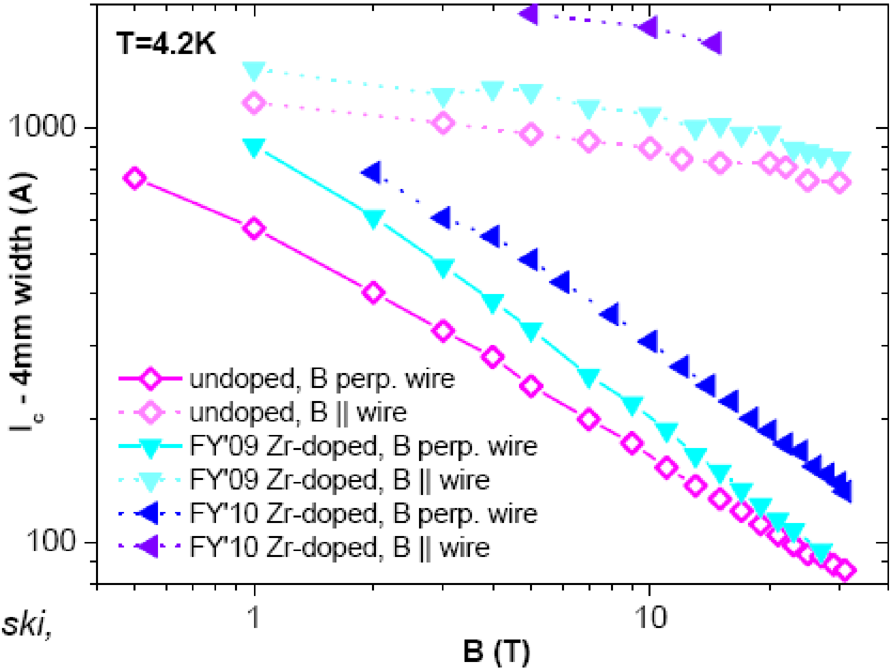
Routine manufacturing of Zr-doped tapes in long length initiated



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

Ic improvement by pinning extends to higher fields





Measurements by V. Braccini, J. Jaroszynski, A. Xu,& D. Larbalestier, NHMFL, FSU

Advances with Zr-doping locked into production

HTS coils for motors and generators

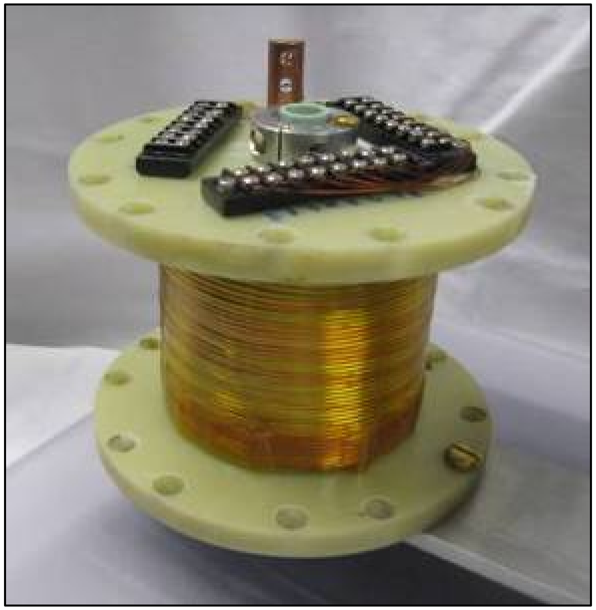
- Distinct Advantages:
  - Improved efficiency
  - 50% reduction in full load losses
  - Improved power quality enabling faster switching speeds
  - 30% - 50% smaller and lighter
  - Higher magnetic fields – greater power density

- 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

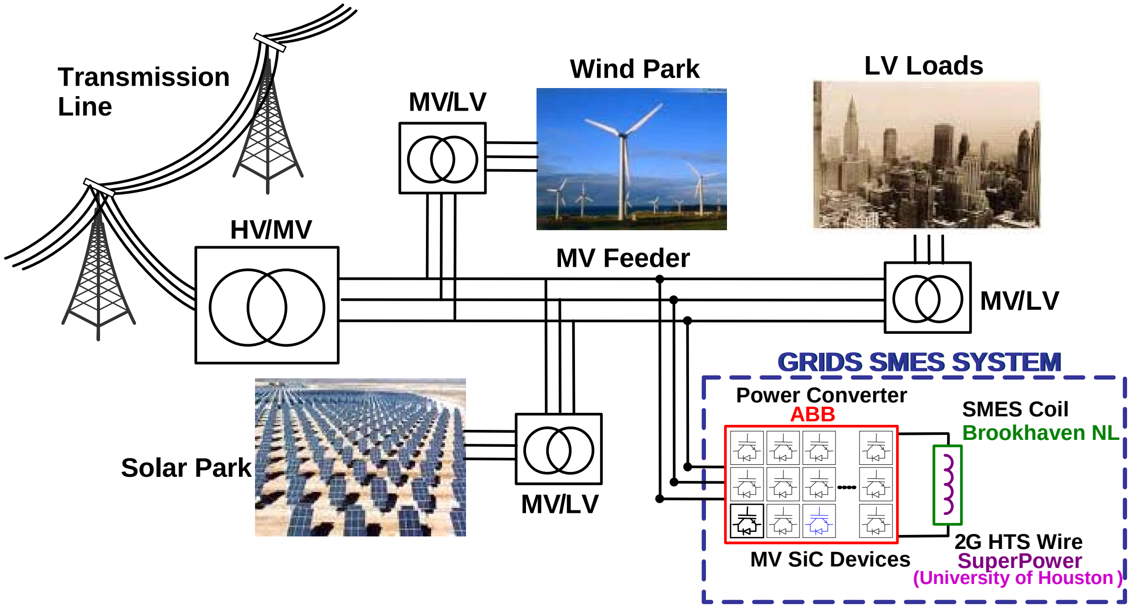


New Superconducting Magnetic Energy Storage (SMES) project initiated

- 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



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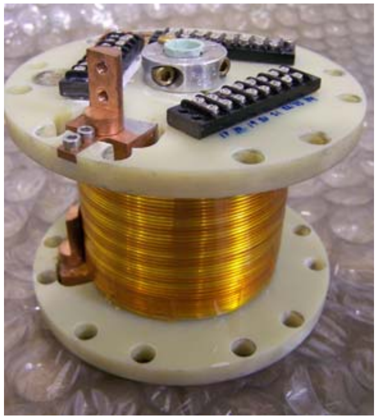
Why high field HTS SMES?

- 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 (//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



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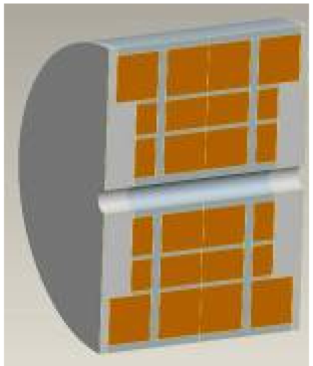

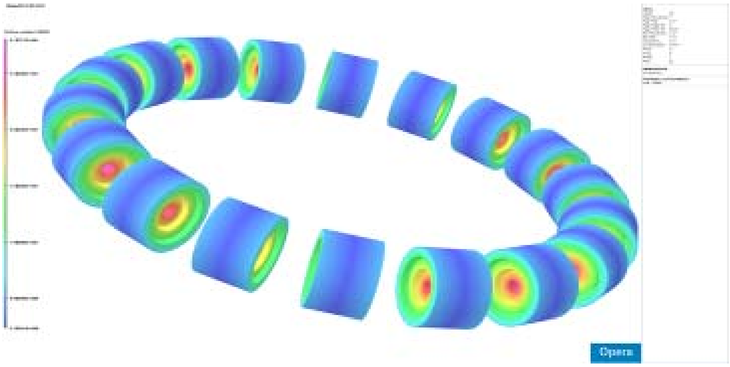

Challenges

- 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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or e-mail: info@superpower-inc.com