Paper Number: C2OrA-4
Date and Time: 7/11/17, 11:45

Effect of High Voltage Electrical Breakdown on Critical Current of High Temperature Superconducting Tapes

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Funded by

N00014-14-1-0346
N00014-16-1-2282

Helium Gas Cooled Superconducting Devices

Benefits

- Wide operating temperature (10 K–80 K)
- Enhanced superconducting properties at lower temperatures
- Lower temperatures allow higher power densities when necessary (Tunability)
- Larger temperature gradients can be maintained without a phase change
- Easier to integrate multiple devices to operate with a single helium loop
- Increased flexibility in power system design optimization with multiple devices

Challenges

- Low heat capacity of helium gas – requires high pressures and flow rates
- Helium gas has low dielectric strength – dielectric designs need solid dielectric – developments are needed to overcome this deficiency

Helium gas cooled HTS power device technology is attractive for some applications

GHe Cooled HTS Devices

Currently US Navy is the driver of helium gas cooled superconducting applications and helium gas cryogenics technology development

- HTS degaussing systems
- HTS ship propulsion motors
- HTS power cable systems

Other studies on GHe cooled HTS devices

- EPRI DC cable feasibility study: S. Eckroad, "A Superconducting DC Cable,“ Electric Power Research Institute, Palo Alto, CA, 2009
- MIT study on GHe cooling for MgB2 DC cable: M. J. Cheadle et. al., IEEE Trans. on Appl. Supercond., vol. 23, no. 3, p. 6200805, 2013
- The MgB_2 20-meter long, 20 kA transmission line tested at 24 K at CERN in the framework of the High-Luminosity LHC project
- 3 GW class MgB_2 HVDC links - part of BEST-PATHS program

HTS Power Cables cooled by helium gas, A Chapter in Superconductors in the Power Grid, editor Christopher Rey, Woodhead Publishing

Superconducting Gas Insulated Line (S-GIL)
Our New Cable Concept

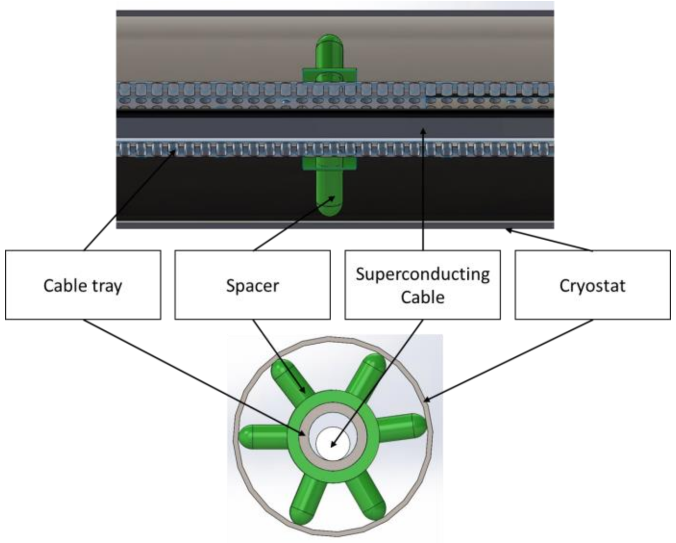
- Utilizes cryogen as both coolant and dielectric
- Ideal maximum electric field for S-GIL design:

$$E_{max} = \frac{V}{r_s \times \ln\left(\frac{r_c}{r_s}\right)}$$

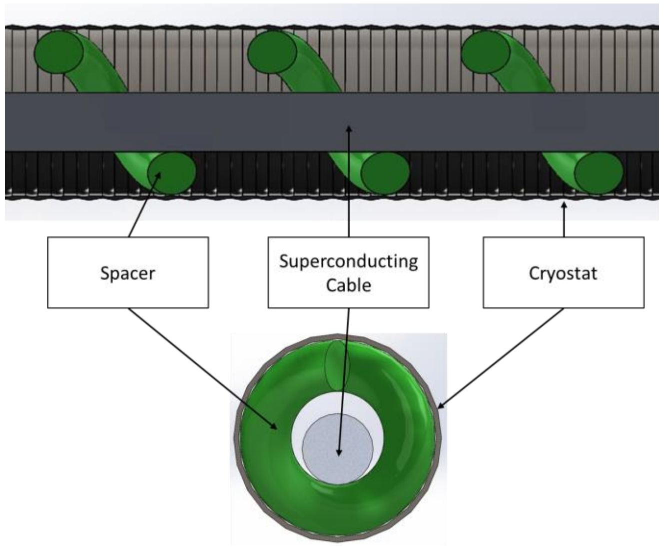
- Most economical design occurs:

$$\ln\left(\frac{R_c}{R_s}\right) = 1$$

S-GIL has the potential to operate after an electrical breakdown as long as there is no/minimal degradation to the critical current of the superconducting cable.



Rigid S-GIL Design



Flexible S-GIL Design

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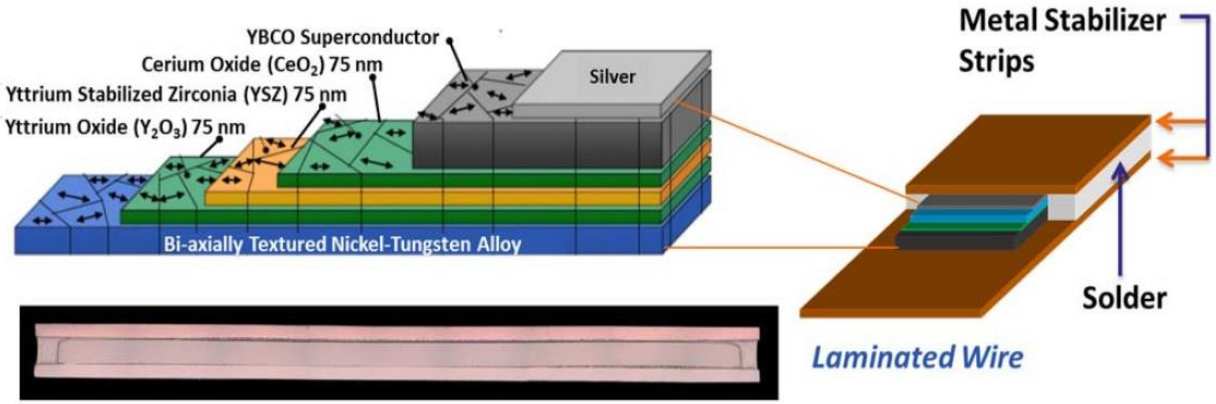
2G HTS Tape Structure

Schematic of the architecture of the substrate (top left) and laminated wire architectures (right)
Micrograph of a wire cross-section is shown in the bottom left



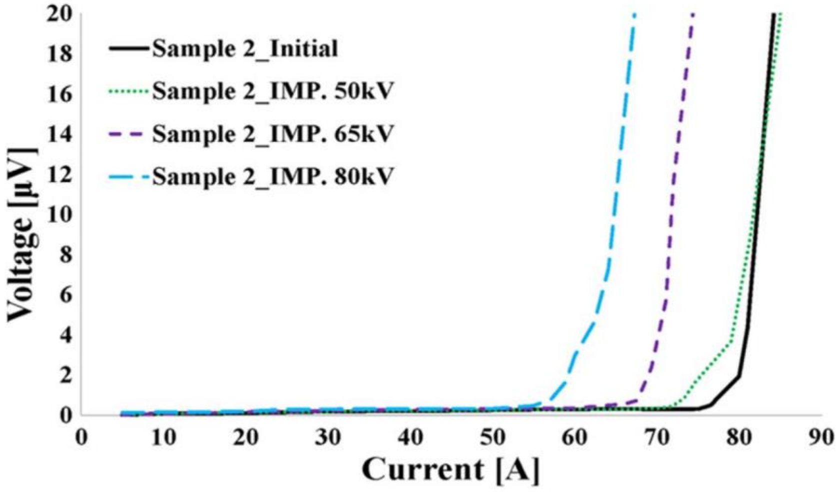
- 2G HTS Type 8501 was used for the investigation on the effect of electrical breakdown events on critical current
- Tapes were formed using rolling assisted biaxially textured substrates (RABiTS)
- A stabilizing layer is added to the top and bottom to enhance the mechanical and electrical properties
- The superconducting material makes up only 1-2% of the HTS tape

M. W. Rupich et al., "Second generation wire development at AMSC," IEEE Trans. Appl. Supercond., vol. 23, no. 3, pp. 3–7, 2013.

Previous Studies on Ic Degradation in Electrical Breakdown Events

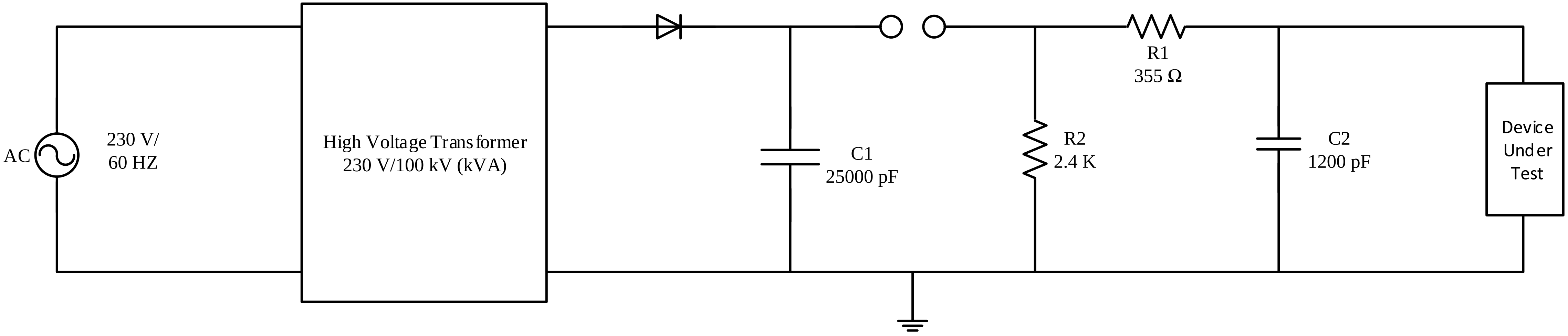
- Previous studies have been performed on HTS tape to track the degradation of Ic after an electrical breakdown
- Lightning impulse allows for the amount of energy released from an electrical breakdown to be easily calculated
- $W = \frac{1}{2} C_1 (V_{0max})^2$
- Determine if lightning impulse measurement can degrade a HTS tape to normal state (critical current ~ 3-5 A)
- Worst case scenario of electrical breakdown occurring directly onto HTS tape

Ic of HTS tape after Lightning Impulse



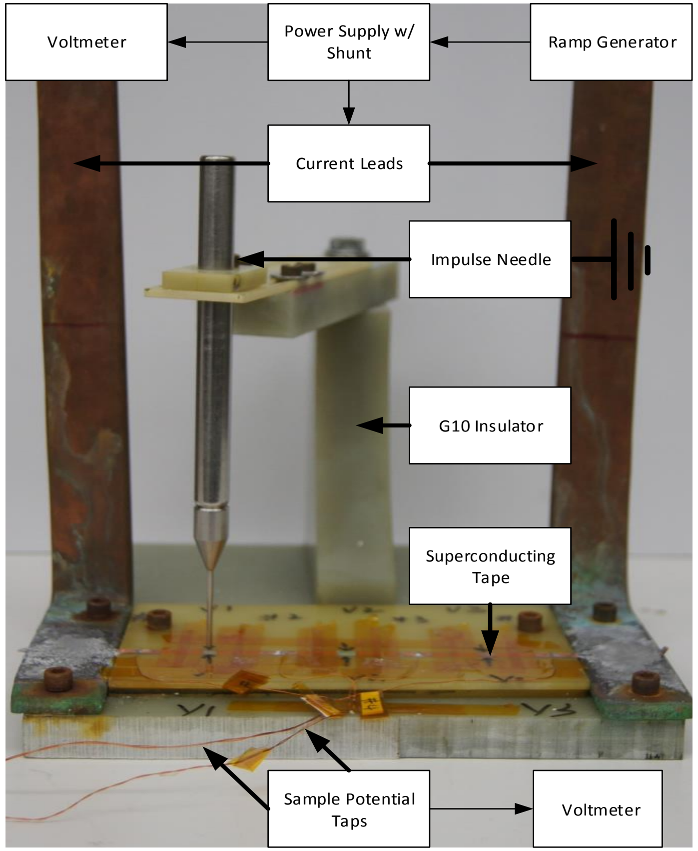
J. O. Kang, O. Lee, S. Bang, J. Kim, H. Lee, and J. Hong, “Degradation Characteristics of Superconducting Wires With Respect to Electrical Breakdown Tests,” vol. 25, no. 3, pp. 3–6, 2015.

Electrical Circuit Used in Lightning Impulse Experiments

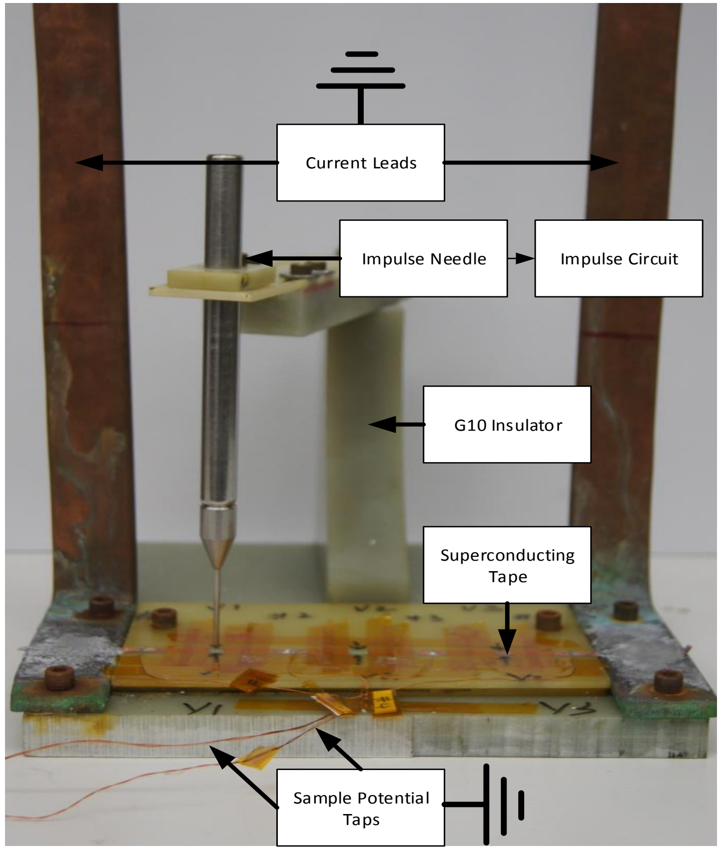


Lightning Impulse Circuit

Experimental Setup

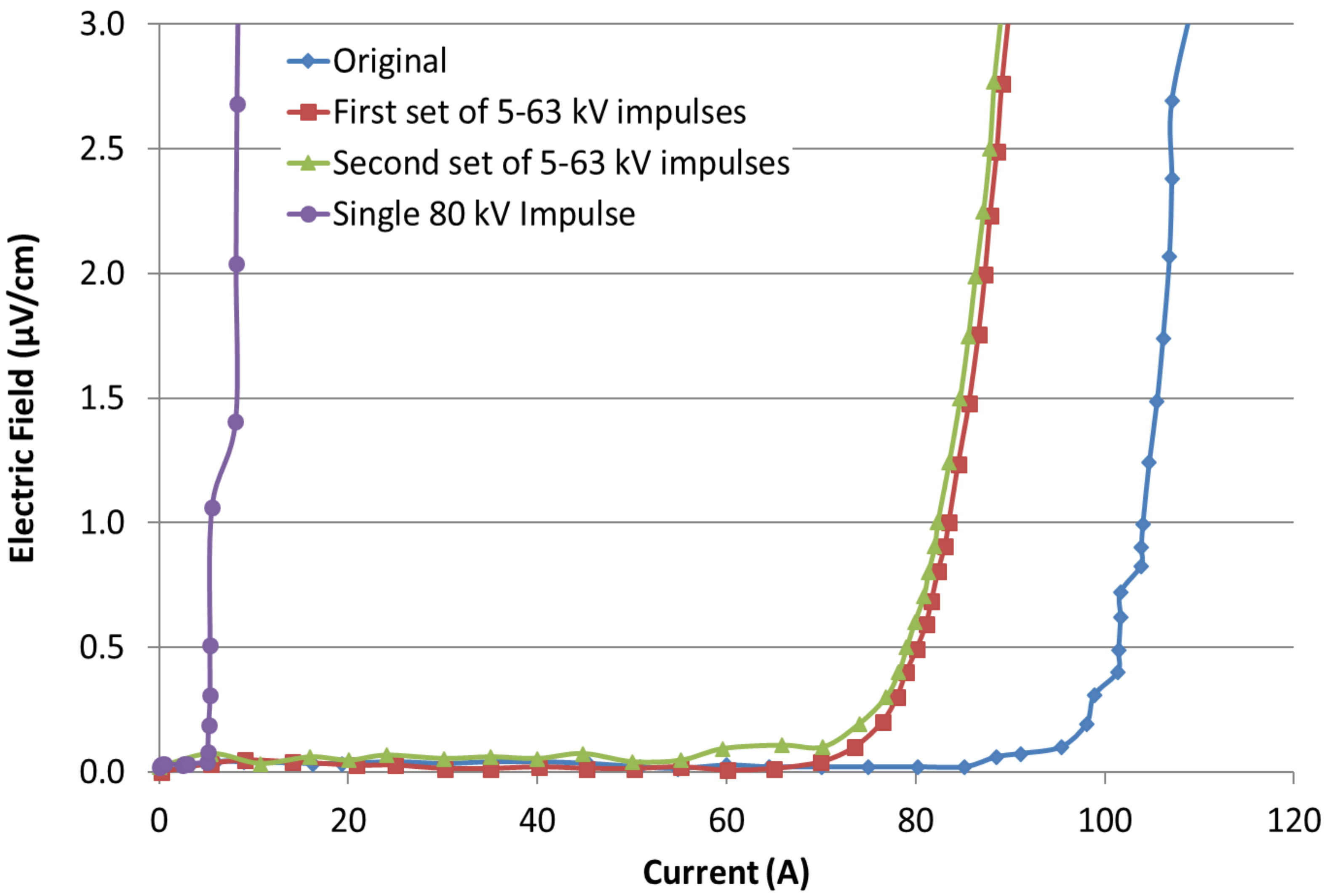


Critical Current Experimental Setup



Lightning Impulse Experiment Setup

Voltage-Current traces of Critical Current Measurements



Summary of Critical Current and Lightning Impulse Measurement Data

Measurement	Average Impulse Voltage C_1 (kV)	Critical Current (A)	Average Energy Released/breakdown (J)	Average Voltage recorded on Impulse Capacitor C_2 (kV)
Original critical current	N/A	104	N/A	N/A
Critical current after 5 impulses	62.5	84	48	48
Critical current after additional 5 impulses	63	82	50	49
Critical current after max rated impulse	122	5.5	186	80

- Severe degradation of the tape occurred after 11 lightning impulses
- Total energy released onto tape during breakdowns was approximately 750 J
- Total energy released is lower than what is expected for an electrical breakdown of an S-GIL cable while in service

Conclusions

- The extent of degradation of critical current of 2G HTS tapes depends on the voltage level of the electrical impulse event and the associated energy released
- Individual superconducting tapes were shown to degrade after multiple electrical impulses
- Future studies are required to determine if the cumulative effect of electrical impulses is equivalent to a single electrical impulse with the same amount of energy released
- Future studies are necessary to develop designs that can prevent damage to the superconductor as well as tolerate breakdowns without any degradation in the performance
- These studies on individual tapes represent worst case scenario

It is important to study degradation in model cables. Cables are mechanically more robust and it is possible that the degradation will be minimal or none.