Design Optimization of a Superconducting Gas-Insulated Transmission Line

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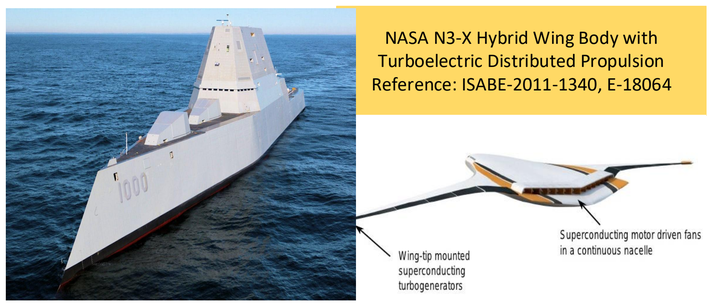
Introduction and Objectives

- Gaseous helium (GHe) is the preferred cryogen by the US Navy for superconducting devices
- GHe allows lower operating temperature than allowed by liquid nitrogen (LN2) with reduced risk of asphyxiation
- Critical current (Ic) of high temperature superconducting (HTS) cables increases significantly at lower temperatures – Ic at 67 K is twice as much as it is at 77 K
- The dielectric strength of GHe is currently limiting GHe cooled superconducting devices to low-medium voltage applications
- We have shown that addition of small mol% of H_2 and/or N_2 to GHe improves dielectric strength significantly without safety concerns
- The S-GIL design was developed to utilize the improved dielectric strength of GHe mixtures with improved dielectric strength
- Investigations have been undertaken to develop a GHe cooled superconducting cable suitable for 12 kV DC for US Navy all-electric ship applications

Benefits of S-GIL

- Partial Discharge is not a limiting factor as apposed to the traditional lapped tape design
- Superior heat transfer characteristics which has the potential to reduce the size of the cryogenic cooling system required
- Continuous flow of gas reduces space charge accumulation – important for DC cables
- Utilizes the improved dielectric properties of GHe-H_2 mixtures
- The design allows for flexibility with either a rigid or flexible cryostat able to be used

Applications



NASA N3-X Hybrid Wing Body with Turboelectric Distributed Propulsion
Reference: ISABE-2011-1340, E-18064

- GHe cooled HTS Technology provides high power density, lightweight and compact solutions
- HTS technology is useful in naval, aerospace and many other applications where high power density and efficiency are demanded

Conclusion

- The dielectric strength of GHe has been significantly improved with the introduction of small mol% of H_2 and/or N_2
- The S-GIL is a potential design of a GHe cooled superconducting cables rated for 12 kV DC for US navy all-electric ship application
- Further development of the rigid and flexible cryostat design is necessary

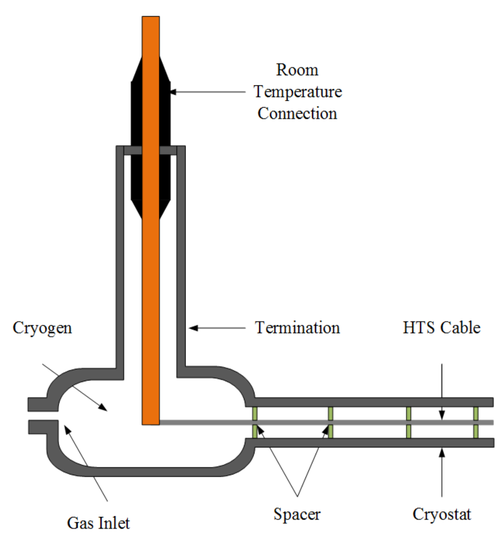
Acknowledgements

This research was funded by the Office of Naval Research under Grant N00014-14-1-0346 and N00014-16-1-2282

Superconducting Gas-Insulated Transmission Line

- The idea is similar to SF_6 insulated GIL
- Utilizes the cryogen as both the coolant and dielectric medium
- Dielectric characteristics dependent on the electric field within the cryostat and the cryogen used

S-GIL Operational Schematic



Co-axial Electric Field Equation

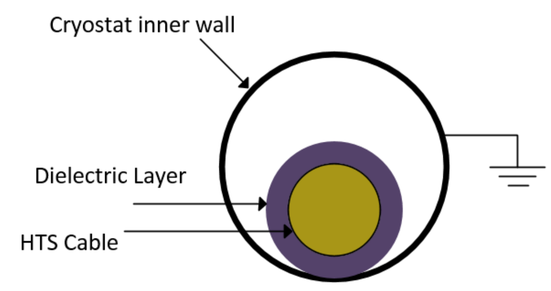
$$E_{max} = \frac{V}{R_s \times \ln\left(\frac{R_c}{R_s}\right)}$$

where E_{max} – maximum Electric Field, V- applied voltage, r_s- radius of superconducting cable and r_c -inner radius of the cryostat

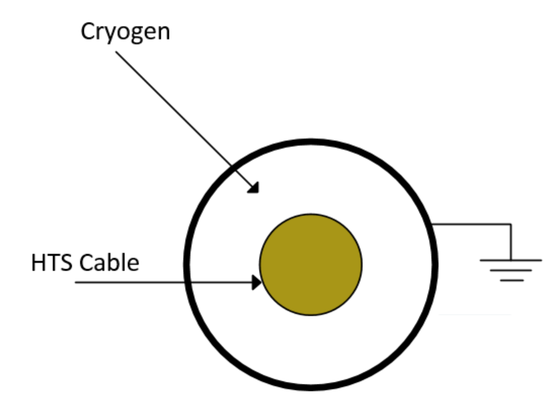
Optimization occurs when

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

Conventional HTS Cable Design



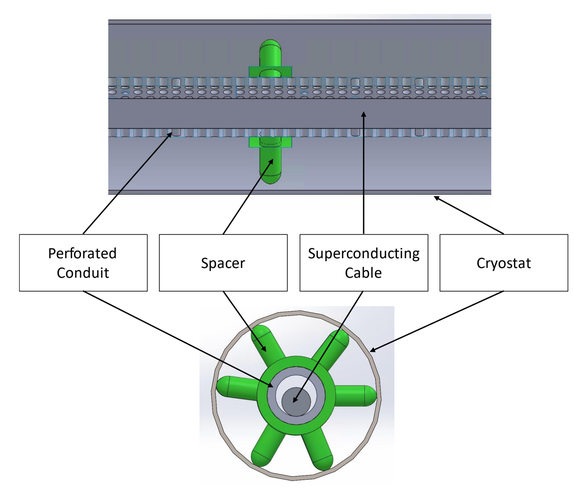
Superconducting Gas-Insulated Transmission Line



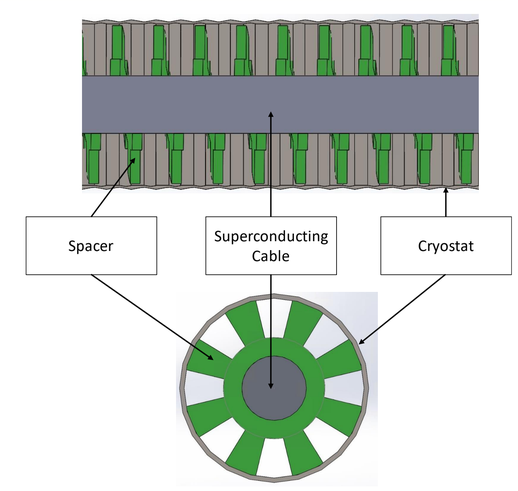
Proposed S-GIL Design

- Both rigid and flexible cryostat designs have been envisioned for the S-GIL.
- Rigid cryostats have been utilized for Gas Insulated Transmission Lines (GIL)
- Flexible cryostats have been a preferred choice of superconducting power cables
- Rigid cryostats typically have lower heat leak than flexible cryostats
- Flexible cryostats lend themselves to a continuous manufacturing and installation process
- Rigid cryostats allow sharper bend radii and simplified spacer design
- Knowledge on cable route required to determine suitability of each design

Rigid Cryostat Design

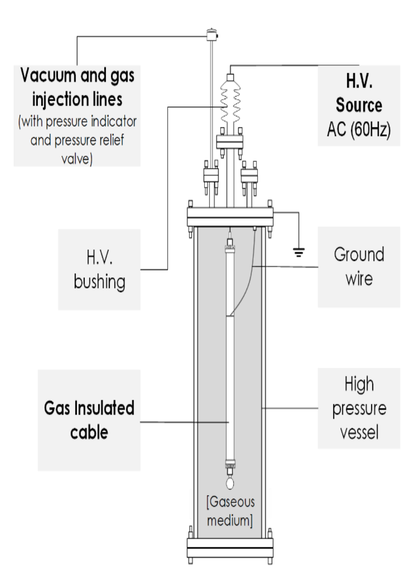


Flexible Cryostat Design



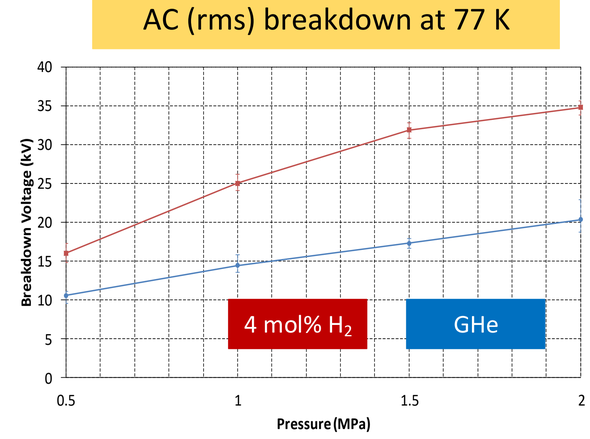
Proof of Concept Experiment

- Proof of concept experiments performed and demonstrated how voltage ratings dependent on dielectric strength of cryogen
- Dimension of the cryostat and superconducting cable selected to reflect what would be used



- At room temperature, approximately 30 - 45% increase in breakdown strength for 4 mol% H_2 mixture over 100% GHe
- At 77 K, approximately 80% increase in breakdown strength for 4 mol% H_2 mixture over 100% GHe
- A relationship exists between breakdown voltage at room temperature and 77 K

AC (rms) breakdown at 77 K



AC (rms) breakdown at 290 K