Modeling Superconducting Components of the Electric Aircraft

Ali Khonya(a), Mathias Noe(a), Wescley de Sousa(a), Frederick Berg(b), Michael Cooper(b)

(a) Institute for Technical Physics (ITEP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

(b) Airbus X-Labs, Taufkirchen, Germany

Introduction and Background

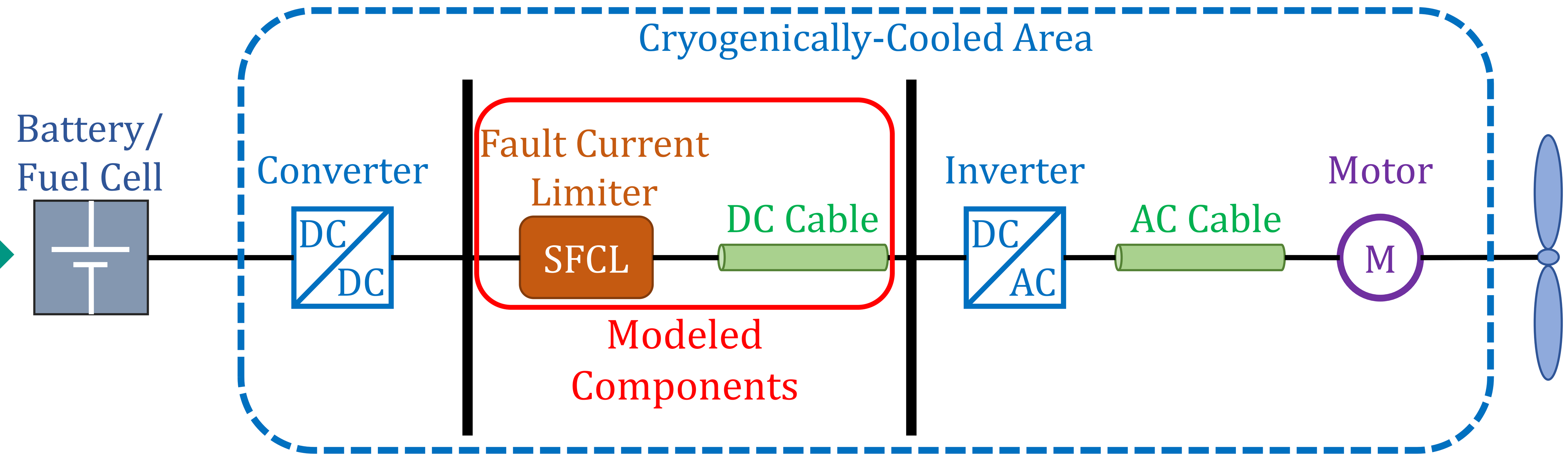
- Development of electric vehicles (road, railway, and shipping)
- 2.4% of annual CO_2 emission by aircraft in 2021
- 3.6% forecasted annual growth rate in the demand for passenger traffic

Aerospace industry goal:

- Example? EU Flightpath 2050: 75% CO2 emission reduction
- How? One potential solution: Electric Aircraft

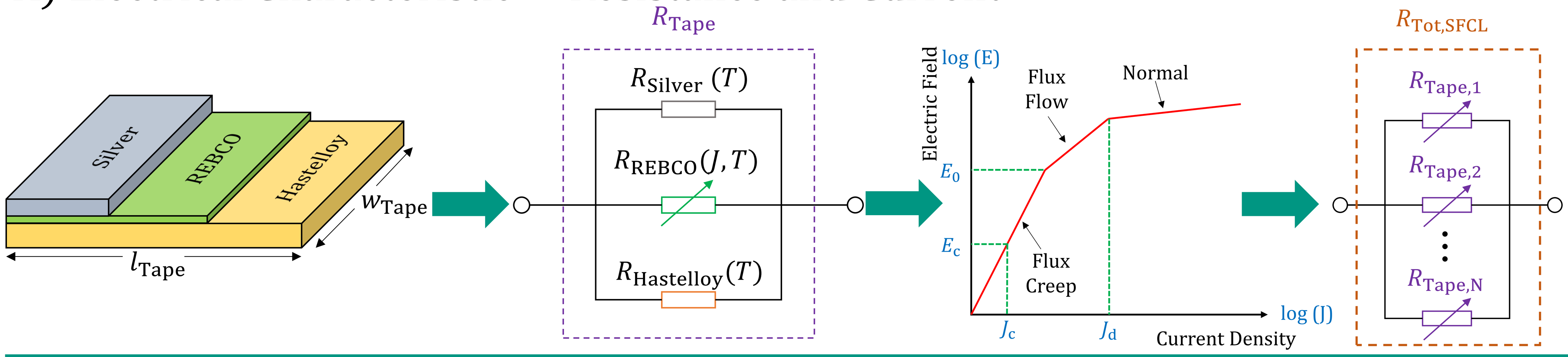
Superconducting technology advantages[1]

- Compactness
- Lightweight
- Higher Efficiency



Resistive Superconducting Fault Current Limiter (RSFCL)

A) Electrical Characteristic → Resistance and Current



B) Thermal Characteristic → Temperature

$$C_{Tape} \cdot \frac{\partial T_{Tape}}{\partial t} = P_{Tape} - P_c$$

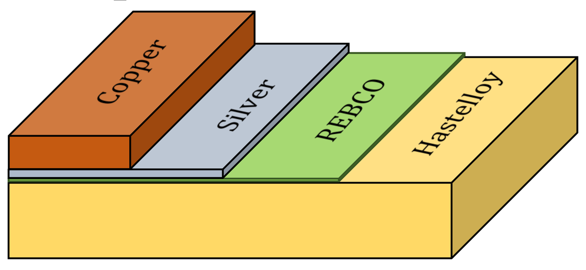
$$P_{Tape} = R_{Tape} \cdot I_{Tape}^2$$

$$P_{c,Adiabatic} = 0$$

$$P_{c,Non-Adiabatic} = 2h_c \cdot w_{Tape} \cdot l_{Tape} \cdot \Delta T$$

Superconducting DC Cable

Temperature calculation along the cable radius and length using finite-difference method (FDM)[2]



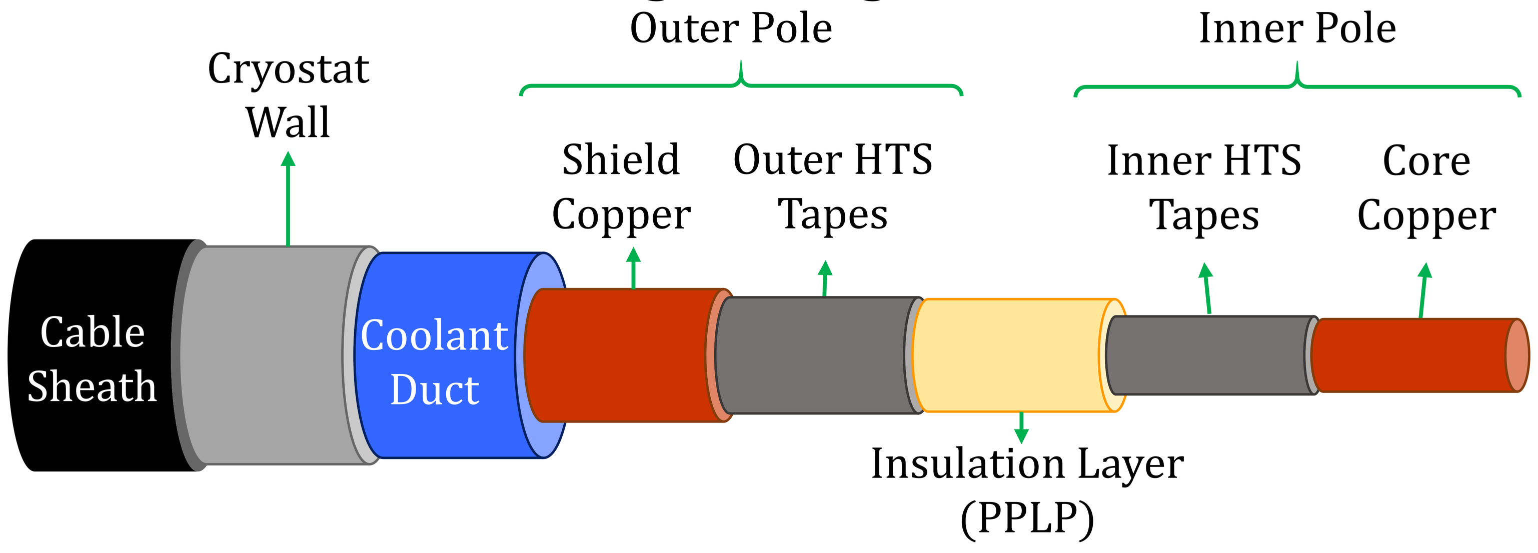
$I_{nom} = 1.5$ kA

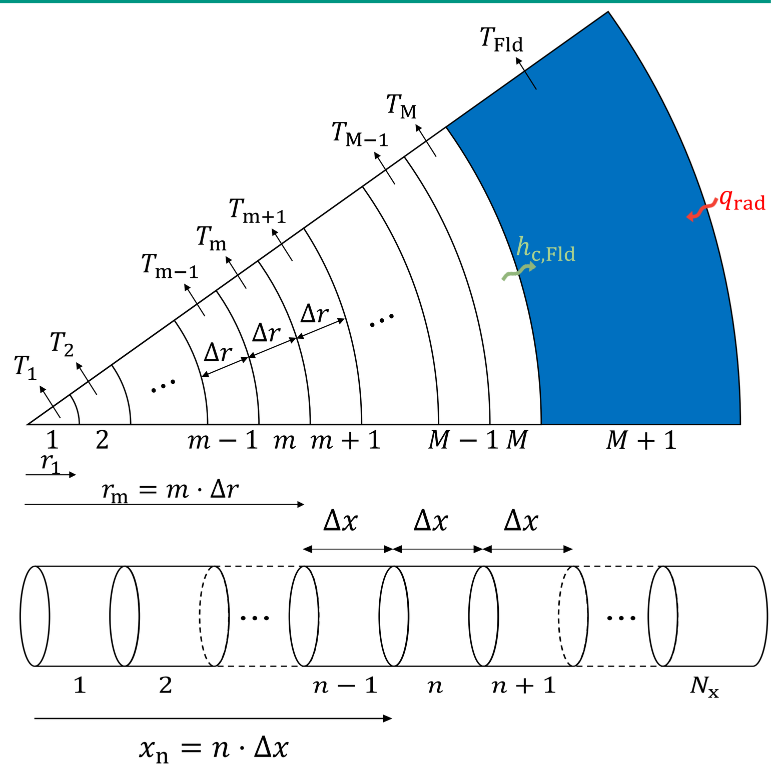
$I_{c,Tape} = 200$ A

LN_2 @ 77 K

8/12 Inner/Outer HTS Tapes

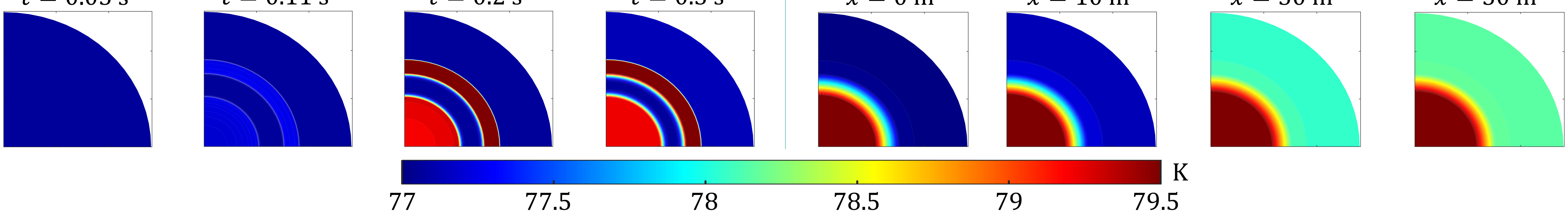
$l_{Cable} = 50$ m





Heat Transfer Equation: $\frac{d^2T}{dr^2} + \frac{1}{r} \cdot \frac{dT}{dr} + \frac{d^2T}{dx^2} + \frac{g}{k} = \frac{\rho \cdot c_p}{k} \cdot \frac{dT}{dt}$

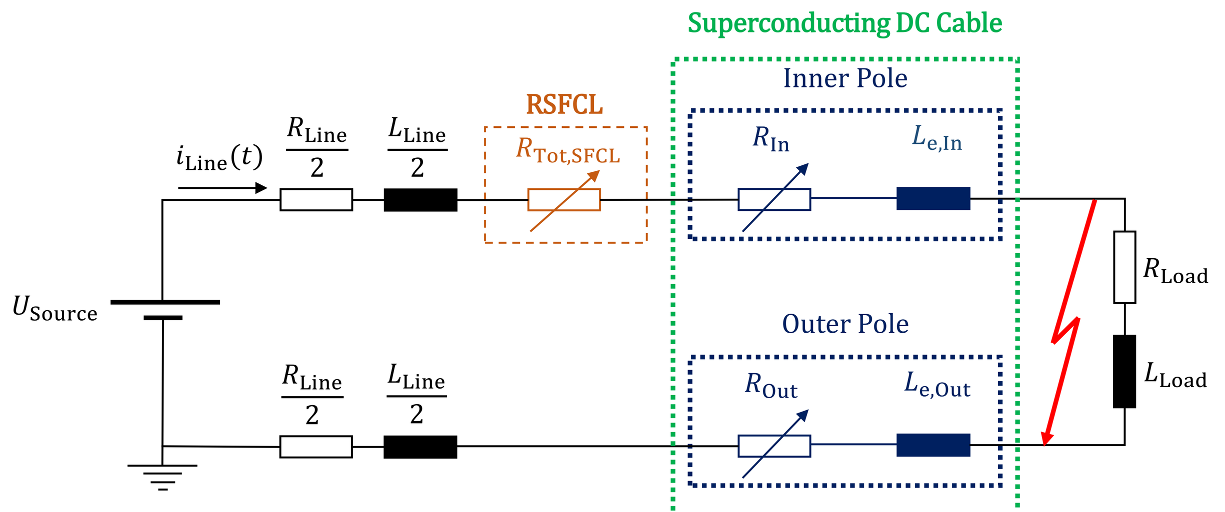
At Different Simulation Times (at the End of the Cable)				At Different Cable Lengths (at 20 s after Fault)			
$t = 0.05$ s	$t = 0.11$ s	$t = 0.2$ s	$t = 0.3$ s	$x = 0$ m	$x = 10$ m	$x = 30$ m	$x = 50$ m

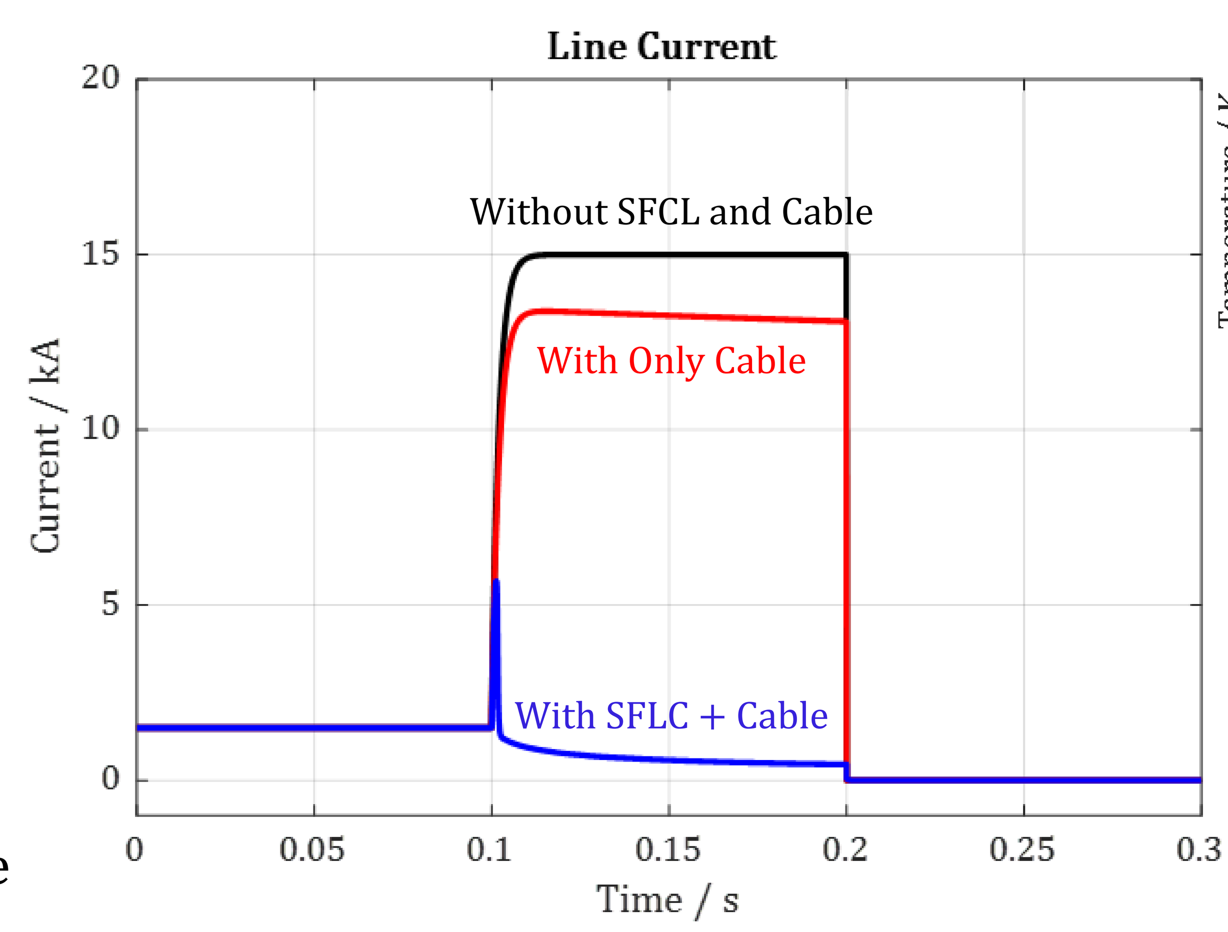


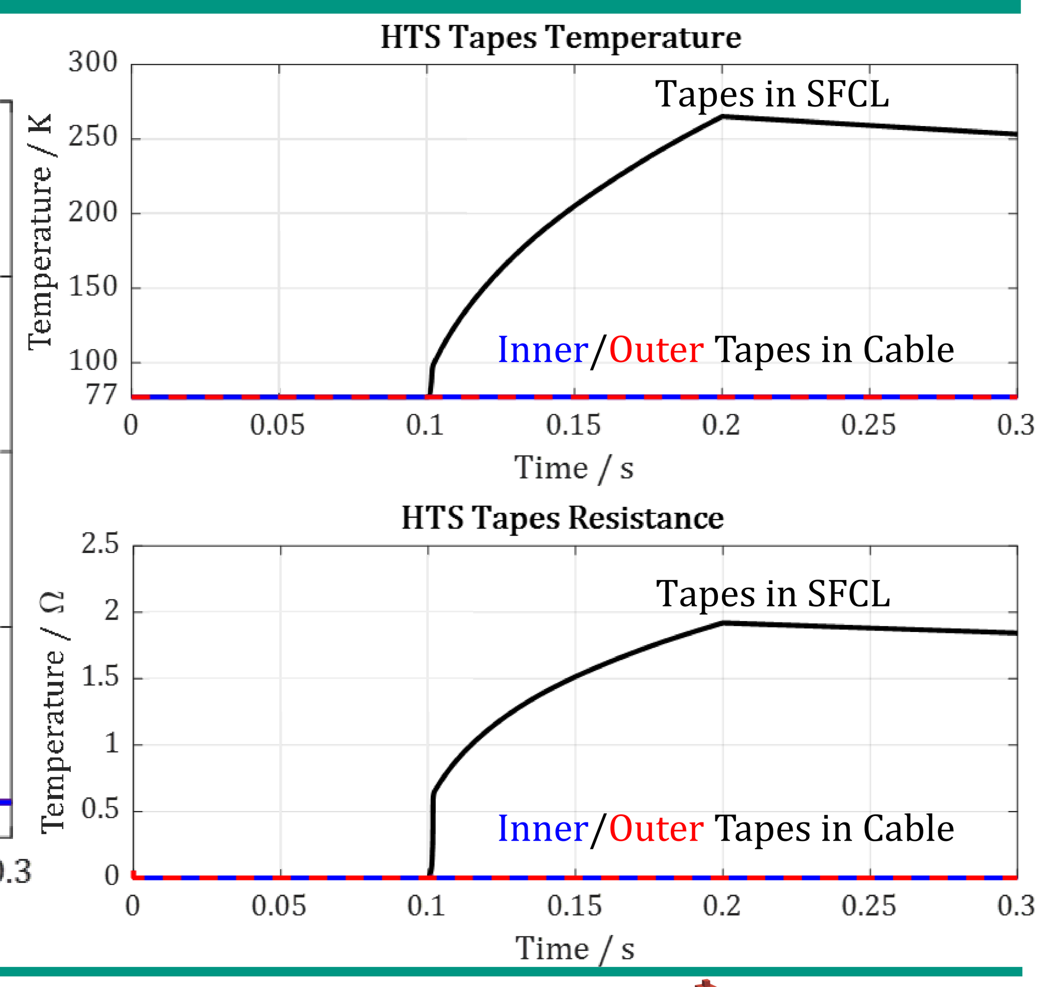
Superconducting Fault Current Limiter + DC Cable

Short-Circuit Behavior Analysis

MATLAB and SIMULINK Modeling







Summary:

- Validation of the cable behavior by 2-D model
- Configurable SIMULINK models for RSFCL and cable

References:

[1] L. Ybanez et al., "ASCEND: The first step towards cryogenic electric propulsion", doi: 10.1088/1757-899X/1241/1/012034.

[2] W. T. B. De Sousa, E. Shabagin, D. Kottonau, and M. Noe, "An open-source 2D finite difference based transient electro-thermal simulation model for three-phase concentric superconducting power cables," Supercond Sci Technol, vol. 34, no. 1, Dec. 2020, doi: 10.1088/1361-6668/ABC2B0.

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