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Design of a 110 kV 2.0 kA SmartCoil SFCL

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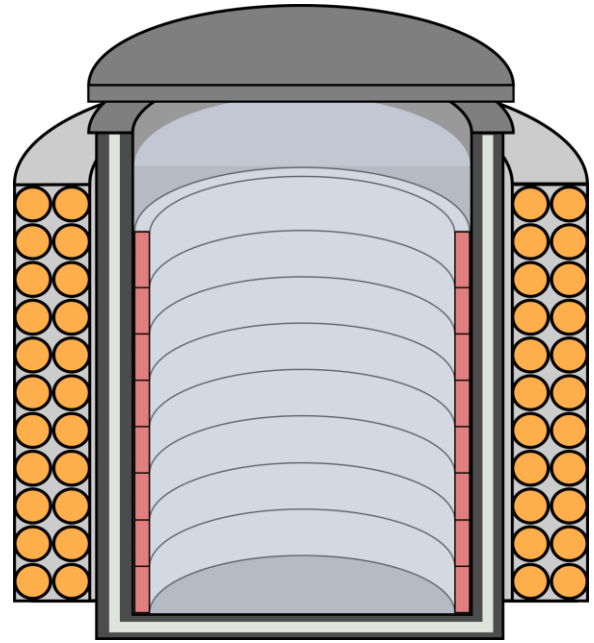


Outlook

- Fault current limitation is of the utmost interest in electrical networks
- Superconducting Fault Current Limiters (SFCLs) have been developed to such an extent in recent years that a use in the high-voltage level appears possible

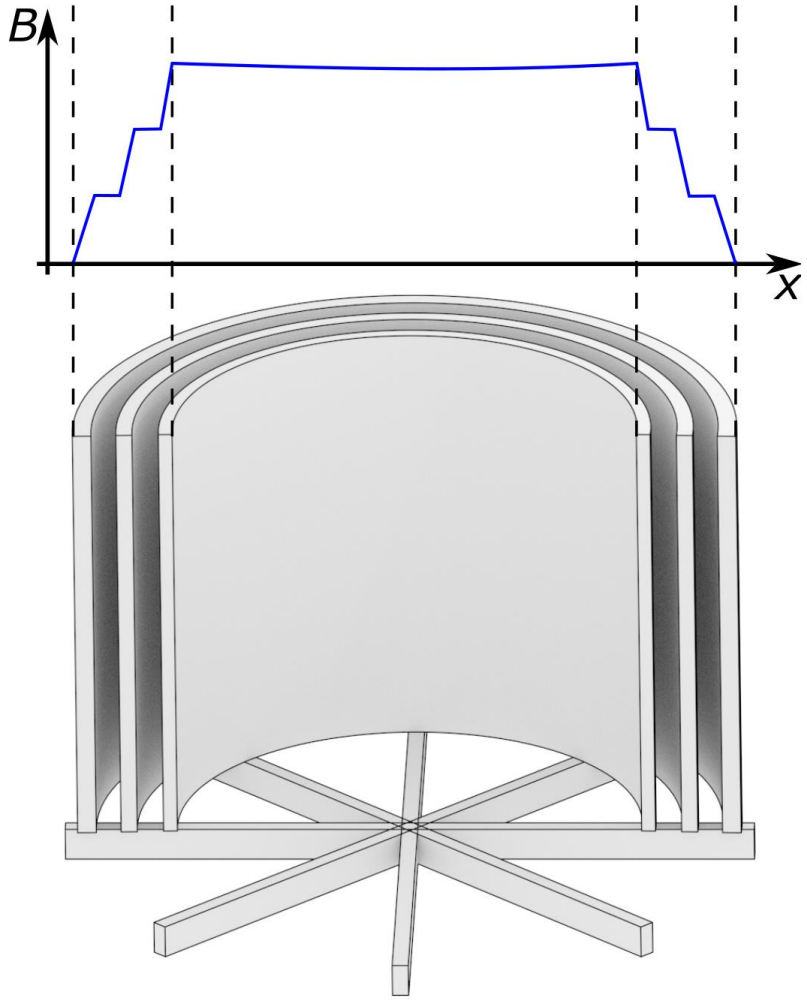
- **EU Project FastGrid**
  - SFCL for HVDC Networks

P. Tixador et al., "Some Results of the EU Project FASTGRID," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 4, pp. 1-6, June 2022, Art no. 560100.

- **SuperOx AC SFCL**
  - 220 kV/300 MVA

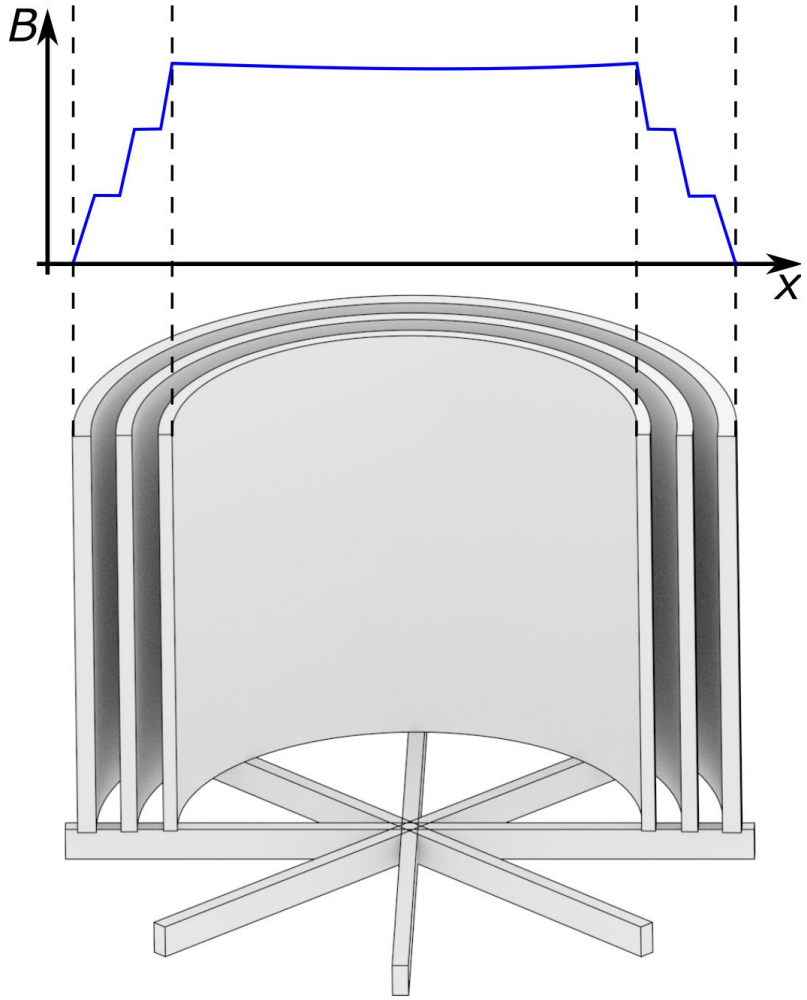
M. Moyzykh et al., "First Russian 220 kV Superconducting Fault Current Limiter (SFCL) For Application in City Grid," in IEEE Transactions on Applied Superconductivity, vol. 31, no. 5, pp. 1-7, Aug. 2021, Art no. 5601707.

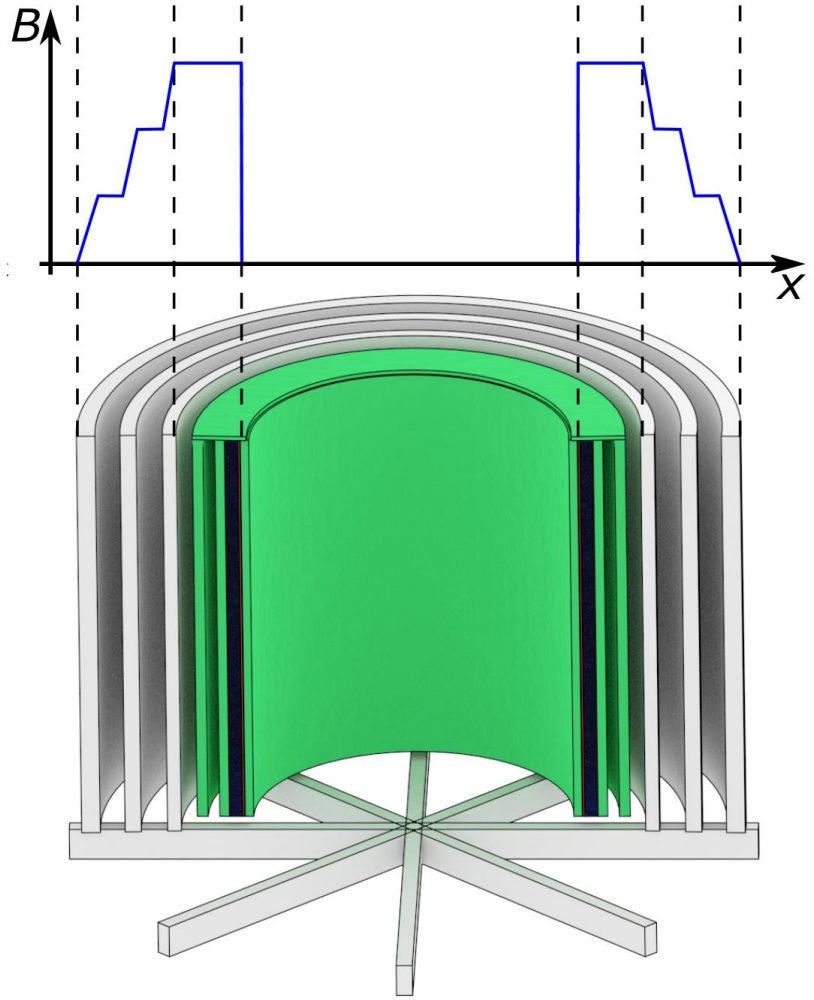
SmartCoil Concept



SmartCoil Concept

- The SmartCoil SFCL consists of an air-core reactor shielded with short-circuited HTS rings





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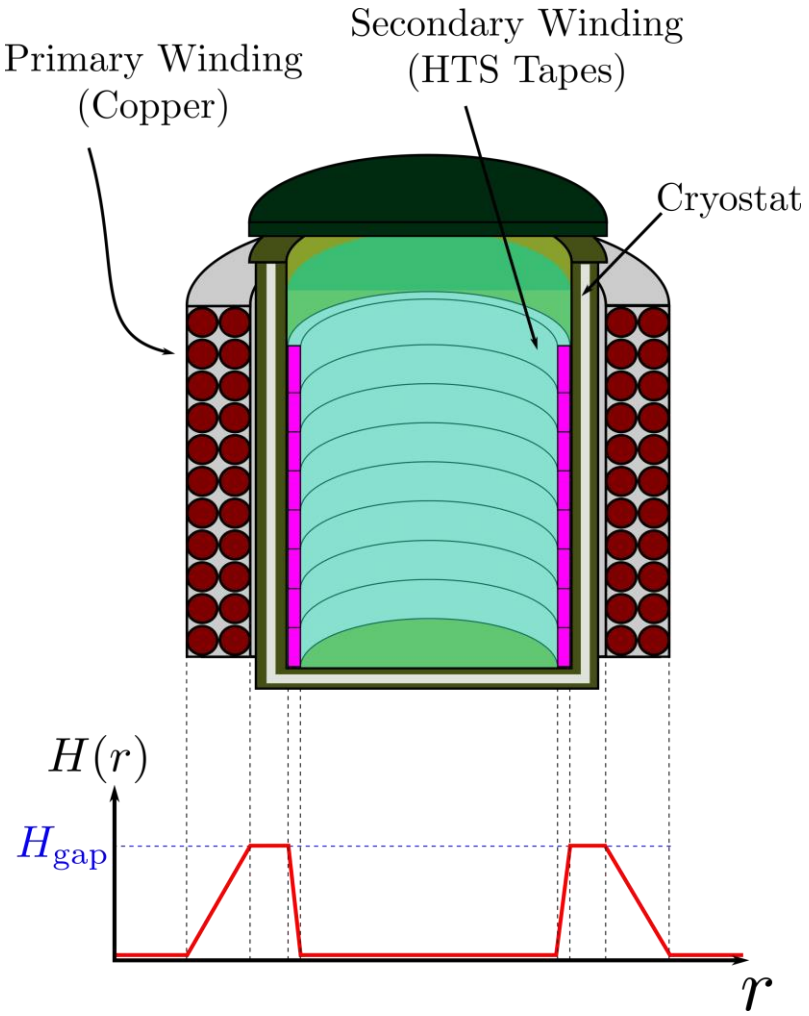
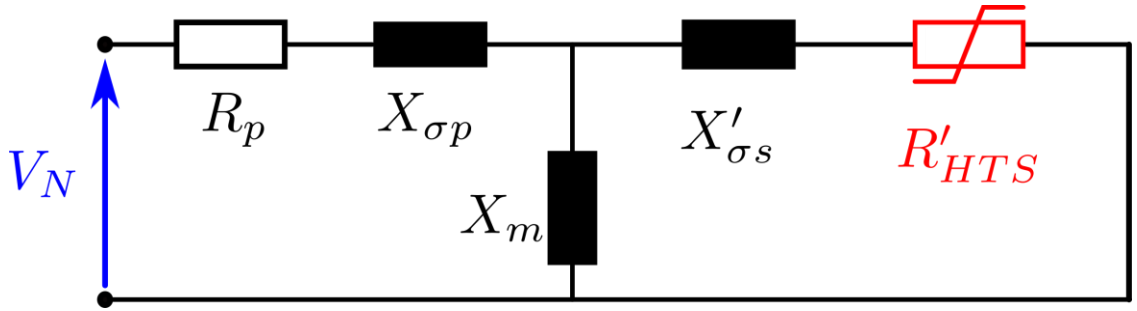




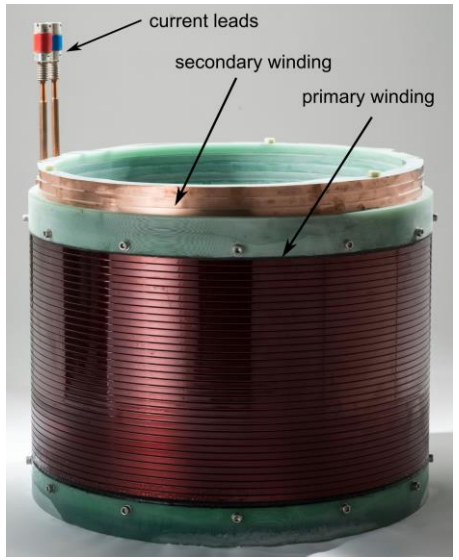
- R_p = primary resistance
- $X_{\sigma p}$ = primary stray reactance
- X_m = main inductance
- $X'_{\sigma s}$ = secondary stray reactance
- R_{HTS} = HTS tapes

$$Z_{Smart} = R_p + jX_{\sigma p} + \frac{X_m \cdot (R'_{HTS} + jX'_{\sigma s})}{jX_m + (R'_{HTS} + jX'_{\sigma s})}$$

SmartCoil SFCL

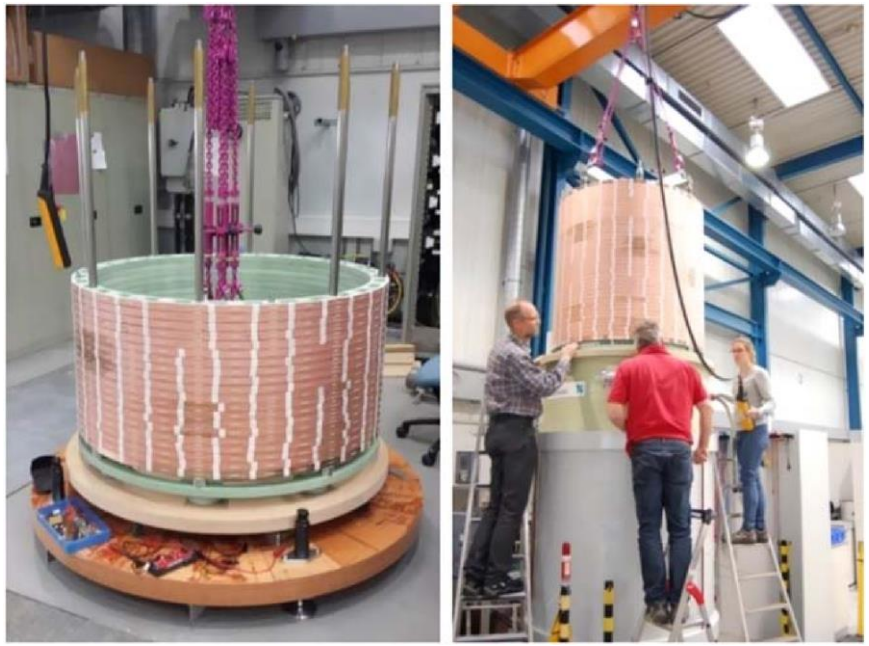
- In 2018 a SmartCoil SFCL was tested in a medium voltage network in Germany

SmartCoil SFCL	
Nominal Voltage	10 kV
Nominal Current	600 A
Nominal Power	10 MVA
Height	1.2 m
HTS Rings	80
Limitation time	80 ms



O. Naeckel and M. Noe, "Design and Test of an Air Coil Superconducting Fault Current Limiter Demonstrator," in IEEE Transactions on Applied Superconductivity, vol. 24, no. 3, pp. 1-5, June 2014, Art no. 5601605.

A. Kudymow et. al., "Smartcoil—design, assembly and test of a 10 MVA superconducting air coil fault current limiter," in Supercond. Sci. Technol, vol. 32, no. 065002, 2019.



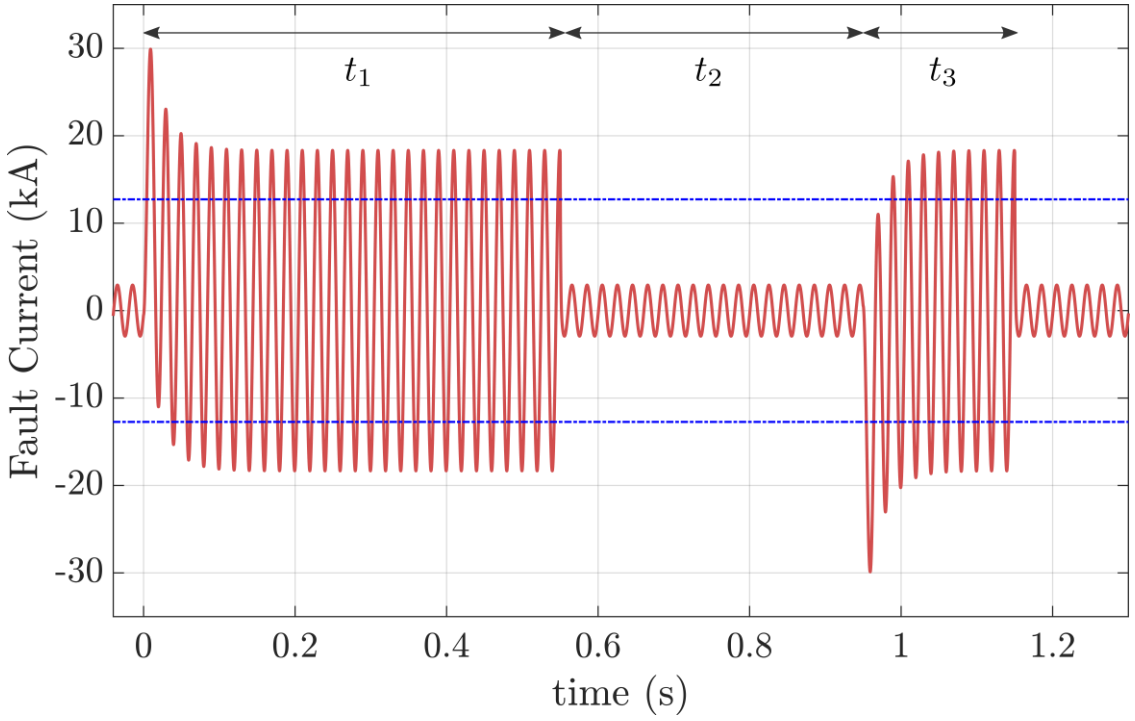
SmartCoil SFCL for HV Networks

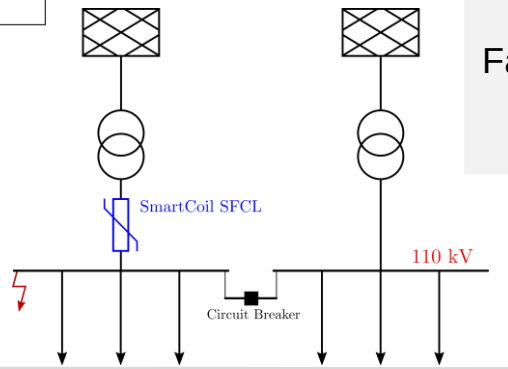
- Due the challenges regarding fault current limitation in 110 kV lines, an study conducted by KIT in cooperation with Vision Electric Super Conductors GmbH (VESC) and German distribution system operators has been conducted to adress the study of a SmartCoil SFCL in high voltage systems

Vergleichende Studie zwischen supraleitendem resistivem Fehlerstrombegrenzer "SSB" und supraleitendem induktivem Fehlerstrombegrenzer "SmartCoil" – Technische und wirtschaftliche Machbarkeit, 2022

Network Requirements

- Requirements were defined by the network operators





Parameter	Symbol	Value
Nominal Voltage	V_N	110 kV
Nominal Current	I_N	2.1 kA
Line frequency	f_N	50 Hz
Fault Current	I_K	13 kA
Limited Current	I_L (rms)	4.5 kA
	I_L (peak)	12.7 kA
Fault Duration	t_1	0.55 s
	t_2	0.3 s
	t_3	0.2 s

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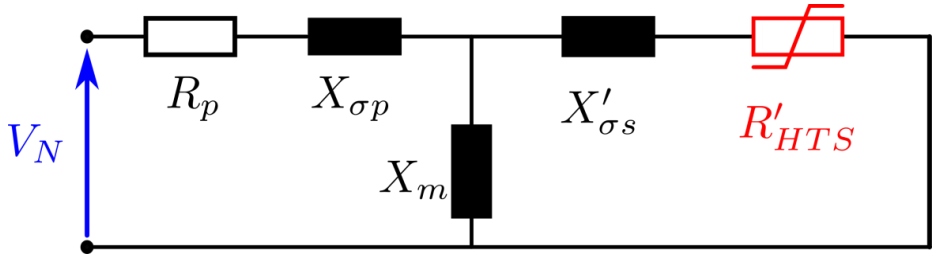

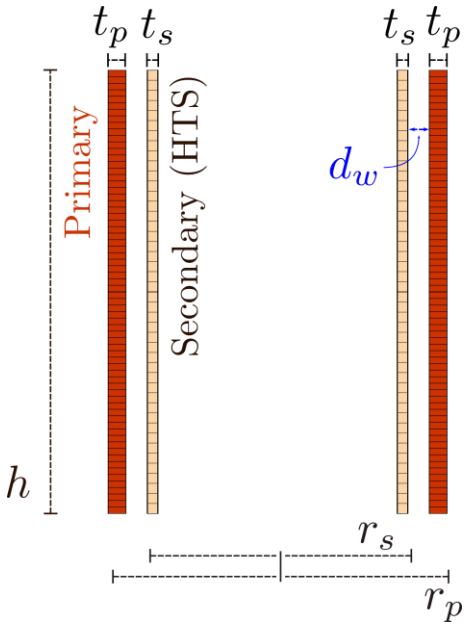

- Appropriate design:
  - 1% < $X_{\sigma p}$ < 5% (0.01 p.u. < $X_{\sigma p}$ < 0.05 p.u.)
  - 20% < X_m < 40% (0.2 p.u. < X_m < 0.4 p.u.)
- Variation of:
  - Primary winding radius (r_p)
  - turns of the primary winding (n_p)

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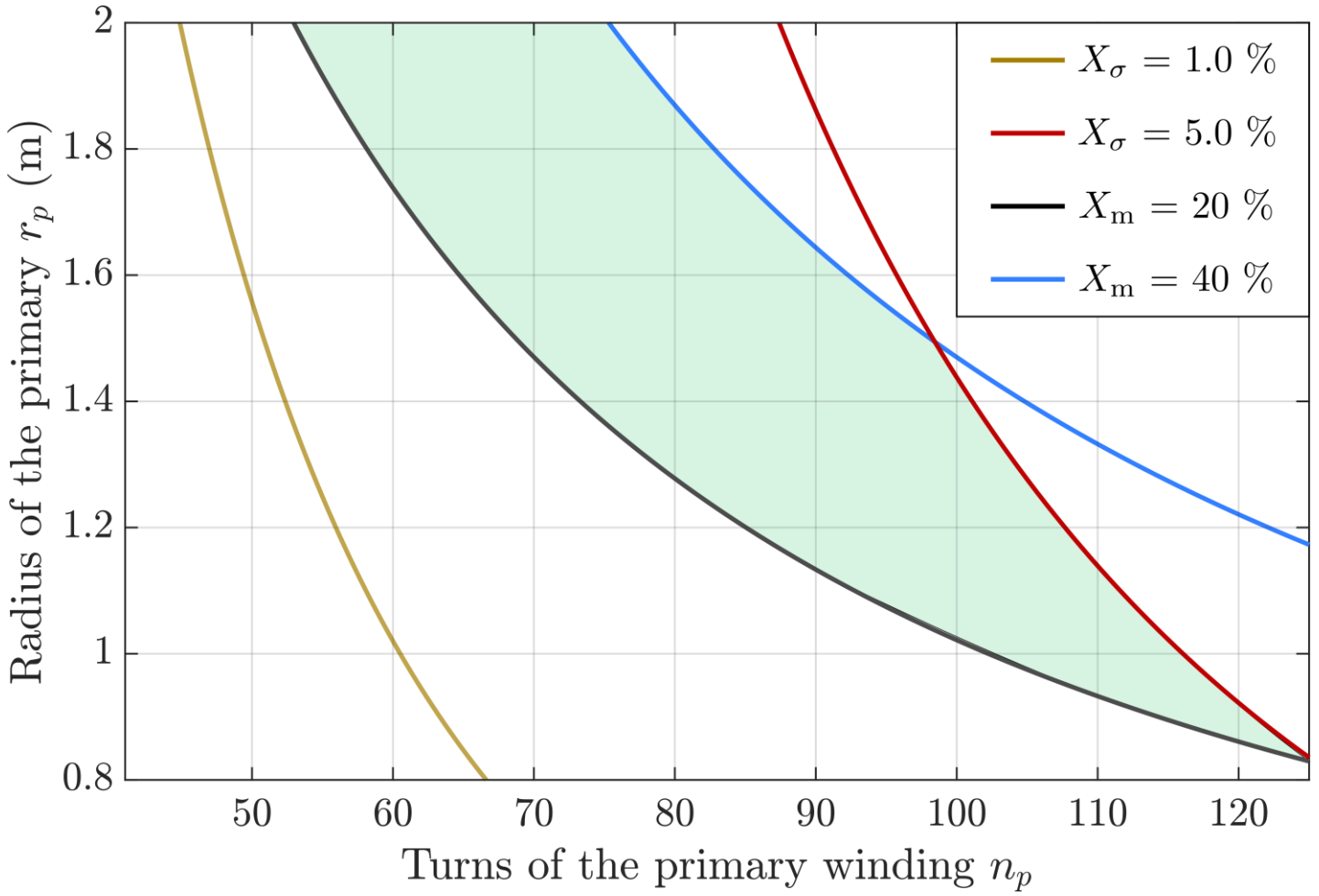
Design Procedures

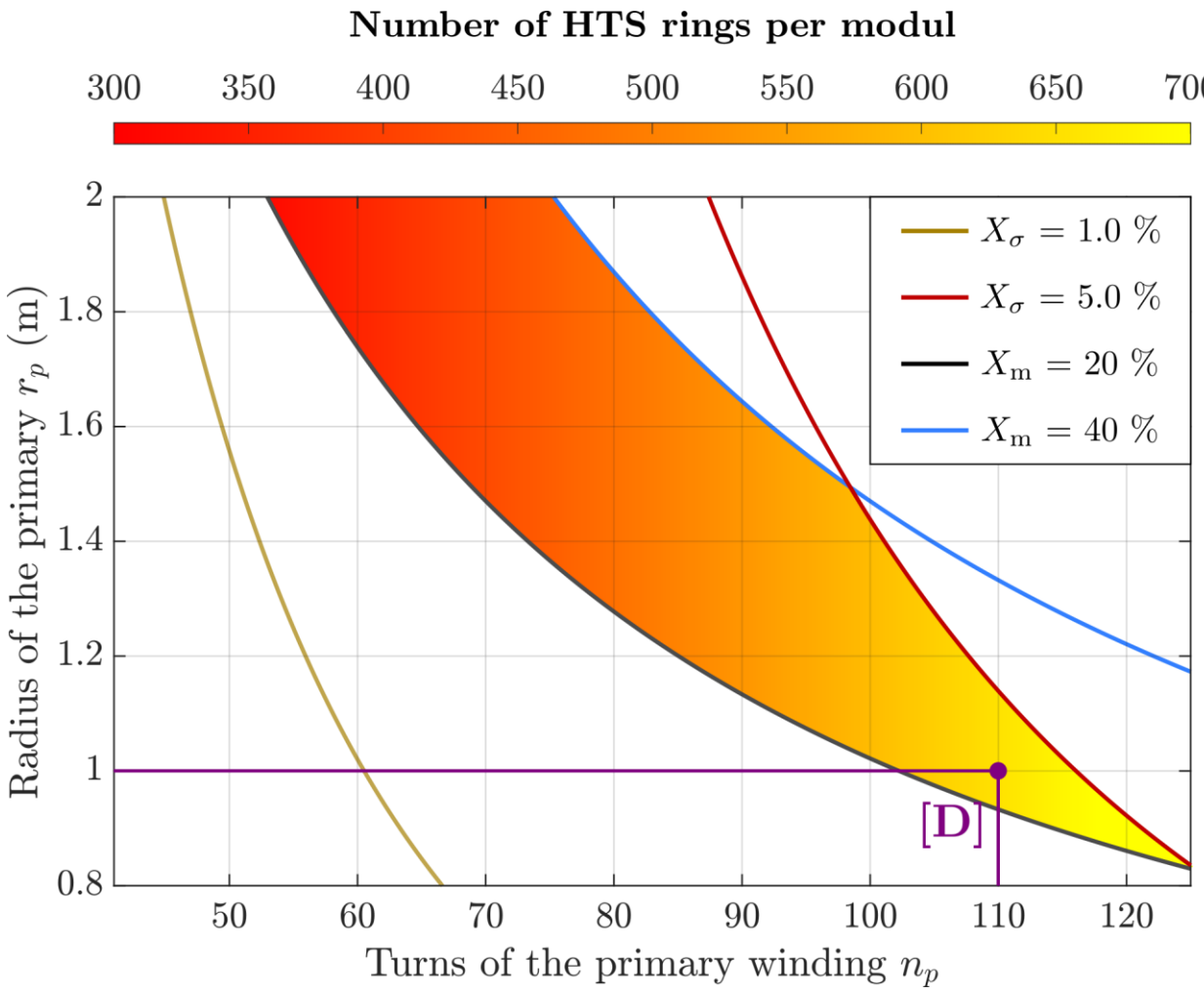
- Determination of the design Area

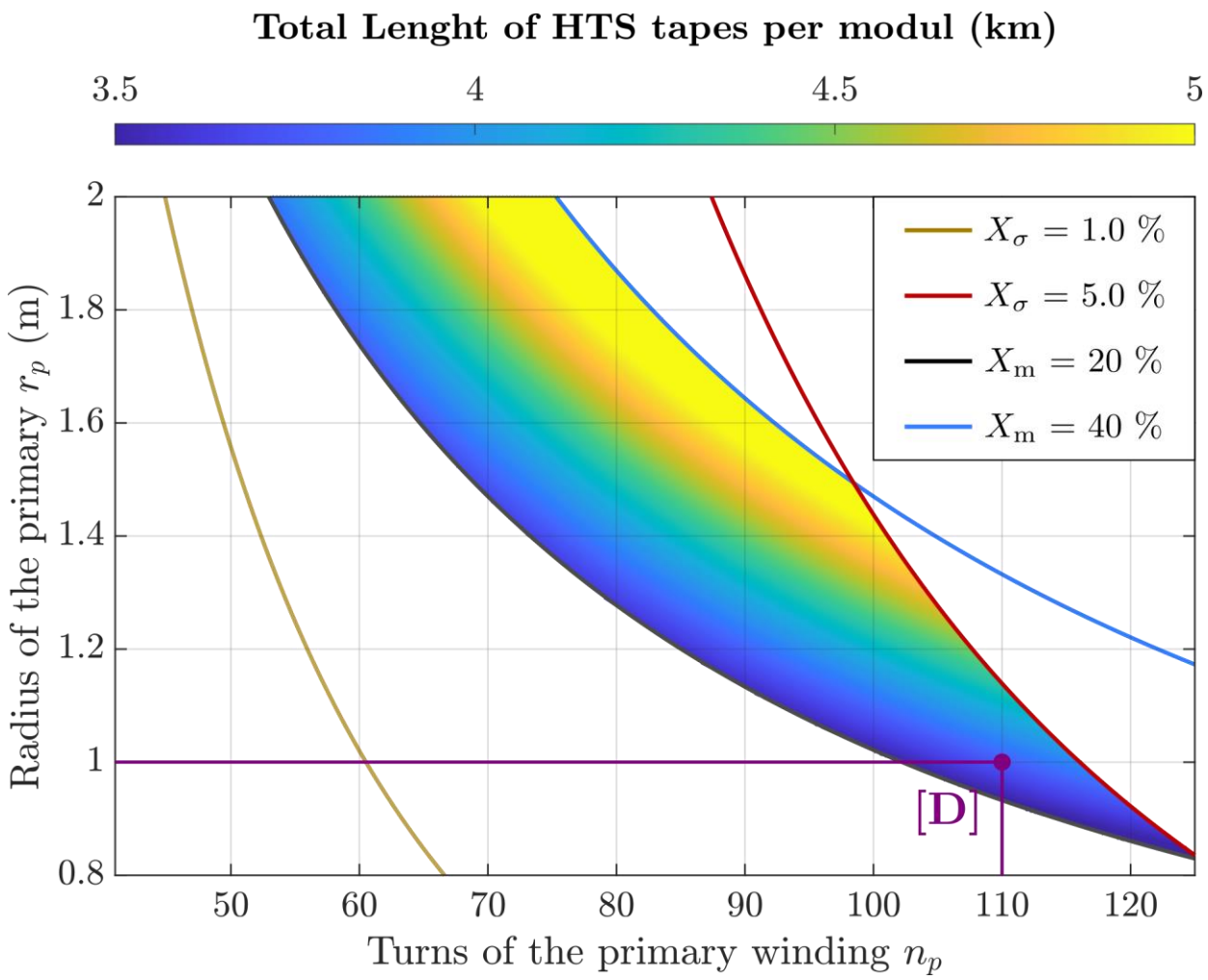
- Appropriate design:
  - 1% < $X_{\sigma p}$ < 5% (0.01 p.u. < $X_{\sigma p}$ < 0.05 p.u.)
  - 20% < X_m < 40% (0.2 p.u. < X_m < 0.4 p.u.)

- Inside of the design area:
  - Number of HTS rings
  - Total amount (lenght) of HTS tapes
  - AC Losses
  - First peak of the limited current
    - < 12.7 kA
  - Maximum value of temperature
    - T_{MAX} < 360 K



Prelimary Designs





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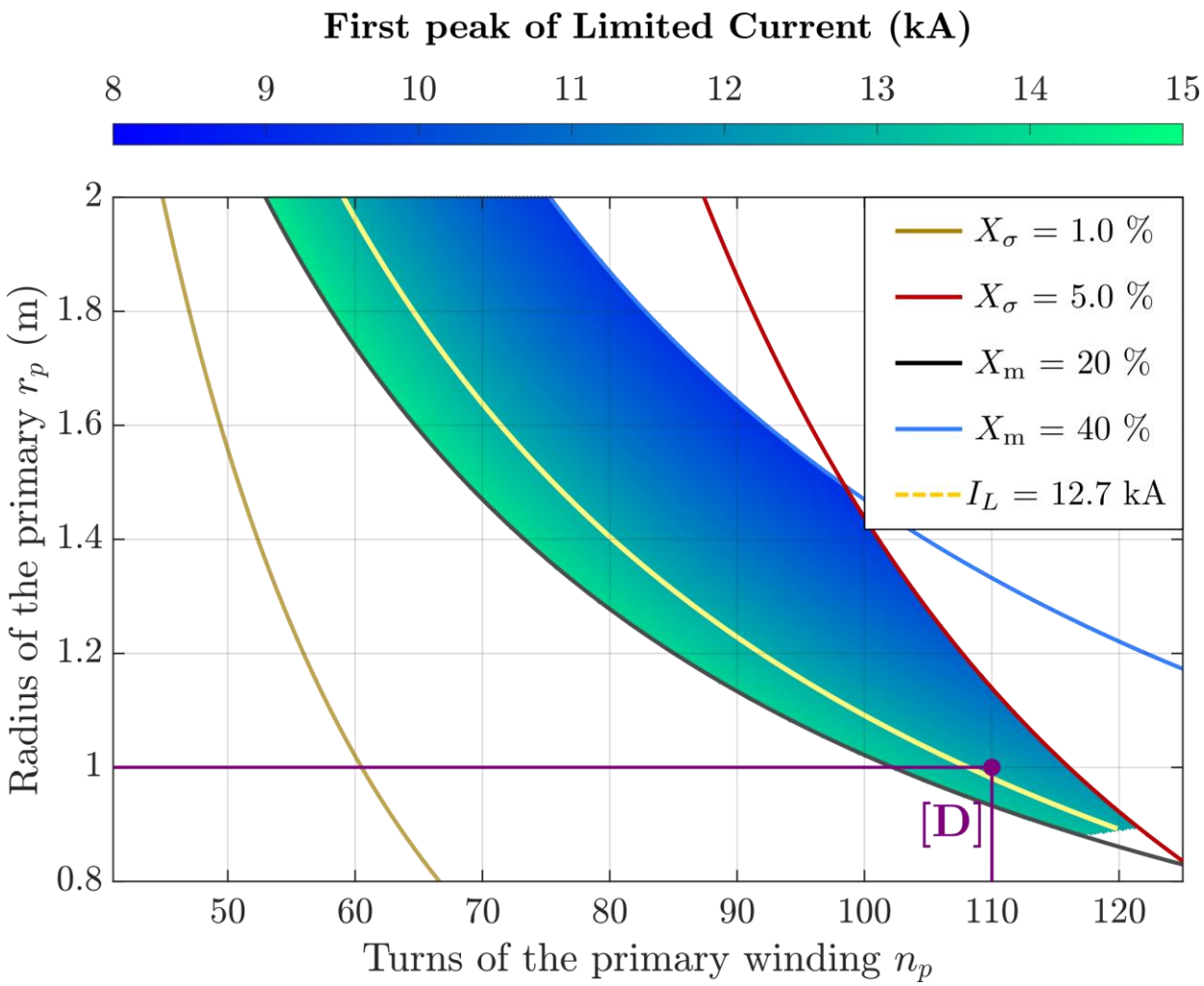

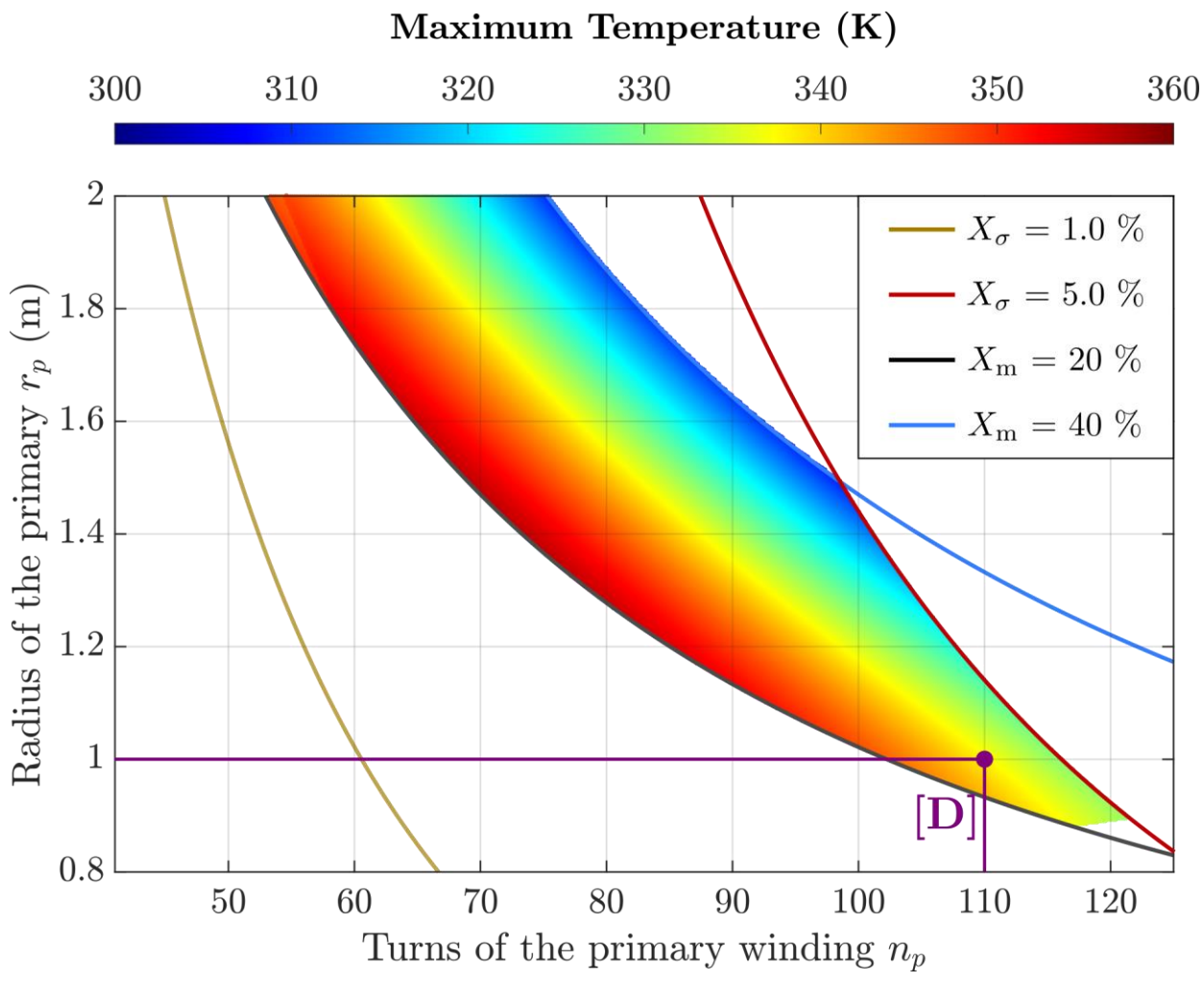

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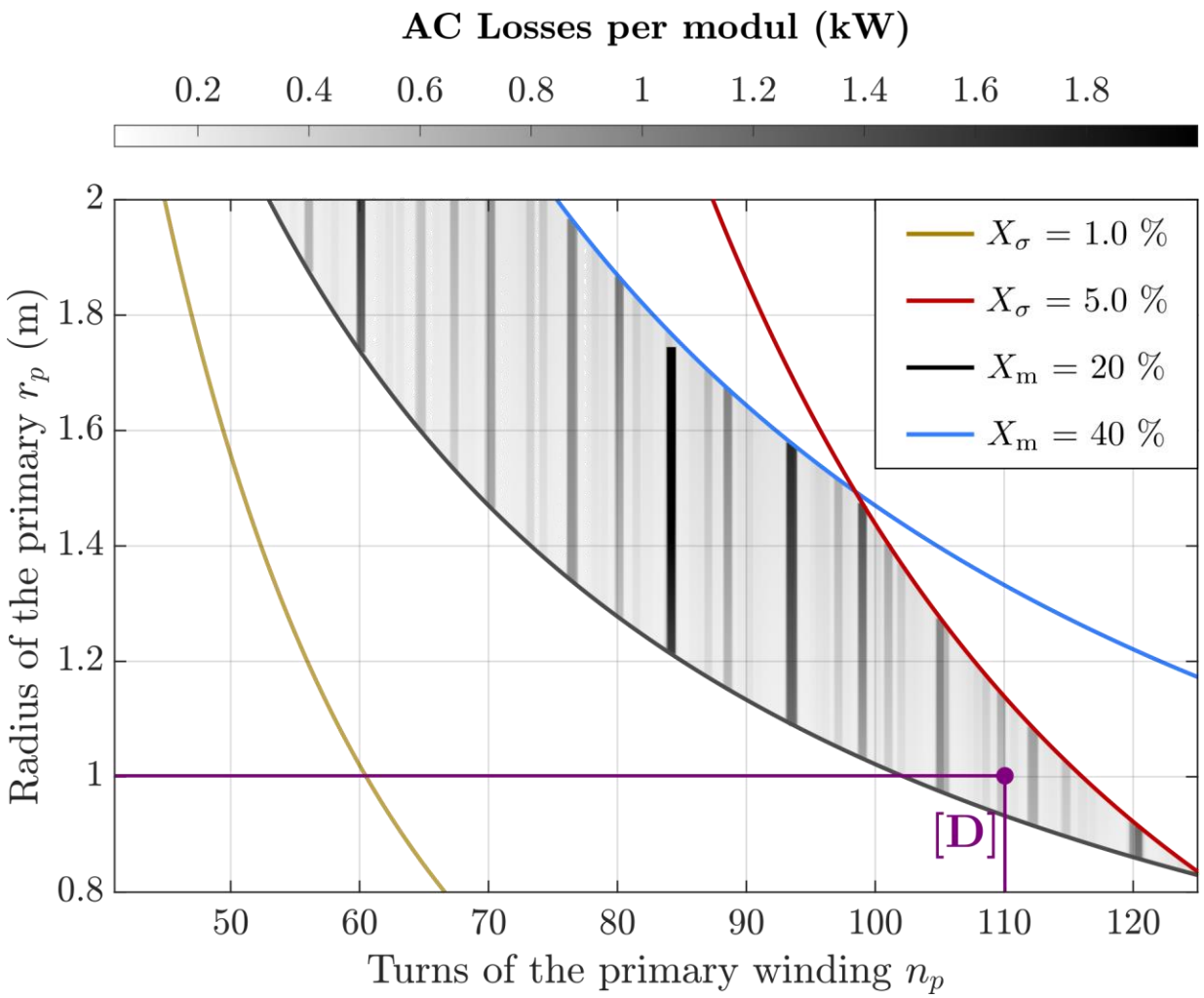
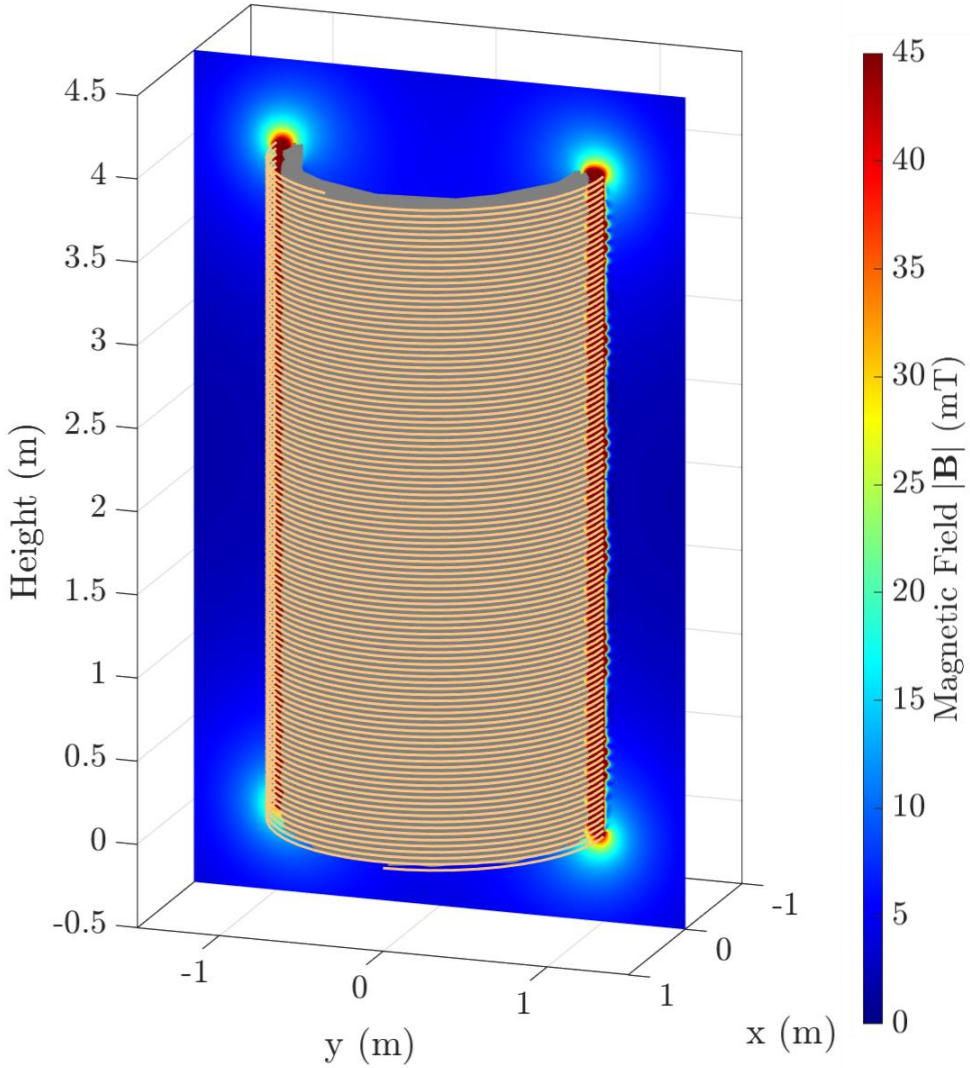
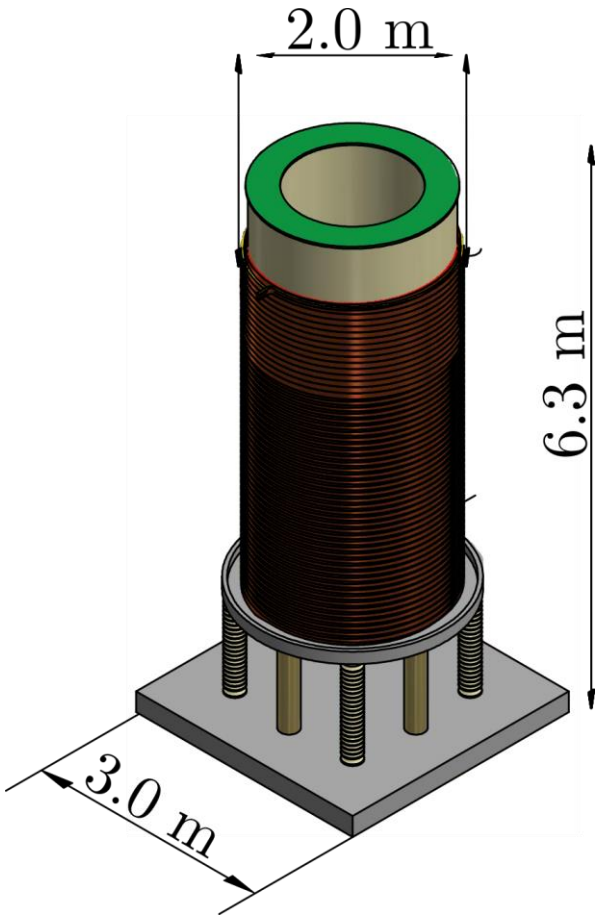




Design [D]

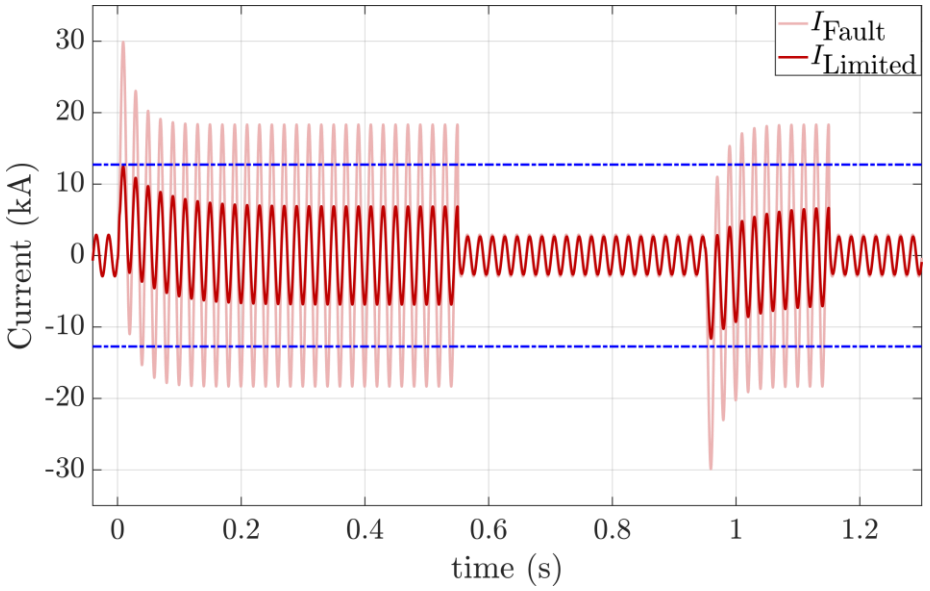


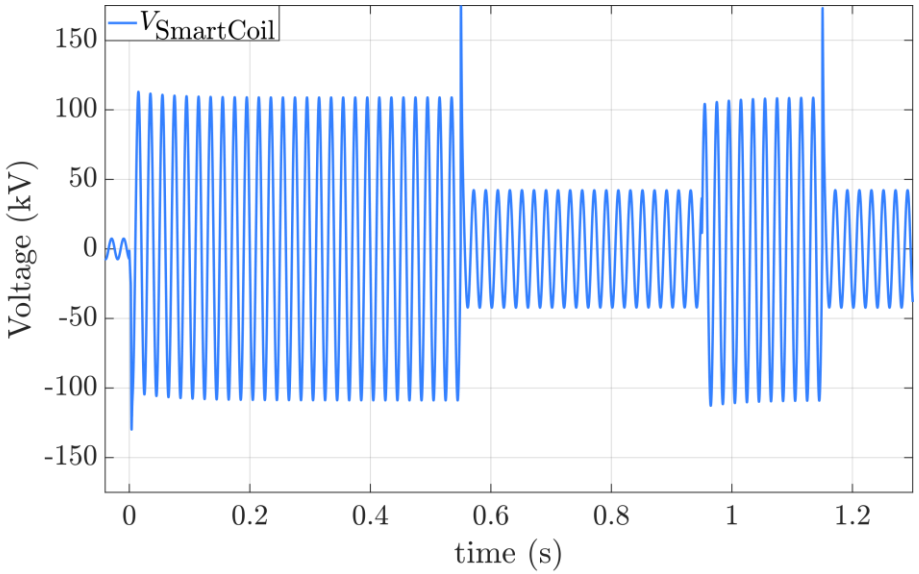
- For each phase, 3 modules in series are needed

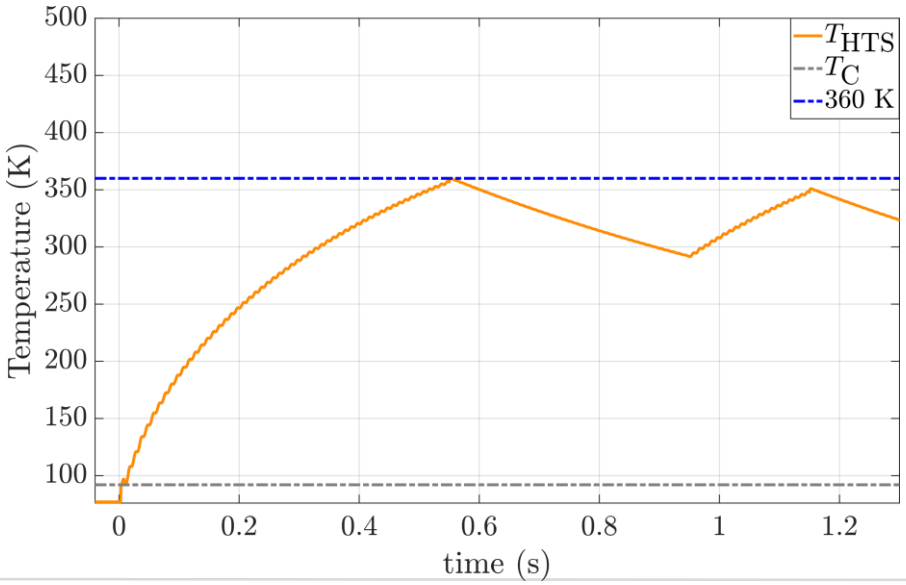
- Parameters of chosen design **[D]**

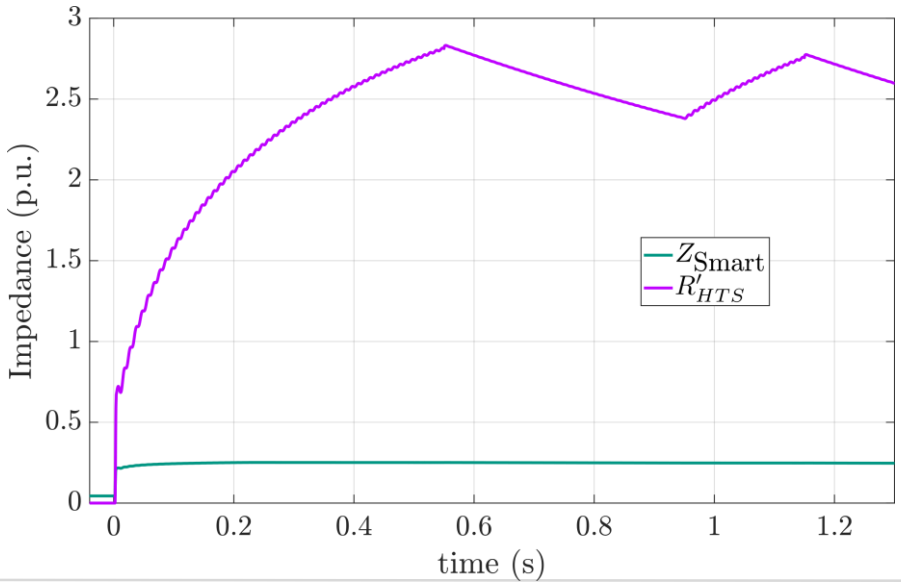
Parameter	Symbol	per module	per phase
Radius primary winding	r_p	1.0 m	
Turns primary winding	n_p	110	
Height (coil)	h	4.0 m	
Number of HTS rings	n_{HTS}	653	1959
Total lenght HTS tapes	L_{HTS}	3.74 km	11.22 km
AC Losses	Q_T	0.2 kW	0.6 kW

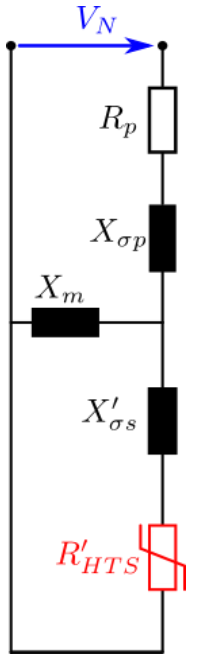
Transient Behaviour design [D]











Conclusions

- The SmartCoil SFCL appears as an update option for convention air-core reactors
- Based on the network operator requirements, several designs have been found.
- A design [D] was chosen
  - With small AC losses
  - Low amount of HTS tapes
  - Neither the limited current threshold (12.7 kA) and maximum temperature value (360 K) were exceeded.

THANK YOU VERY MUCH FOR YOUR ATTENTION

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