

DC Grid Stabilization using a Resistive Superconducting Fault Current Limiter

L. Quéval¹, F. Trillaud², B. Douine³

¹ GeePs, CNRS UMR 8507, CentraleSupélec, UPSud, UPMC, Gif-sur-Yvette, France

² Instituto de Ingeniería, National Autonomous University of Mexico (UNAM), Mexico

³ GREEN, Université de Lorraine, Nancy, France



UNIVERSITÉ
DE LORRAINE

Superconducting fault current limiters have been proposed to provide over-current protection during fault conditions in DC grids.

Outside of fault condition, what could we do with a superconducting fault current limiter in a DC grid ? Could it provide another functionality ?

→ Superconducting power filter to increase the DC grid stability !

Content

- I. Stability limit of a DC grid
- II. Improved stability of a DC grid with a r-ScFCL
 - 1. About superconductors
 - 2. Power law model
 - 3. Limiter mode and power filter mode
 - 4. Simulation results
- III. Conclusion

I. Stability limit of a DC grid

DC grid with a constant power load

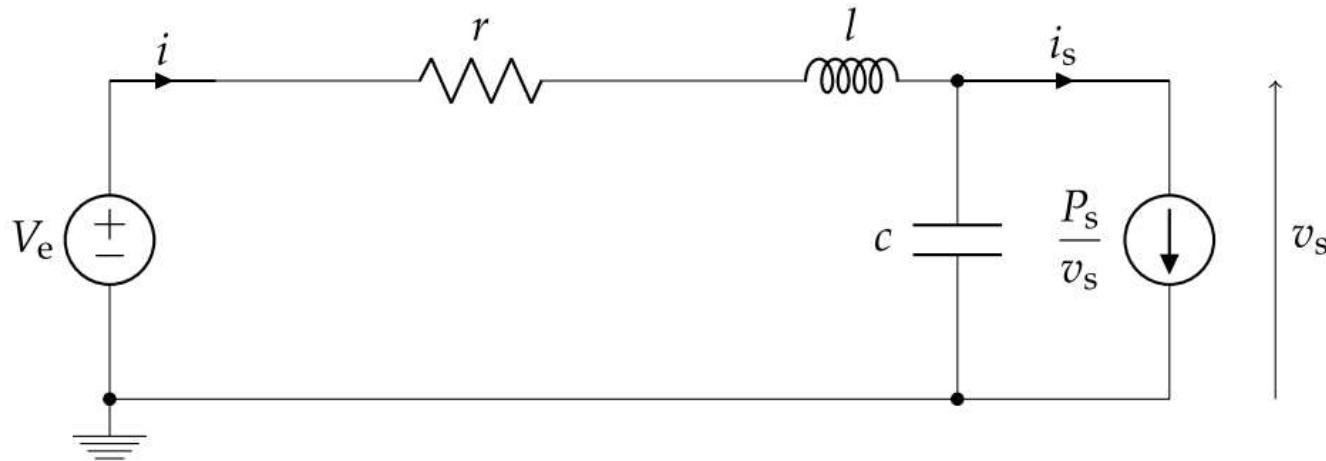


Table 1: DC grid parameters

Symbol	Parameter	Value
V_e	source voltage	5 kV
r	resistance	40 mΩ
l	inductance	0.6 mH
c	capacitance	1.4 mF

Analytical stability region

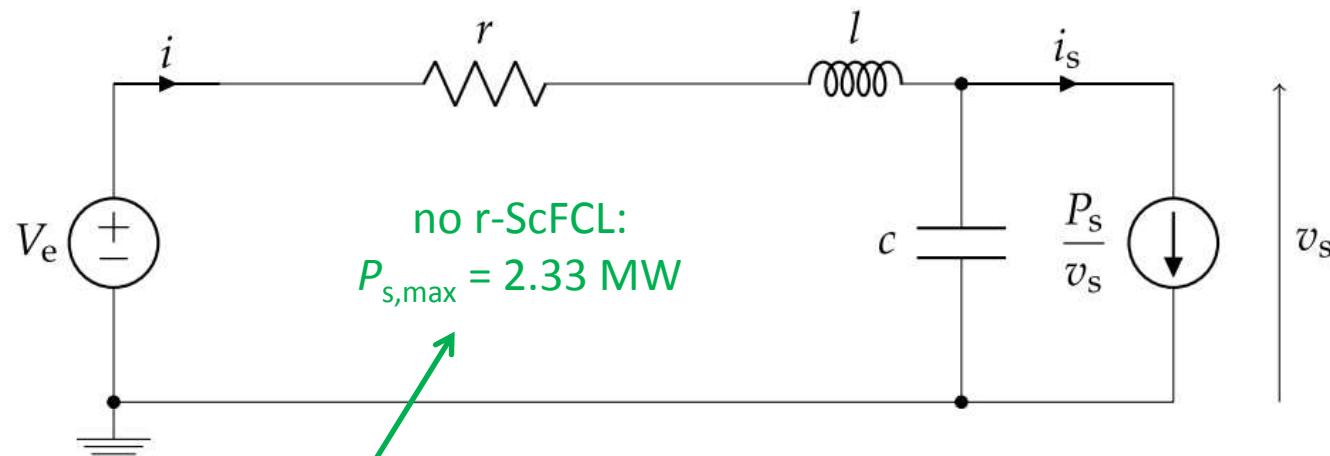
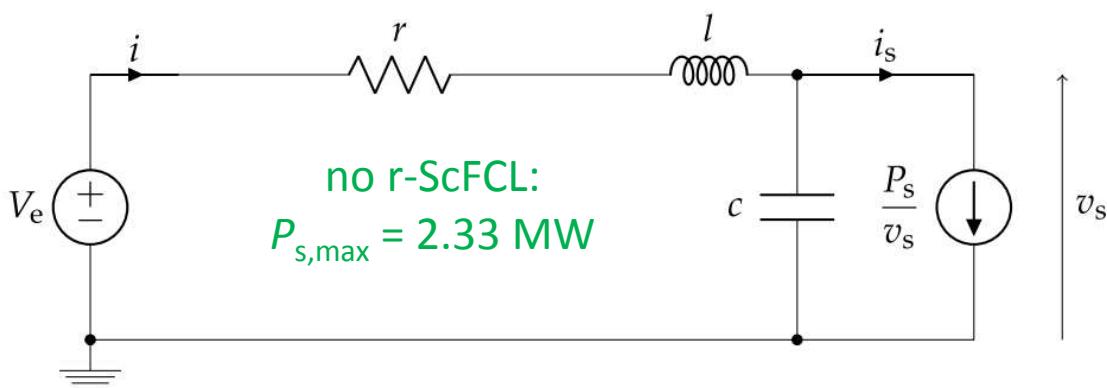


Table 1: DC grid parameters

Symbol	Parameter	Value
V_e	source voltage	5 kV
r	resistance	40 mΩ
l	inductance	0.6 mH
c	capacitance	1.4 mF

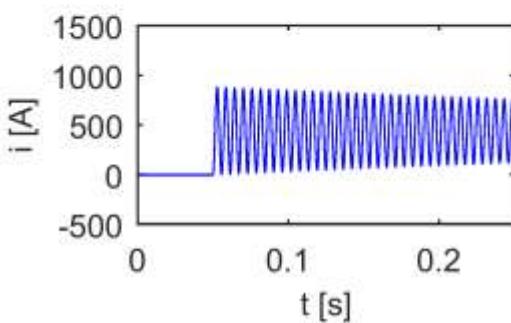
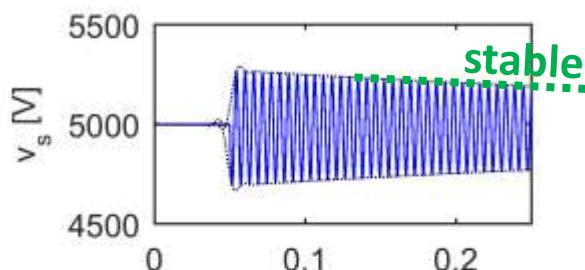
[1] M. Cupelli, F. Ponci, G. Sulligoi, A. Vicenzutti, CS. Edrington, T. El-Mezyani, A. Monti, "Power flow control and network stability in an all-electric ship," *Proceedings of the IEEE*, vol. 103, no. 12, pp. 2355-2380, Dec. 2015.

Numerical stability

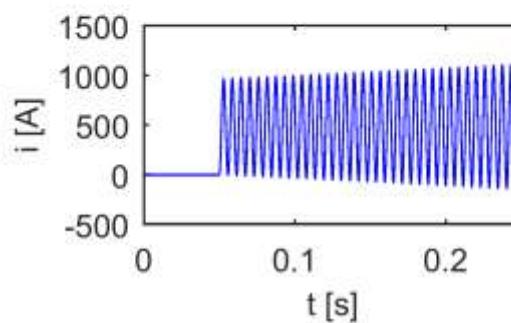
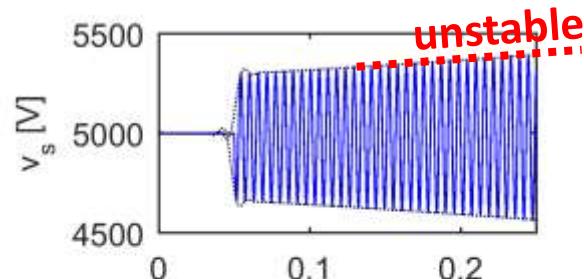


How to evaluate the stability ?

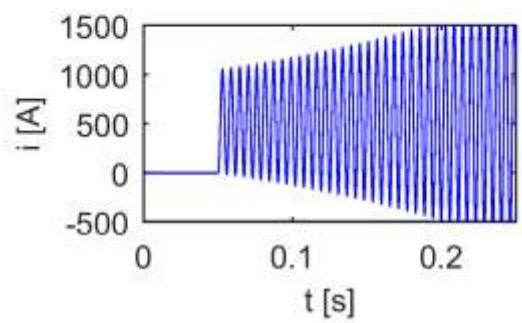
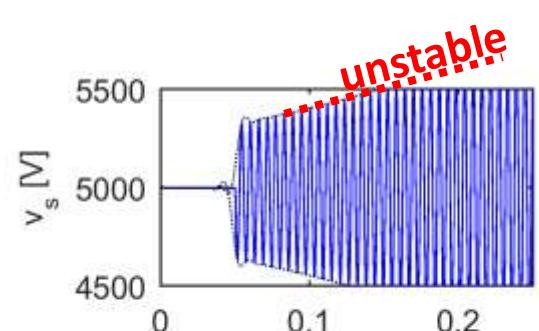
-> envelope of v_s



$P_s = 2.2 \text{ MW}$: stable



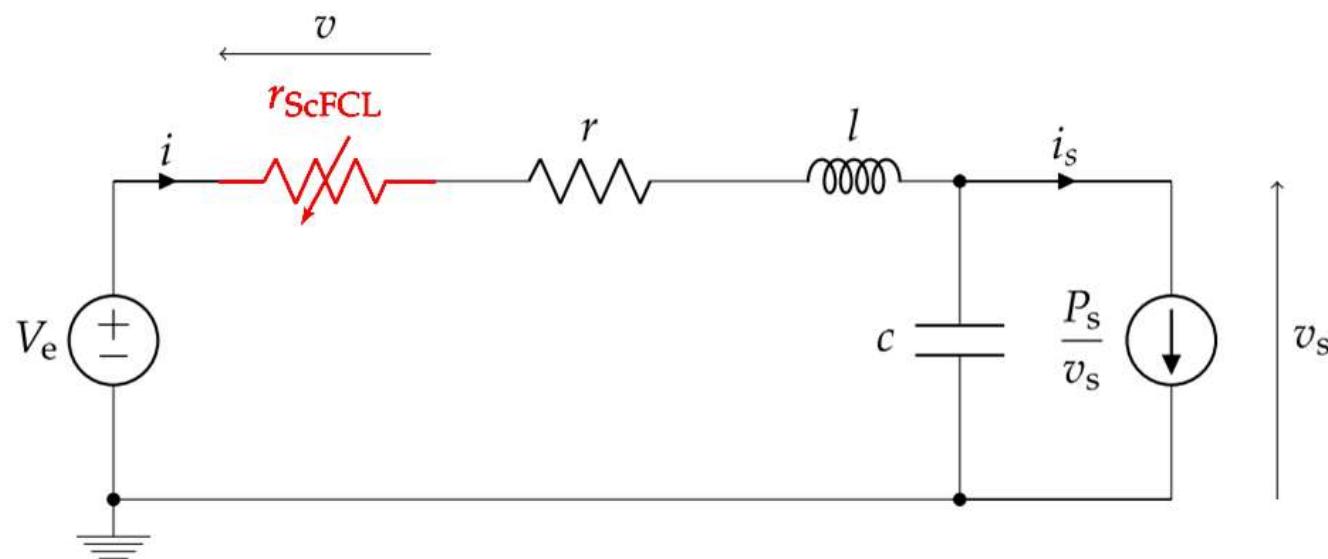
$P_s = 2.4 \text{ MW}$: unstable



$P_s = 2.6 \text{ MW}$: unstable

II. Improved stability of a DC grid with a resistive superconducting fault current limiter (r-ScFCL)

DC grid with a constant power load and a resistive superconducting fault current limiter (r-ScFCL)



II. Improved stability of a DC grid with a r-ScFCL

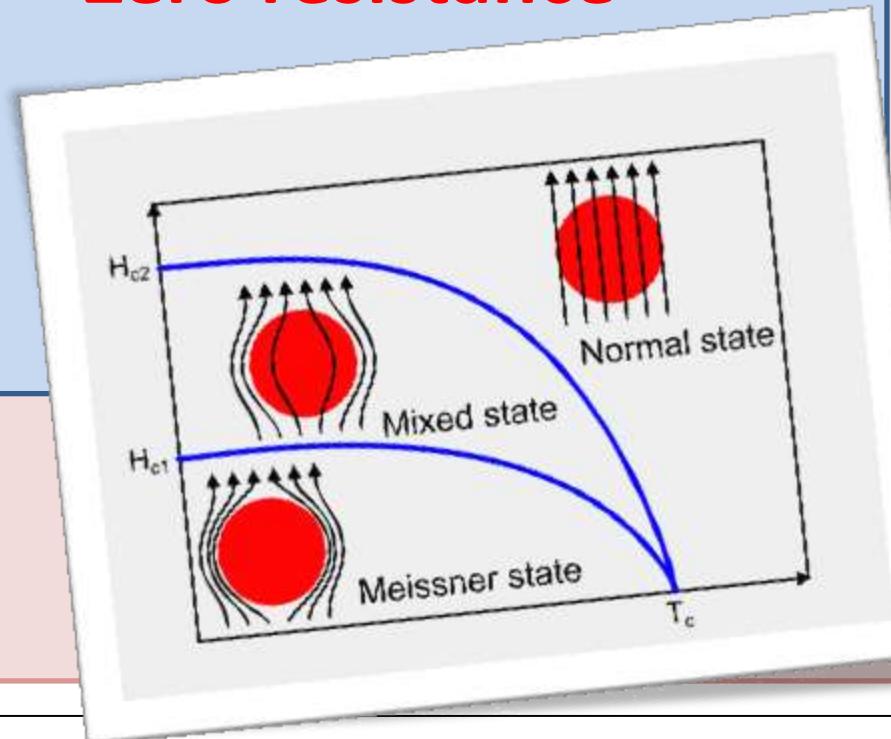
1. But... what's a superconductor ?

But... what's a superconductor ?

Type II

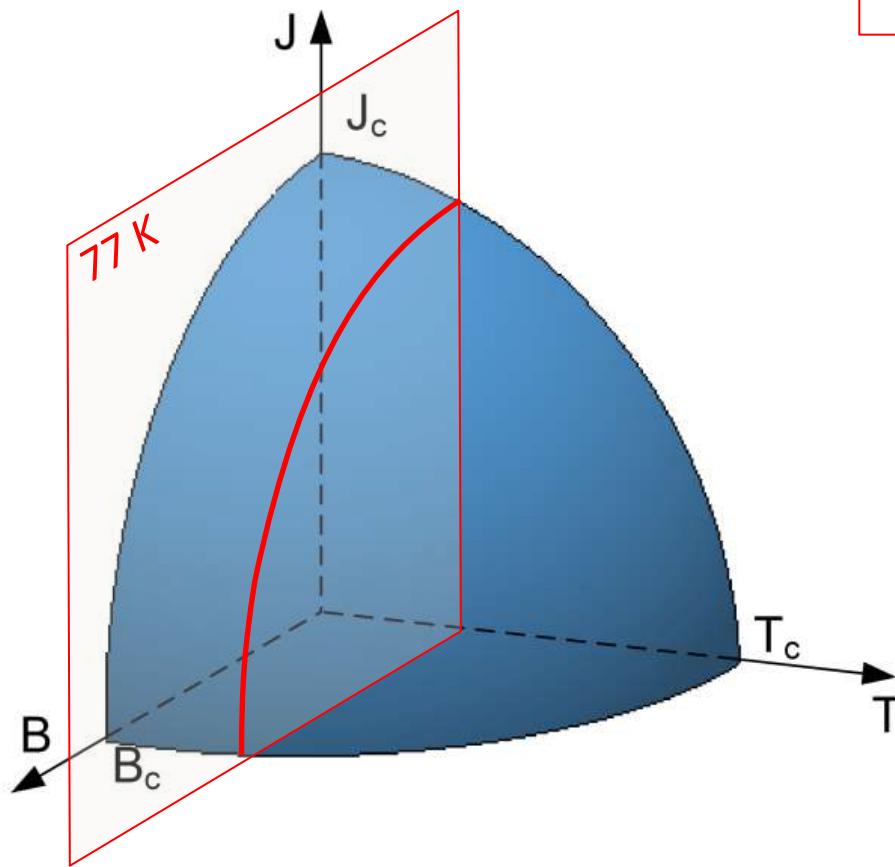
Type I

- Perfect conductivity = Zero resistance
- Meissner effect
- Flux trapping effect



But... what's a superconductor ?

Hypothesis
thermal effect
neglected

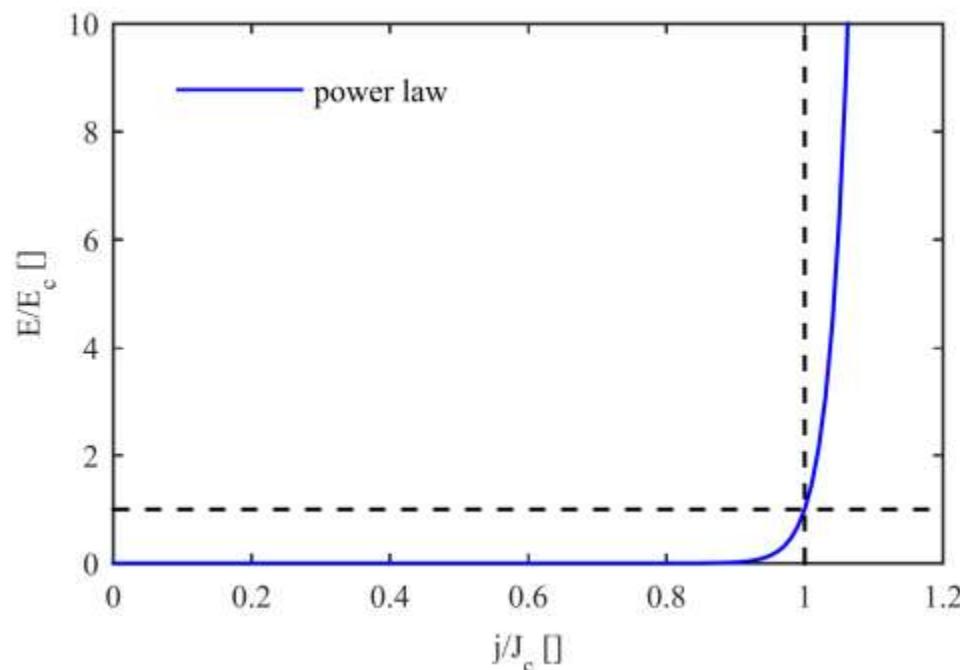


[1] B.B. Jensen, A.B. Abrahamsen, M.P. Sørensen, J.B. Hansen, "A course on applied superconductivity shared by four departments," US-China Education Review A, vol. 3, no. 3, 141-152, 2013.

But... what's a superconductor ?

$$E(j) = \frac{E_c}{J_c} \left| \frac{j}{J_c} \right|^{n-1} j$$

Hypothesis
thermal effect
neglected



II. Improved stability of a DC grid with a r-ScFCL

2. Power law model

r-ScFCL power law model

$$V_c = E_c l_{sc}$$

$$I_c = J_c A_{sc}$$

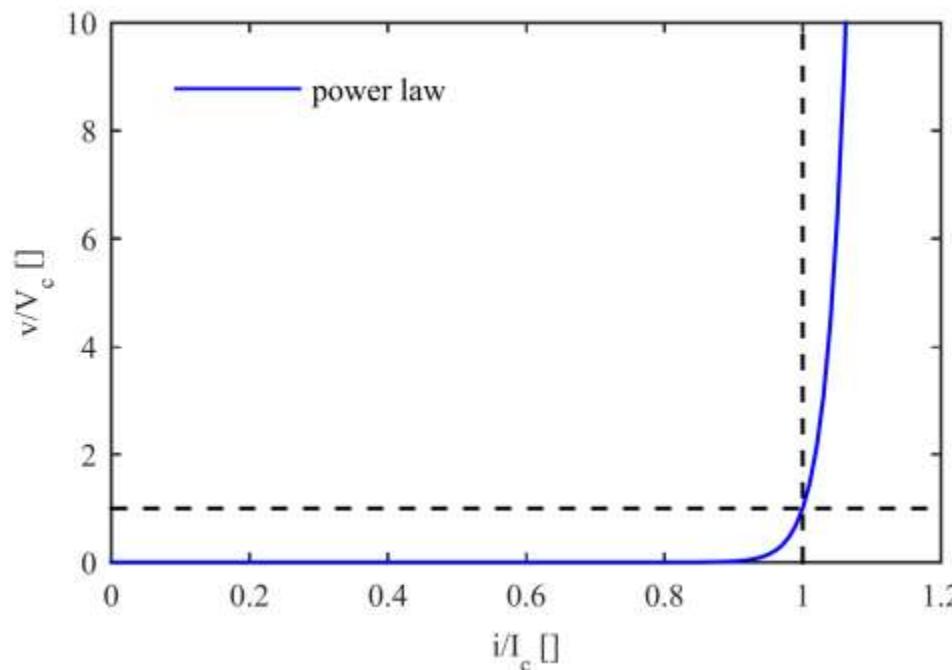


$$E(j) = \frac{E_c}{J_c} \left| \frac{j}{J_c} \right|^{n-1} j$$

$$v(i) = \frac{V_c}{I_c} \left| \frac{i}{I_c} \right|^{n-1} i$$

r_{sc}

Hypothesis
thermal effect
neglected



r-ScFCL power law model

$$V_c = E_c l_{sc}$$

$$I_c = J_c A_{sc}$$



$$E(j) = \frac{E_c}{J_c} \left| \frac{j}{J_c} \right|^{n-1} j$$

$$v(i) = \frac{V_c}{I_c} \left| \frac{i}{I_c} \right|^{n-1} i$$

$\underbrace{\phantom{\frac{V_c}{I_c}}}_{r_{sc}}$

Hypothesis
thermal effect
neglected

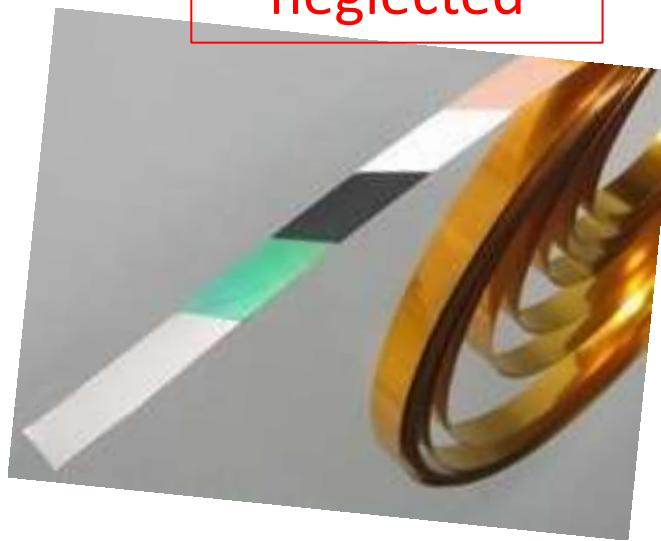


Table 2: r-ScFCL parameters

Symbol	Parameter	Value
E_c	critical current criterion	10^{-4} V/m
I_c	r-ScFCL critical current	550 A → 6// tapes
n	power law exponent	38 → YBCO
l_{sc}	r-ScFCL length	1000 m
r_{sh}	shunt resistance	10 mΩ

r-ScFCL power law model

$$V_c = E_c l_{sc}$$

$$I_c = J_c A_{sc}$$



$$E(j) = \frac{E_c}{J_c} \left| \frac{j}{J_c} \right|^{n-1} j$$

$$v(i) = \frac{V_c}{I_c} \left| \frac{i}{I_c} \right|^{n-1} i$$

r_{sc}

Hypothesis
thermal effect
neglected

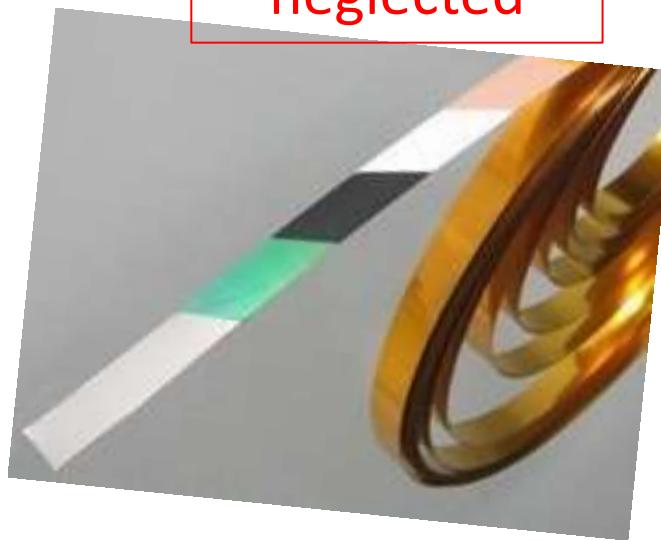
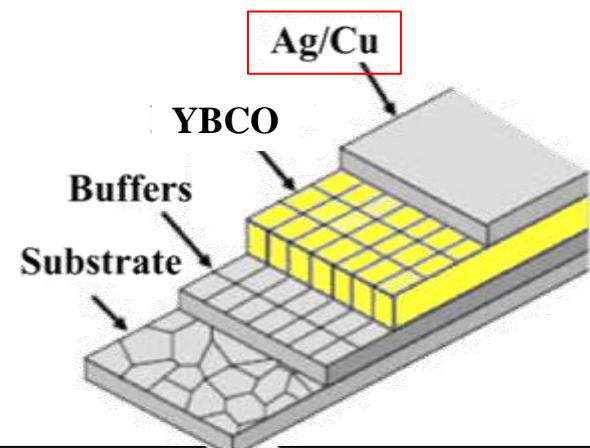


Table 2: r-ScFCL parameters

Symbol	Parameter	Value
E_c	critical current criterion	10^{-4} V/m
I_c	r-ScFCL critical current	550 A
n	power law exponent	38
l_{sc}	r-ScFCL length	1000 m
r_{sh}	shunt resistance	10 mΩ



r-ScFCL power law model

$$V_c = E_c l_{sc}$$

$$I_c = J_c A_{sc}$$



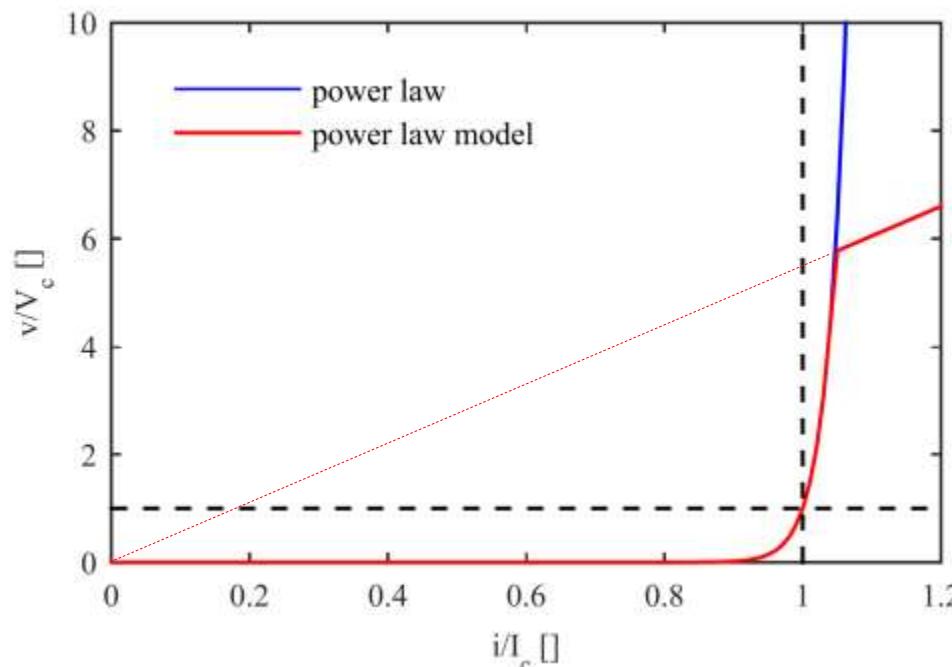
$$E(j) = \frac{E_c}{J_c} \left| \frac{j}{J_c} \right|^{n-1} j$$

$$v(i) = \frac{V_c}{I_c} \left| \frac{i}{I_c} \right|^{n-1} i$$

Hypothesis
thermal effect
neglected

+ shunt:

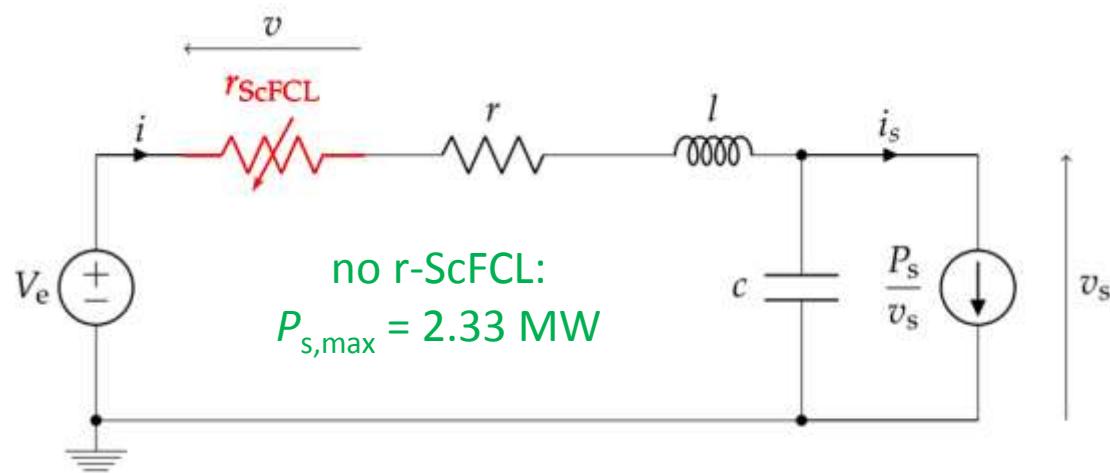
$$r_{ScFCL} = \min(r_{sc}, r_{sh})$$



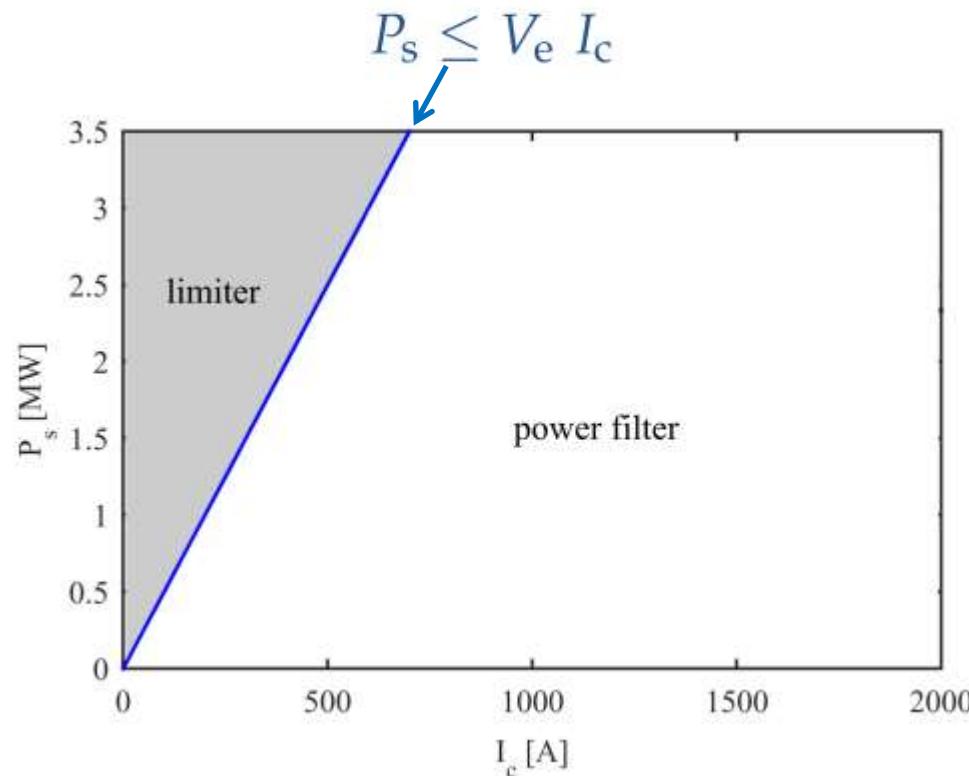
II. Improved stability of a DC grid with a r-ScFCL

3. Limiter mode and power filter mode

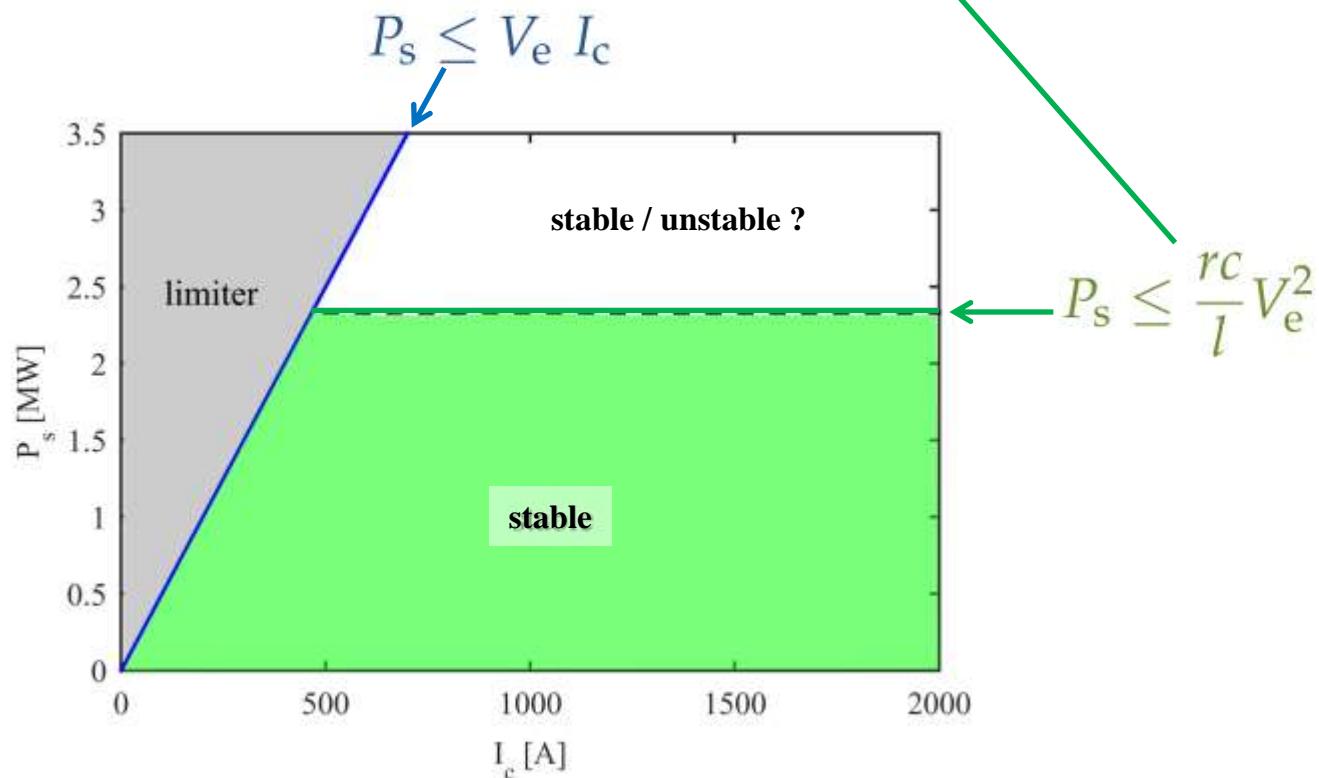
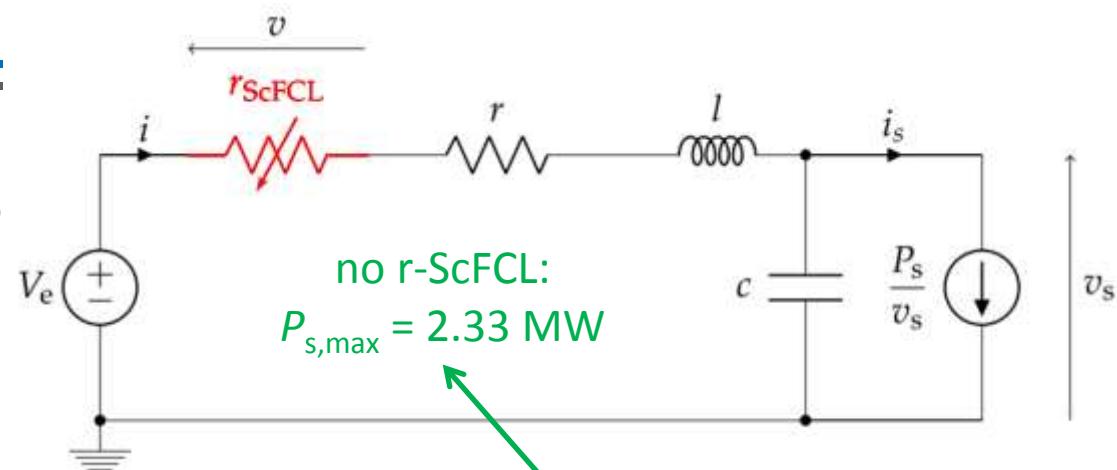
Current limiter mode & Power filter mode



Max power that can be used by the load:



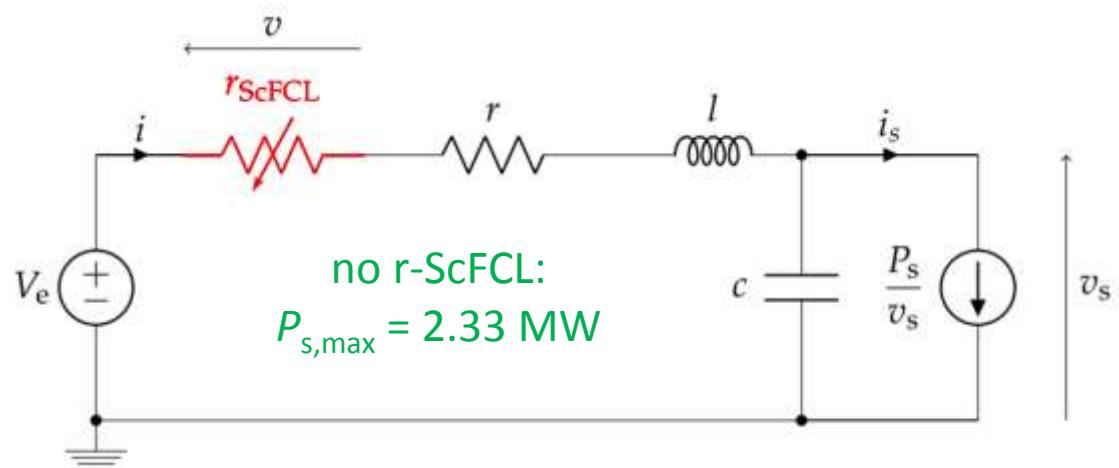
Current limiter mode & Power filter mode



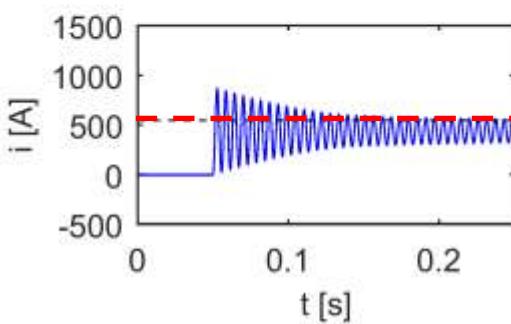
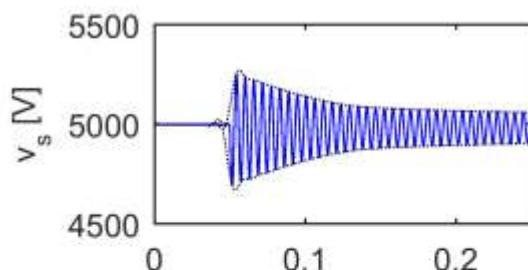
II. Improved stability of a DC grid with a r-ScFCL

4. Simulation results

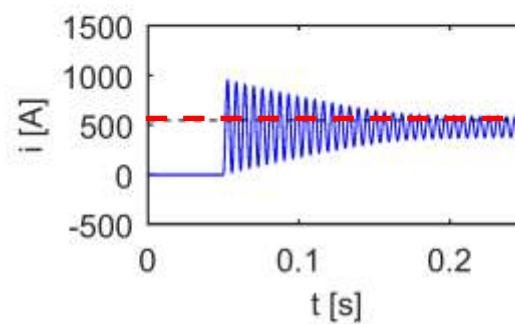
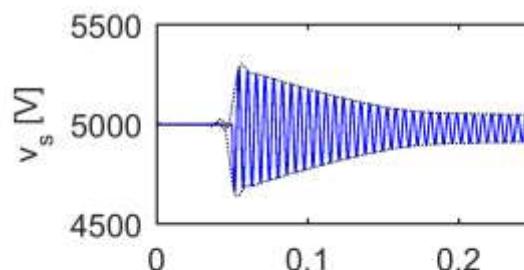
Numerical stability (power law model)



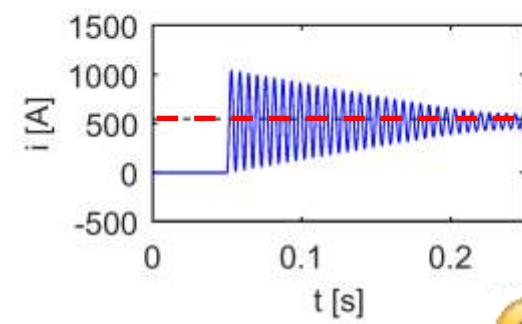
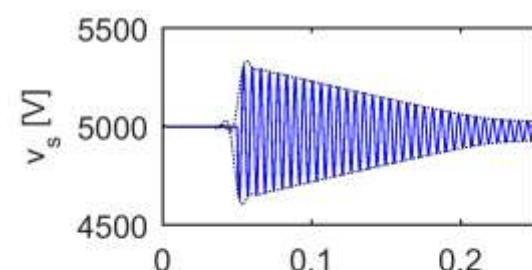
$I_c = 550 \text{ A}$



$P_s = 2.2 \text{ MW: stable}$



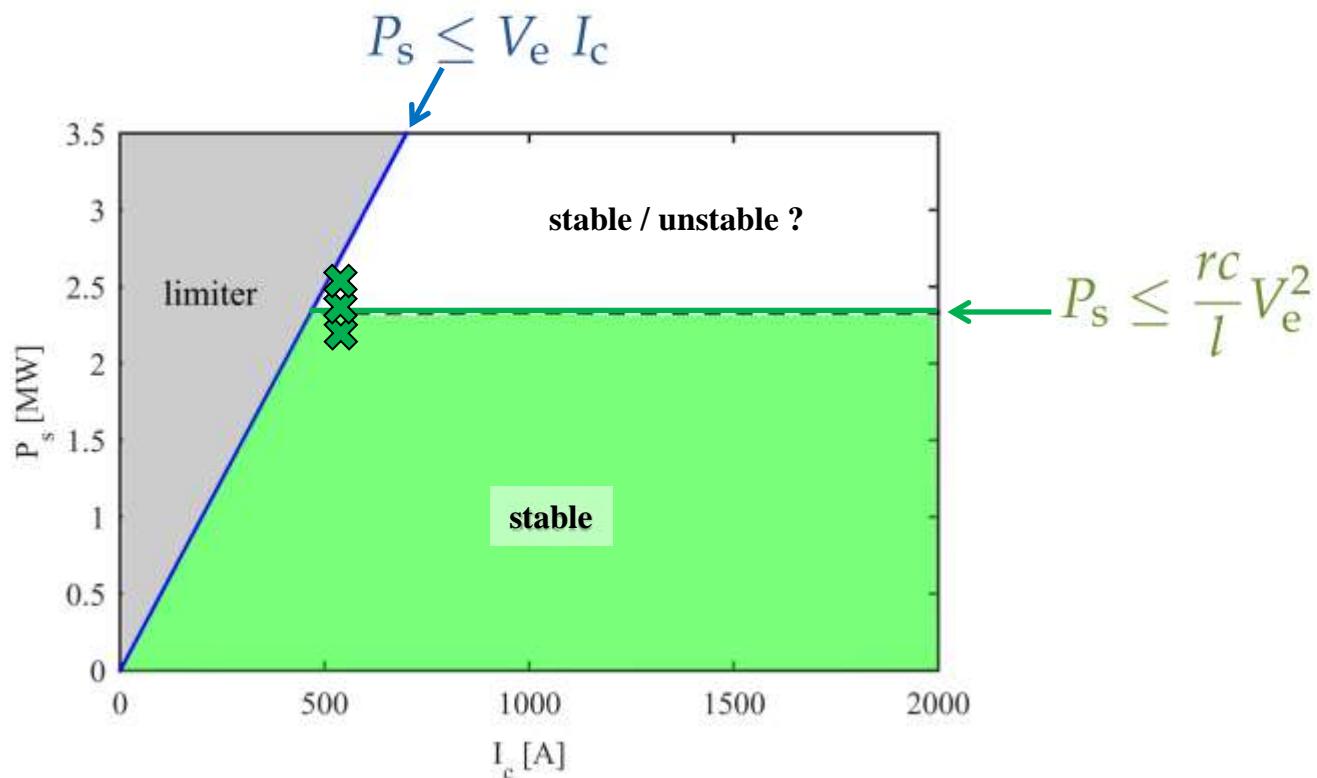
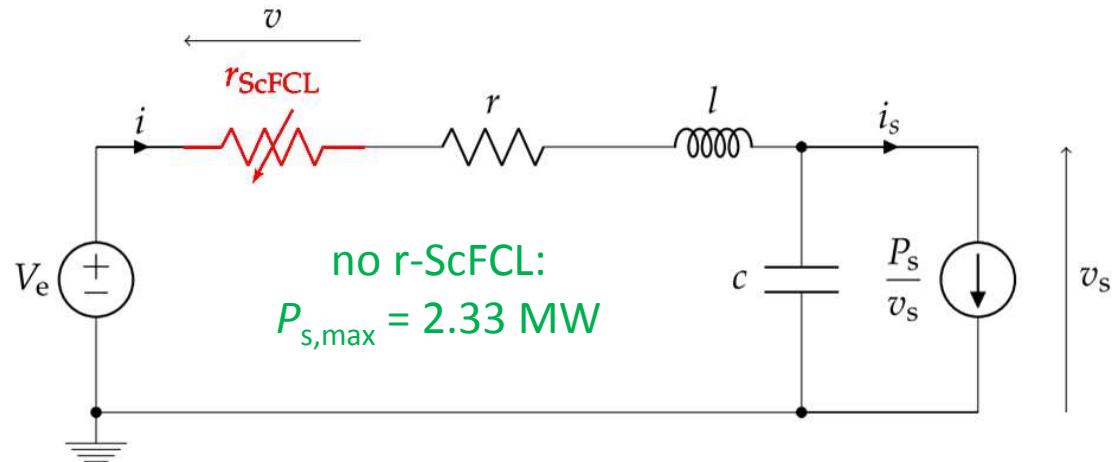
$P_s = 2.4 \text{ MW: stable}$



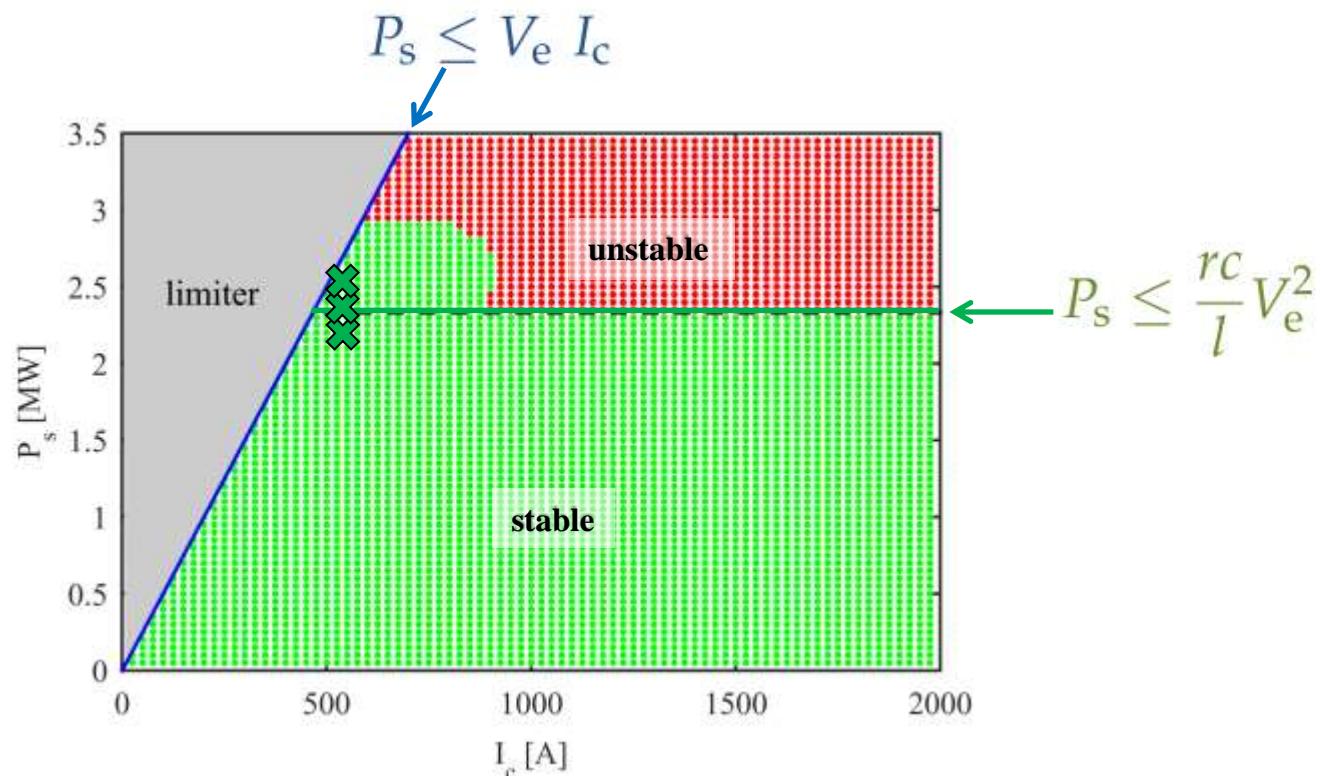
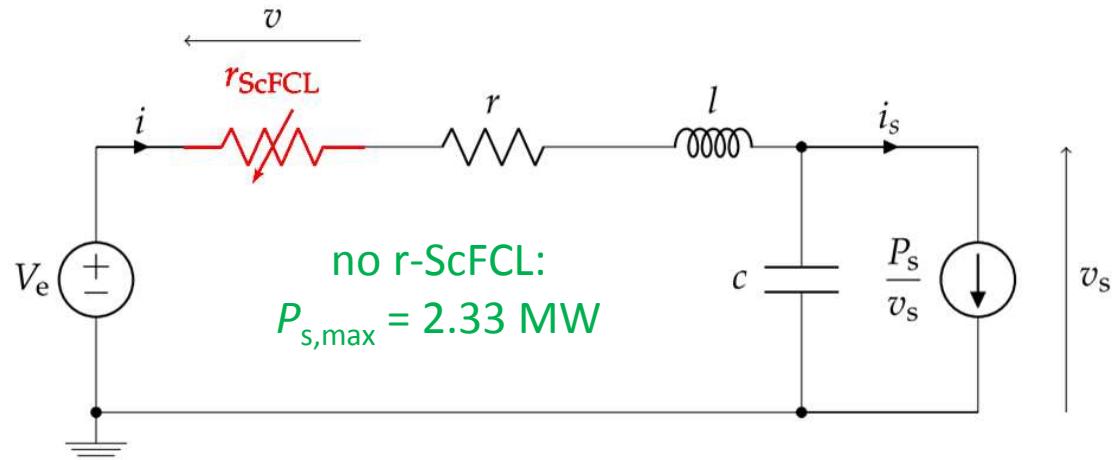
$P_s = 2.6 \text{ MW: stable}$



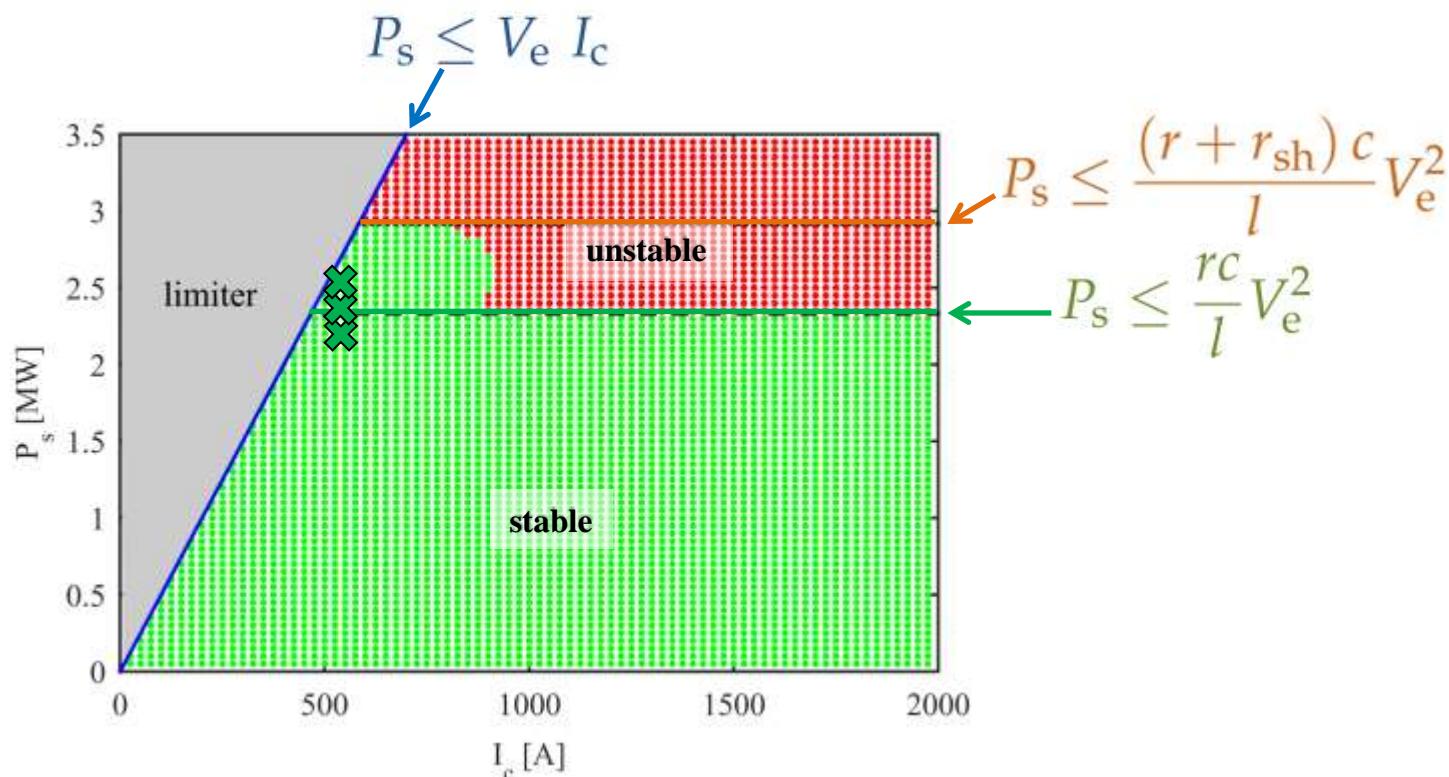
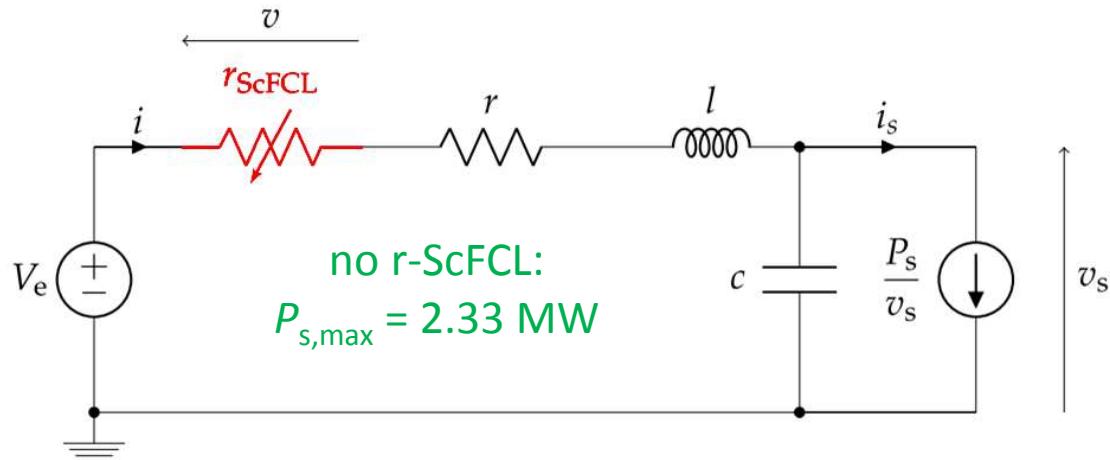
Stability region (power law model)



Stability region (power law model)



Stability region (power law model)



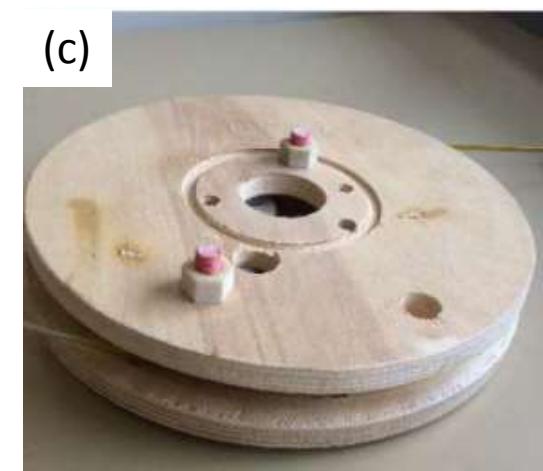
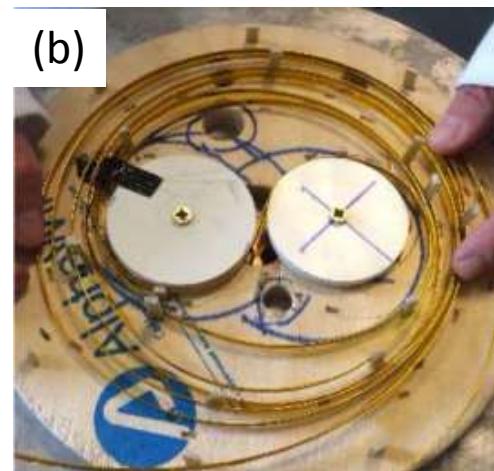
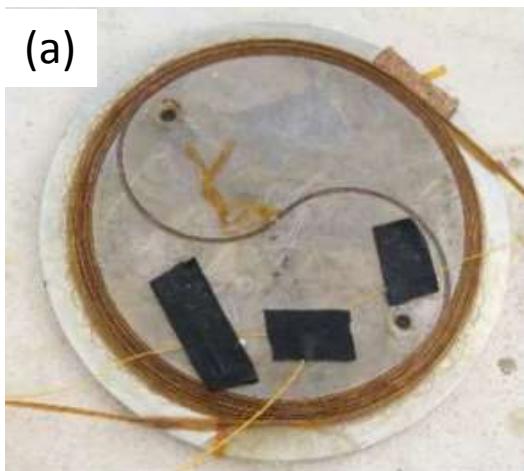
III. Conclusion

Conclusion

- A resistive superconducting fault current limiter can be used as **power filter**.
- Together with a classical RLC filter, it offers an **extended stability region** in comparison to the RLC filter alone.
- In comparison with conventional passive stabilization, the efficiency of the system is not reduced in nominal operation.
- A **power law model** (including the shunt resistor) seems adapted for stability studies.
- We obtained the **stability region** of a simple DC grid with a constant power load and a r-ScFCL.

Future works

- Detailed thermal analysis
- Experimental validation of the concept



[1] G.B. Huang, B. Douine, K. Berger, G. Didier, I. Schwenker, J. Lévéque, "Increase of stability margin in embedded DC electric grid with superconducting stabilizer," *IEEE Trans. on Applied Superconductivity*, vol. 26, no. 4, June 2016.

Thank you for your attention !



UNIVERSITÉ
DE LORRAINE