POLITECNICO DI TORINO
NEMO

Performance analysis of the first PF coils design for the EU DEMO fusion reactor

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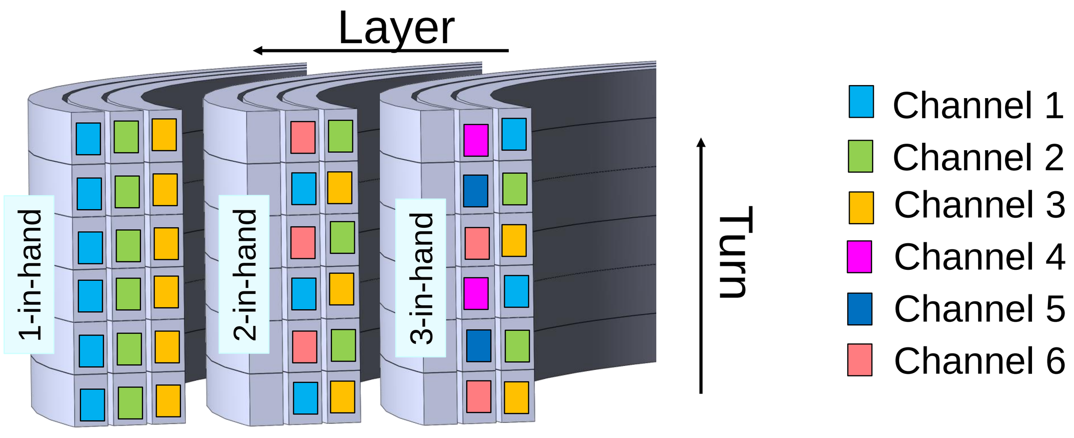
1. Aim of the work

- Pre-conceptual design of Poloidal Field (PF) coils of EU DEMO fusion reactor developed by SPC and ENEA, within WPMAG
- Pulsed operation → AC (coupling) losses → heat deposition
  - Check of the design in terms of minimum temperature margin and hydraulic performance
  - nτ not known for the proposed conductor design → parametric analysis

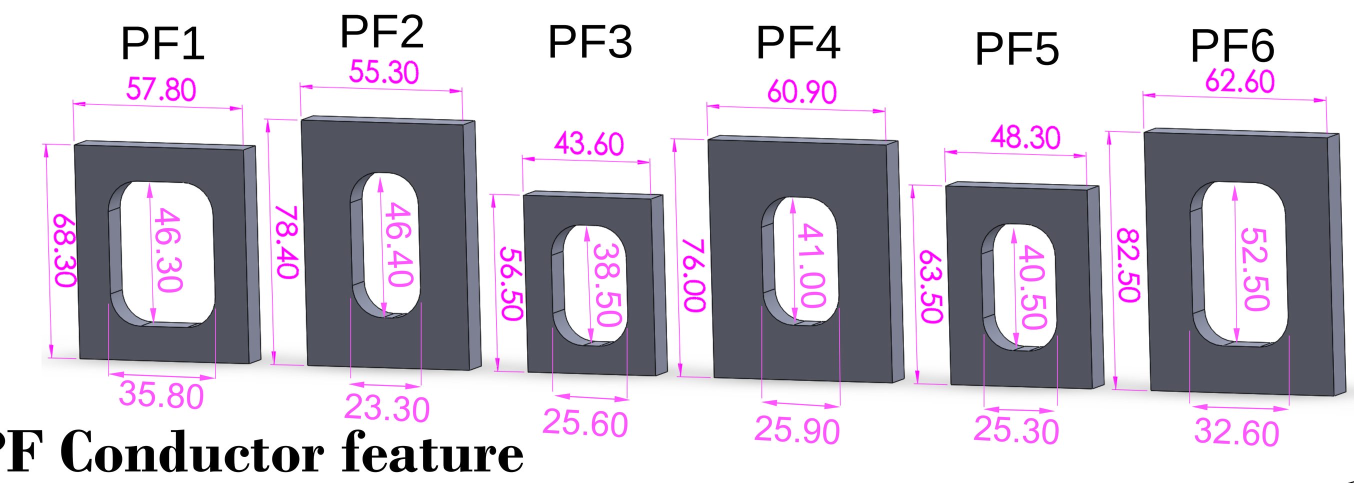
2. PF Coils design

Coil topology

Multiple-in-hand winding strategy to keep low (<500 m) the hydraulic length [1]



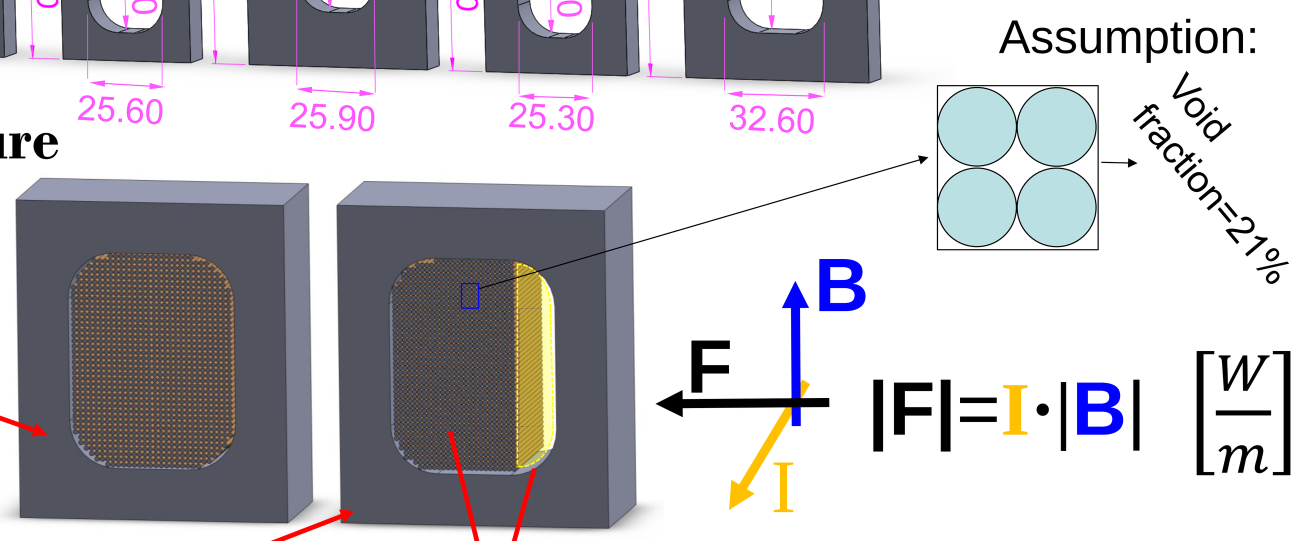
Conductor dimensions



PF Conductor feature

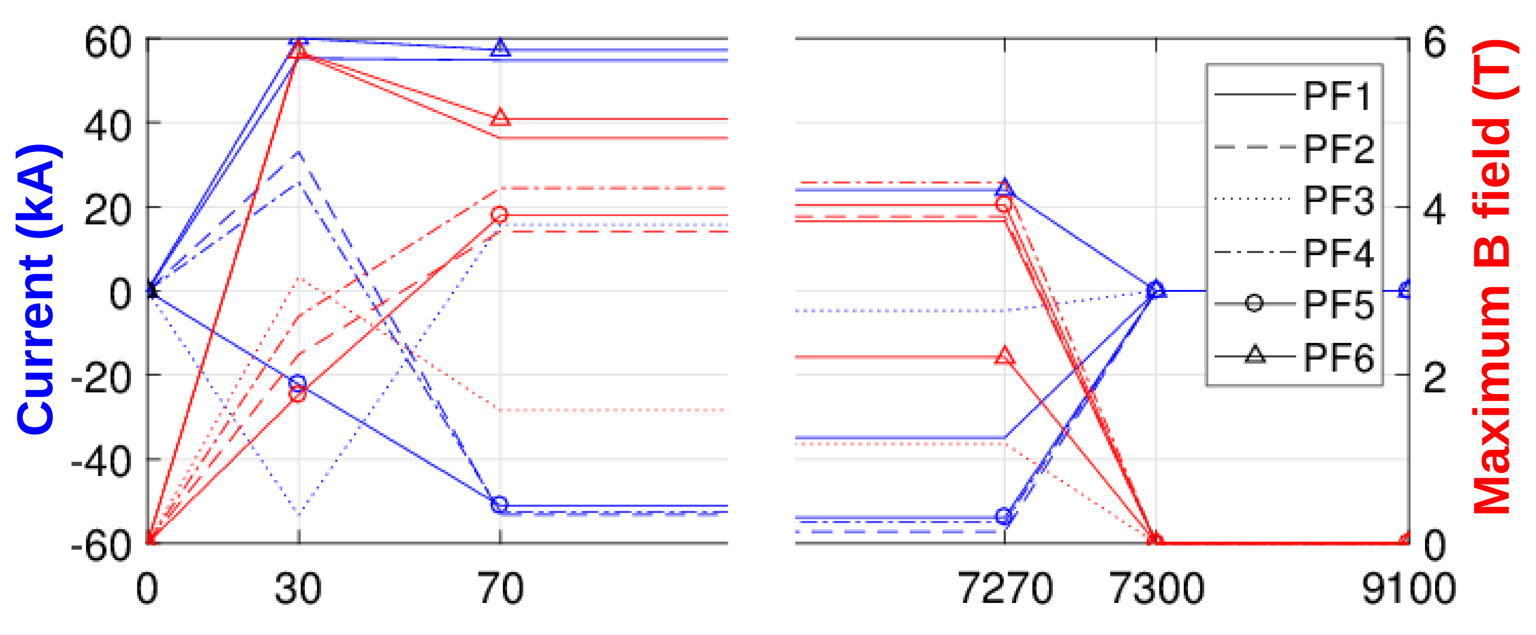
High void fraction (40%)…

…so that if ***B*** and *I* are present



Bundle void fraction decreases (21%)
low impedance channel opens! [2]

3. Plasma scenarios



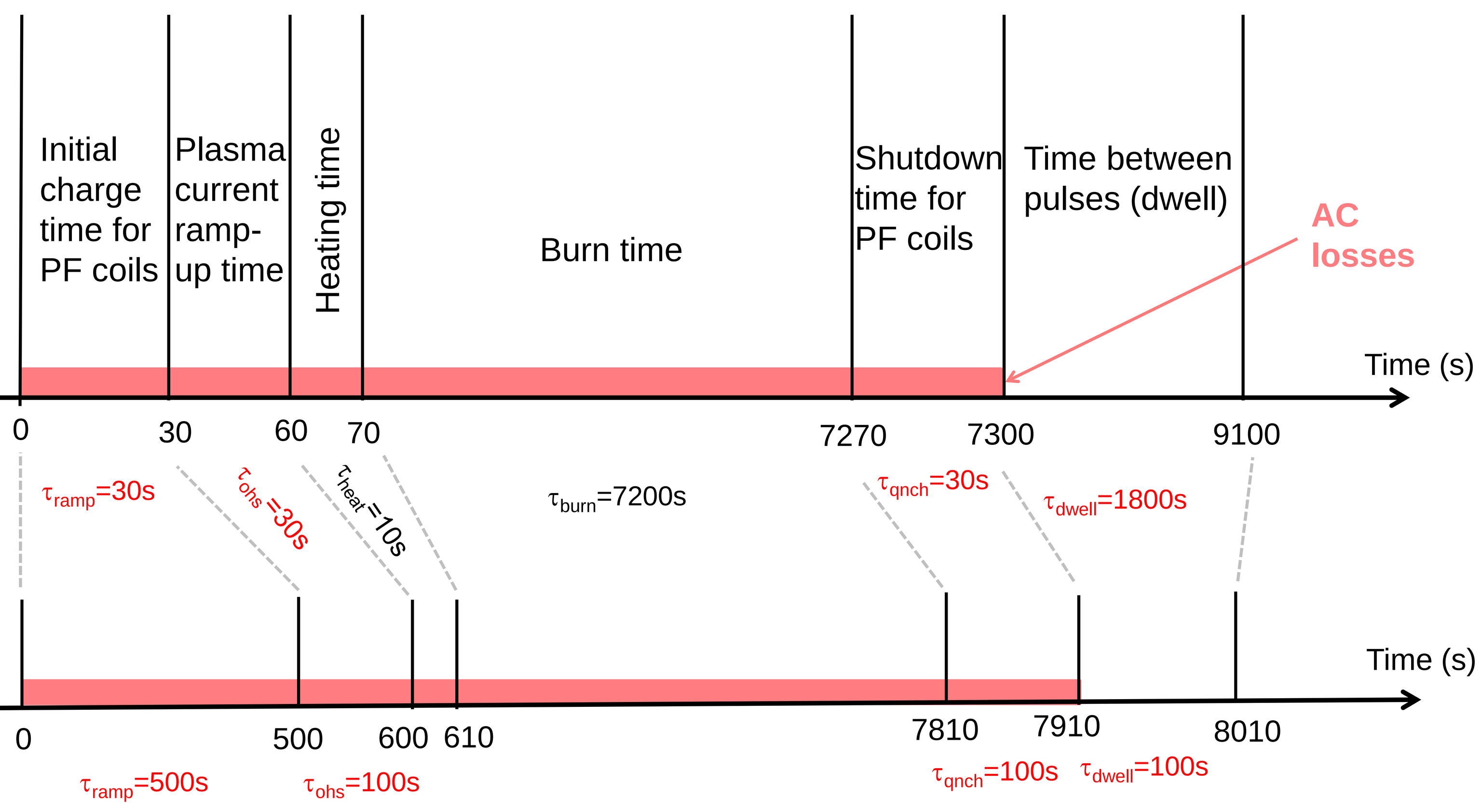
Process 2015 output

1

[B. Meszaros, "EU DEMO1 2015 Plasma and Equilibrium description," EFDA_D_2LJFN7, 18/05/2015]

2

[A. Ferro, et al., "DEMO input power profiles," EFDA_D_2MXL88, 15/12/2016]

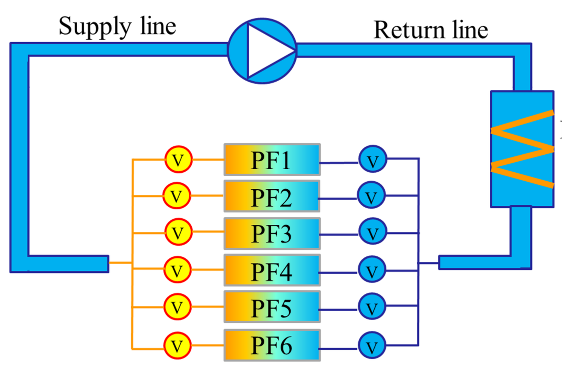


4. 4C model

- Thermal-hydraulic model of the PF coils and cryogenic circuit developed using 4C code [3], including:

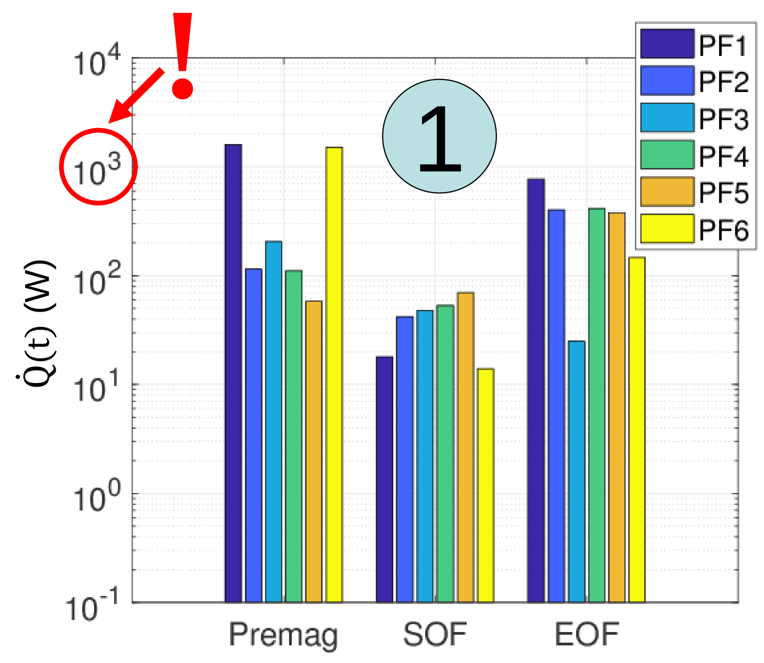
1. **Winding pack** (1D M&M [4] compressible model for each conductor)
2. **Cooling circuit** (0D/1D Dymola model [5]) [dimensions scaled from ITER PF&CC cooling circuit]

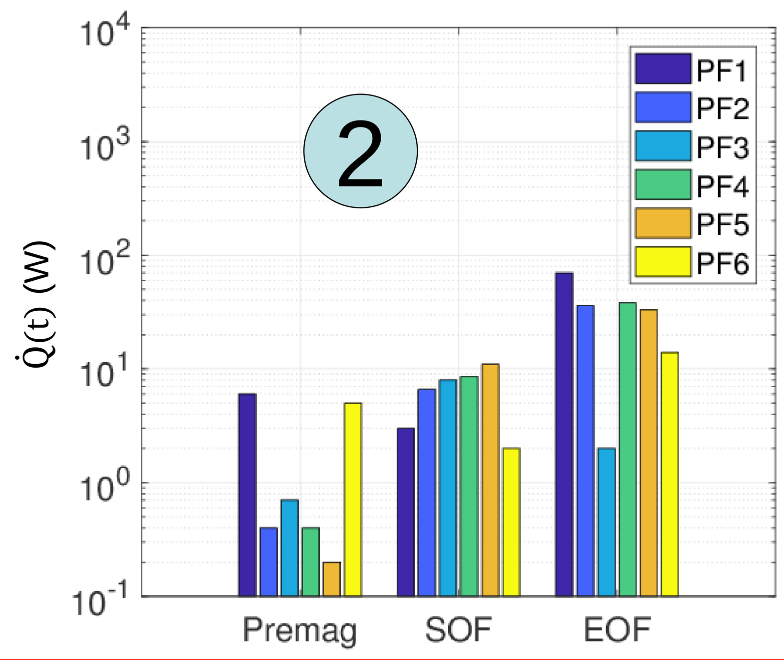
Inter-turn / Inter-layer thermal coupling accounted for



Driver: AC (coupling) losses

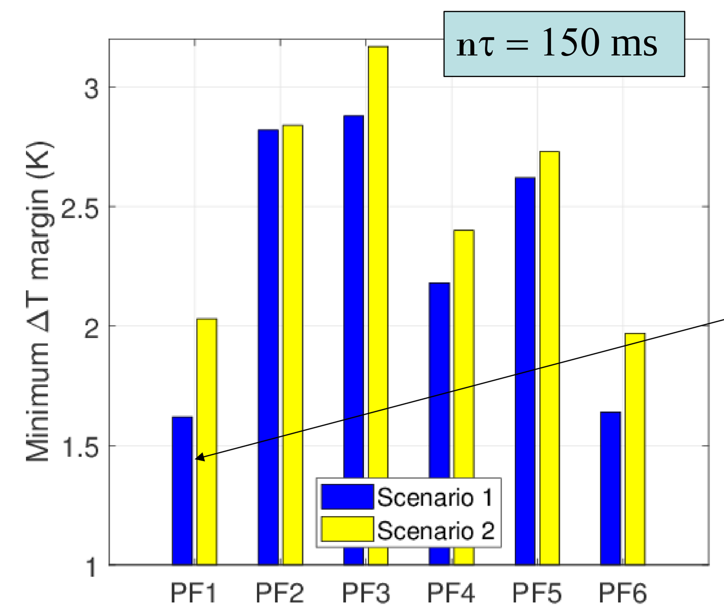
$$\dot{Q}(x,t) = \frac{n\tau}{\mu}\cdot\left(\frac{\partial B(x,t)}{\partial t}\right)^2\cdot(A_{SC}+A_{Cu}) \quad \left[\frac{W}{m}\right] \Rightarrow \dot{Q}(t) = \int_{x=0}^{x=L_{cond}} \dot{Q}(x,t)\,dx \quad [W]$$

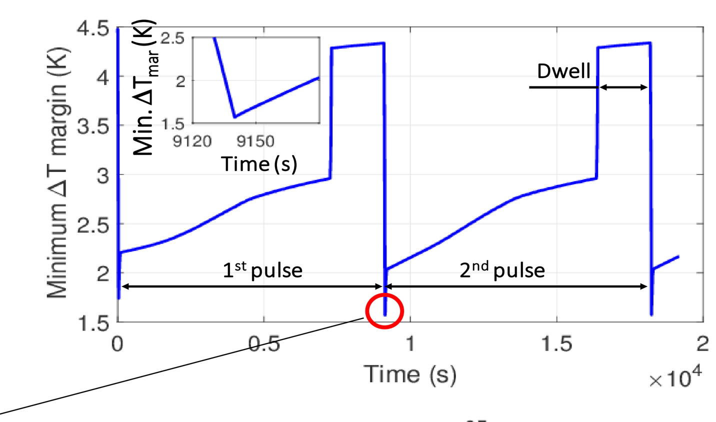


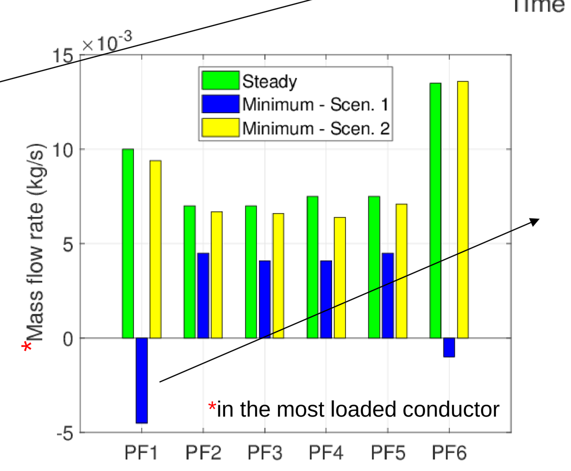


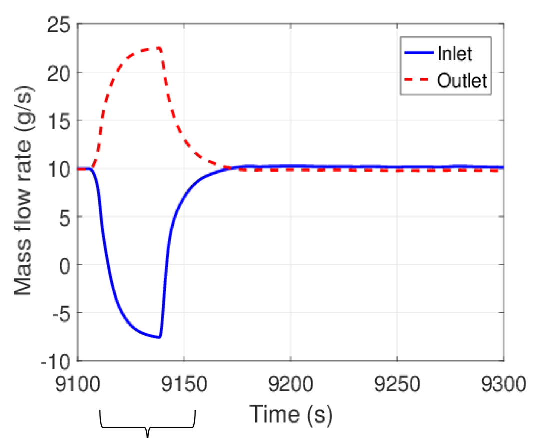
5. Results

Temperature margin









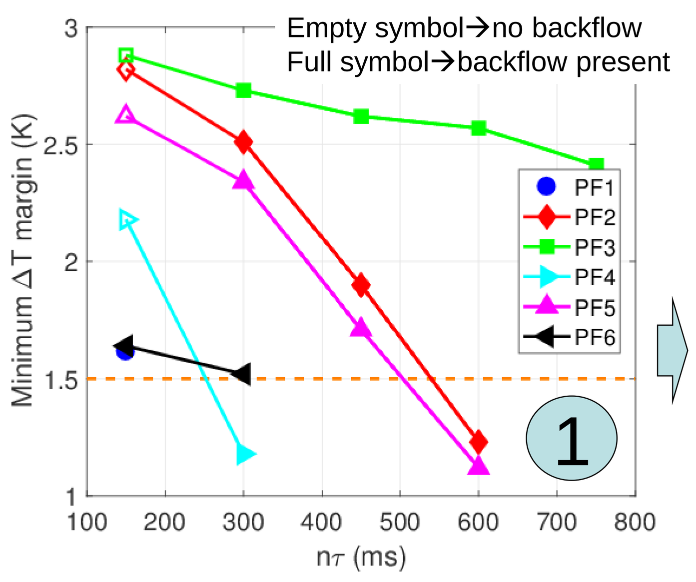
Premagnetization

Minimum temperature margin requirement (ΔT_{mar}>1.5 K) is always fullfilled

But if >1 kW/conductor are deposited, backflow is in the first ~100 m, while minimum ΔT_{mar} @ ~300 m!

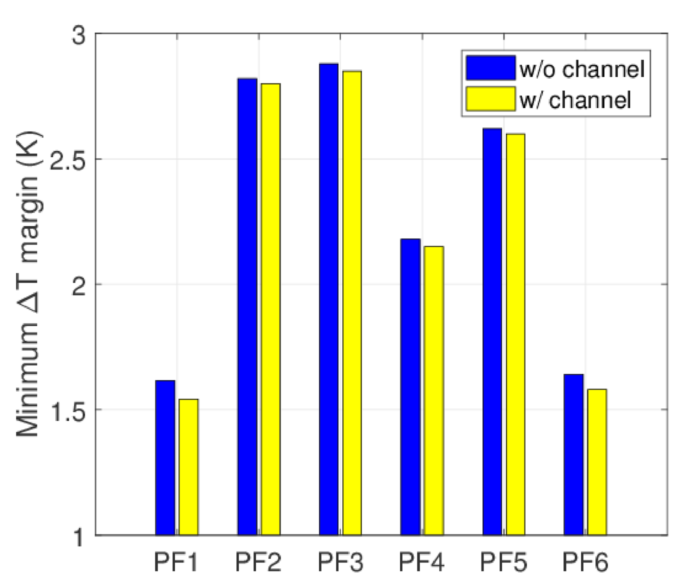
Backflow does not influence ΔT_{mar}, but still not advisable during normal operation

Parametric study on nτ

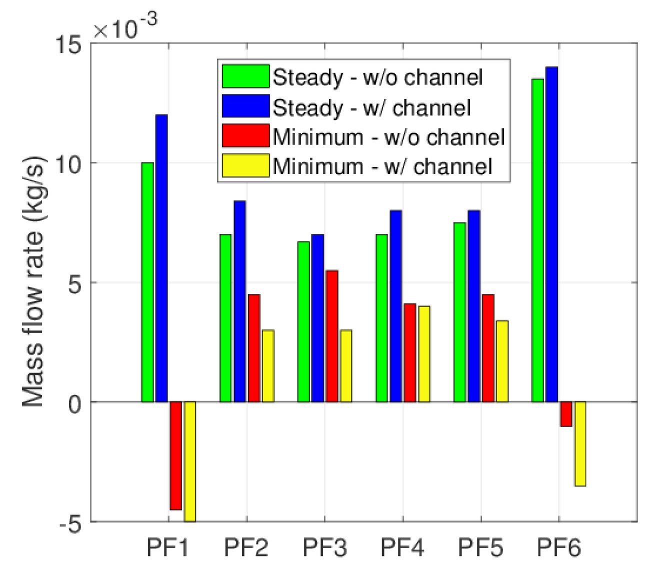


nτ can be increased for various PF (2, 3 and 5) conductors by more than 3 times if temperature margin requirement is considered, but backflow arises already when nτ is doubled!

Effect of channel opening due to Lorentz force



Minimum temperature margin is not greatly affected by the channel opening



Total mass flow increases if channel opens (lower hydraulic impedance), but backflow at conductor inlet also increases!

6. Conclusions

- EU DEMO PF coil system 4C model developed and applied to two different scenarios
- Minimum temperature margin requirement always fulfilled
- Backflow is present in few conductors

[1] K. Sedlak, "SPC PF Winding Pack Design", EUROfusion, Tech. Rep. EFDA_D_2MKJJE, May 24, 2017.
[2] K. Hamada et al., "Effect of electromagnetic force on the pressure drop and coupling loss of a cable-in-conduit conductor," Cryogenics, vol. 44, 2004, pp 45-52.
[3] L.Savoldi et al., "The 4C code for the cryogenic circuit conductor and coil modeling in ITER," *Cryogenics*, vol. 50, no. 3, Mar. 2010, pp. 167-176
[4] L.Savoldi et al., "M&M: Multi-conductor Mithrandir code for the simulation of thermal-hydraulic transients in superconducting magnets," *Cryogenics*, vol. 40, no. 3, Mar. 2000, pp 179-189
[5] R. Bonifetto et al., "Dynamic modeling of a SHe closed loop with the 4C code," AIP Conference Proceedings, vol. 1434, 2012, pp. 1743-1750

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.