Coil power supplies in DTT

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DTT S. c. a r. l.

Industrial Opportunity Days 2022

Osservatorio Astronomico di Capodimonte (Napoli)

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Summary

- Coil PSs (high-current PSs)
  - Not included in this presentations:
    - H&CD (high voltage)
    - STATCOM
- Two categories, related to respective coil procurements
  - Superconducting coils
  - Copper (in-vessel coils)

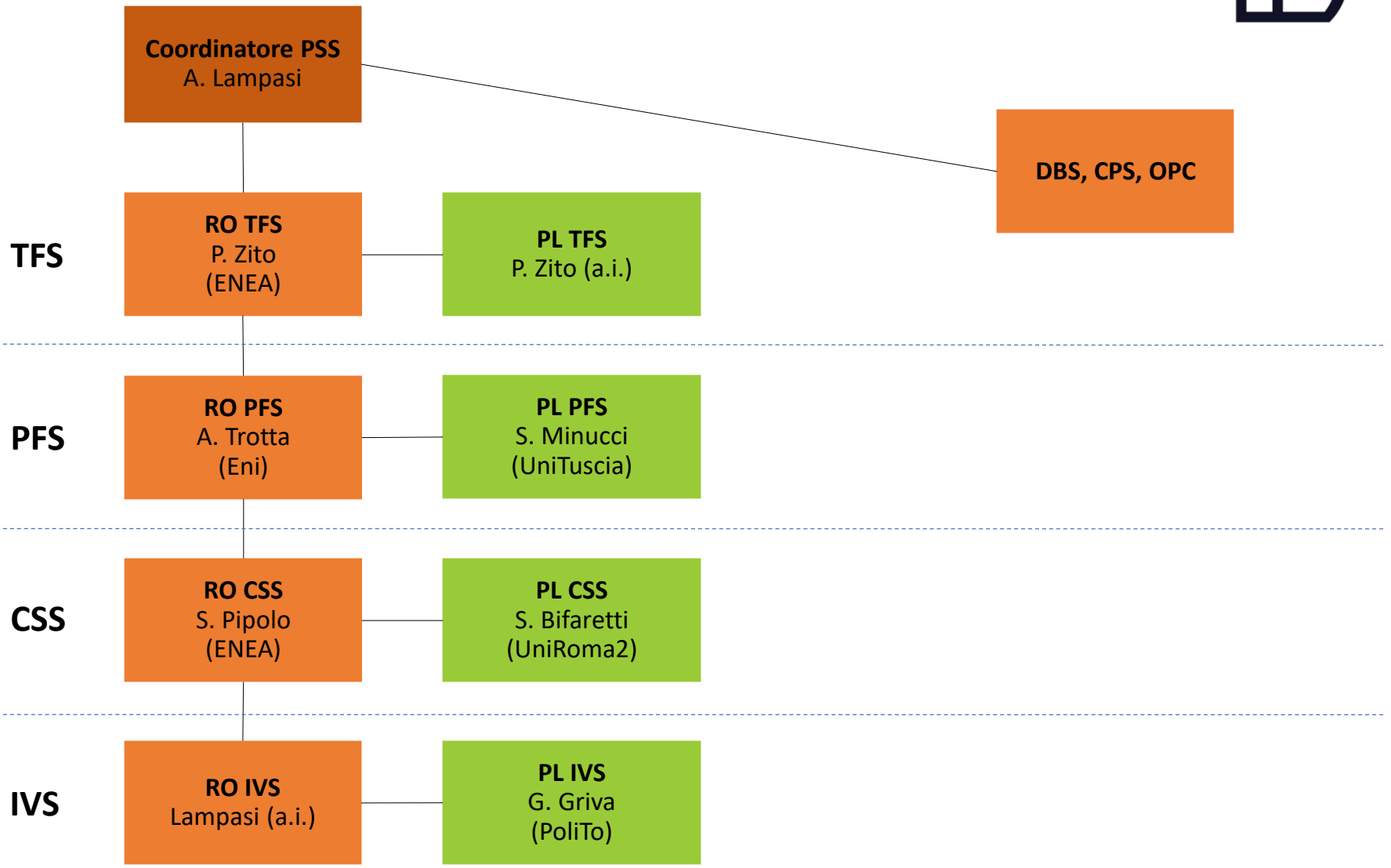
Less urgent, but now PNRR

Overview of main high-current PSs

Update in progress

- 1 Toroidal Field (TF) PS
- 6 Poloidal Field (PF) PSs
- 6 Central Solenoid (CS) PSs
- 2 Vertical Stabilization (VS) PSs
- 3-4 Divertor (DIV) PSs
- 27 Non-Axisymmetric (NA) PSs
- Other minor PSs

Presented subsystems & partners



PSs: General Status

- Budget
- Schedule
- Performances
- Layout

Compliant with expectations

It is not obvious:

- Raw material increase
- Russian components

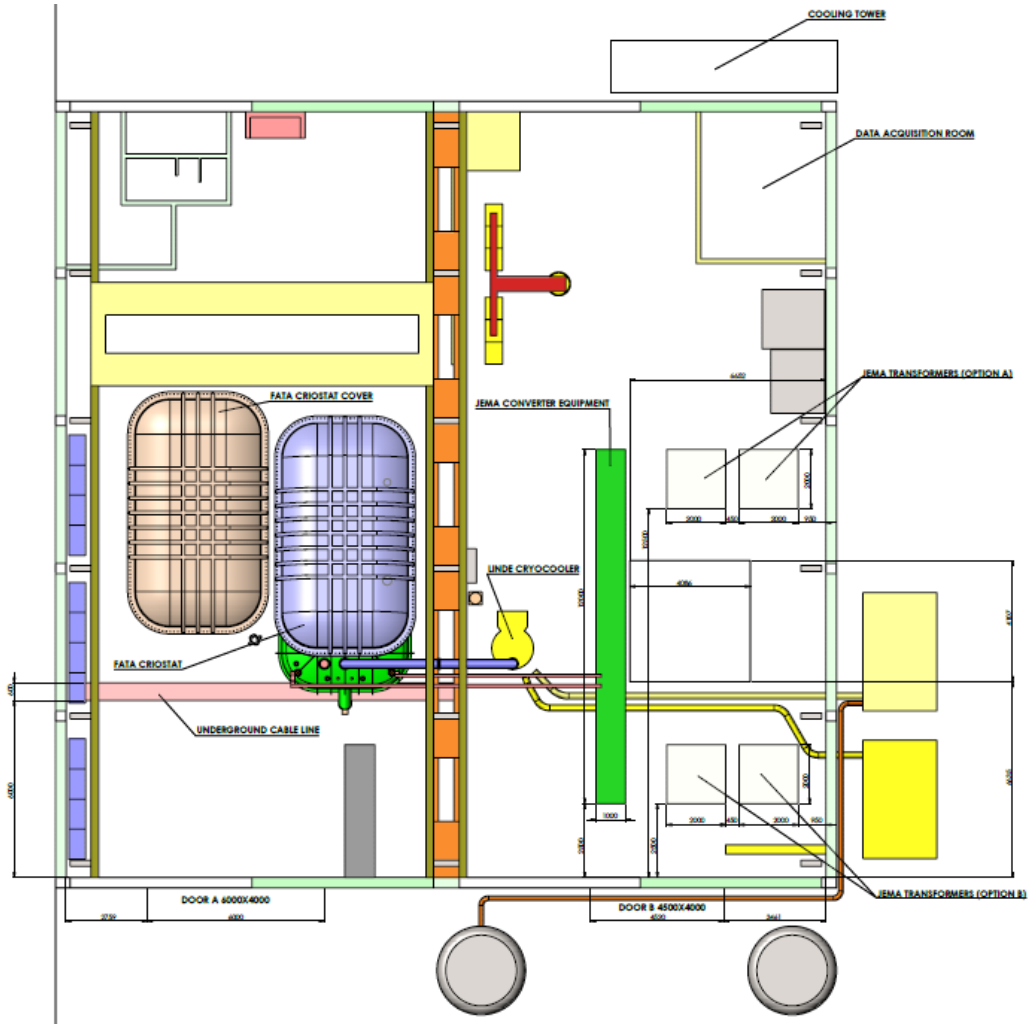
- Resources
- Inputs/Interfaces

Not in line with expectations

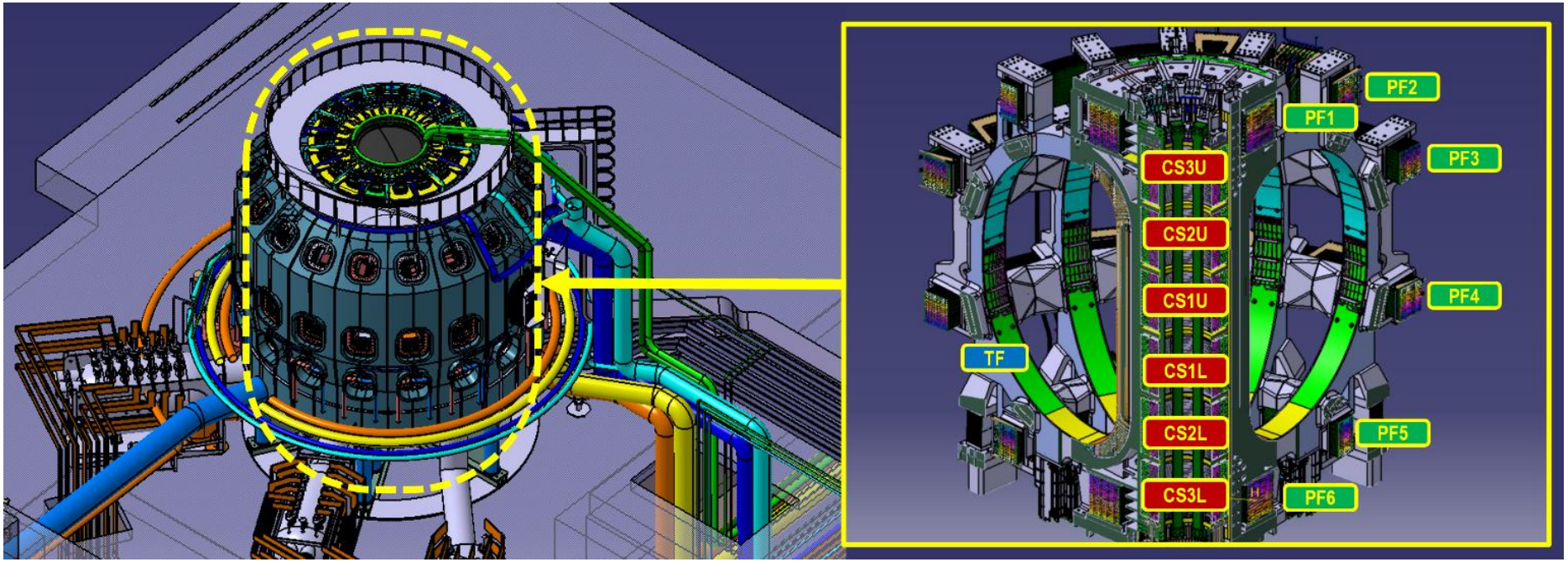
Problem of Cold Test Facility (CTF)

In Frascati

Ready in ≈1 year



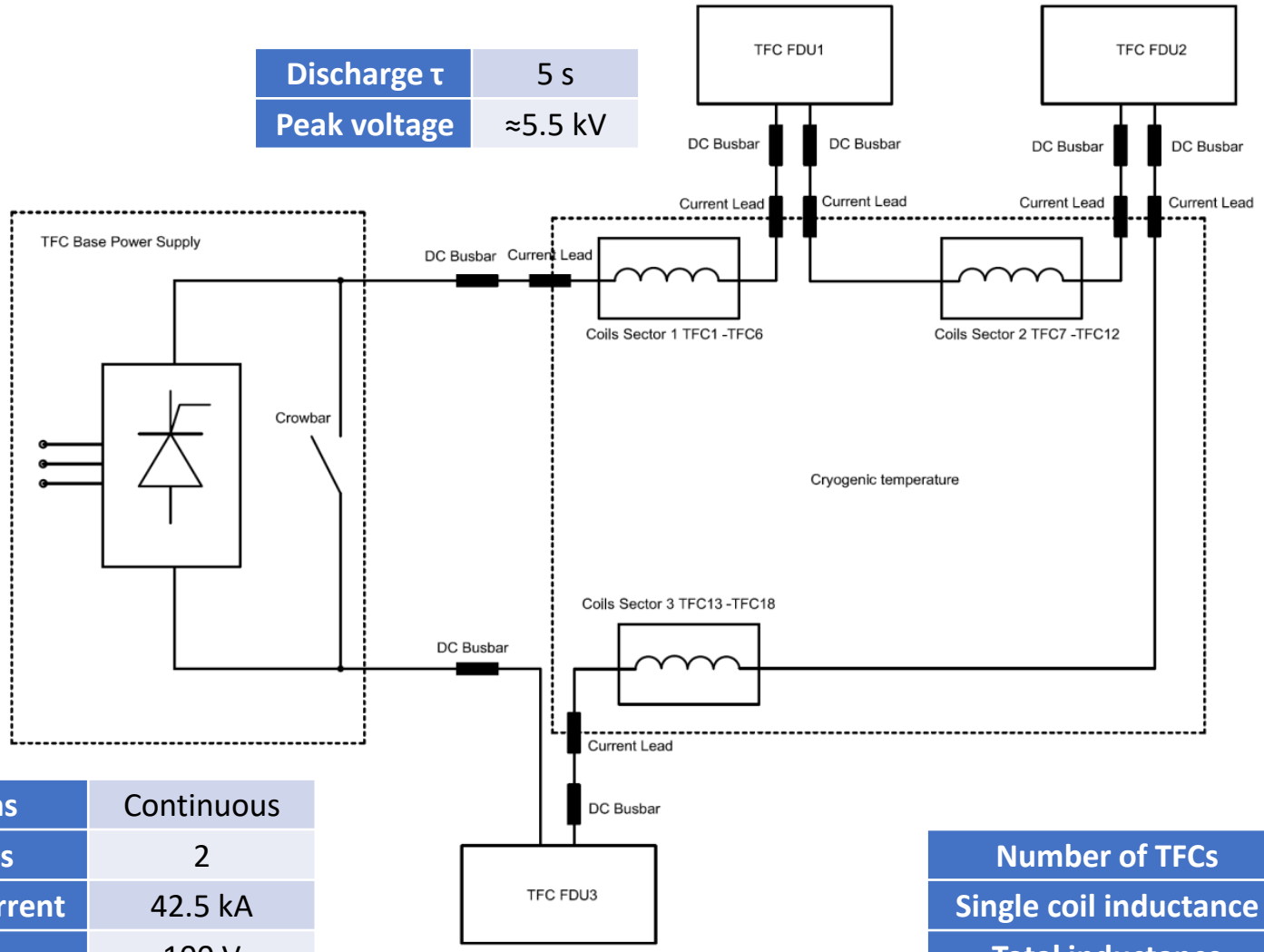
DTT superconducting coils



- TF, PF and CS PSs have very different characteristics
  - ≈100/3600 s/s vs. Steady state
- Different PSs also in CTF

TF PS: 2 Procurements: TF PS + FDUs

Discharge τ	5 s
Peak voltage	≈5.5 kV



Operations	Continuous
Quadrants	2
Operating current	42.5 kA
Voltage	100 V

Number of TFCs	18
Single coil inductance	48 mH
Total inductance	2.272 H

TF PS technical issues

- 24-pulses thyristor bridge
- Contract signed on 08/03/22 with Jema (Spain)
- KoM held on 22/03/22
- Delivery in CTF foreseen at September '23
- Aftwerwards, new contract for installation in DTT

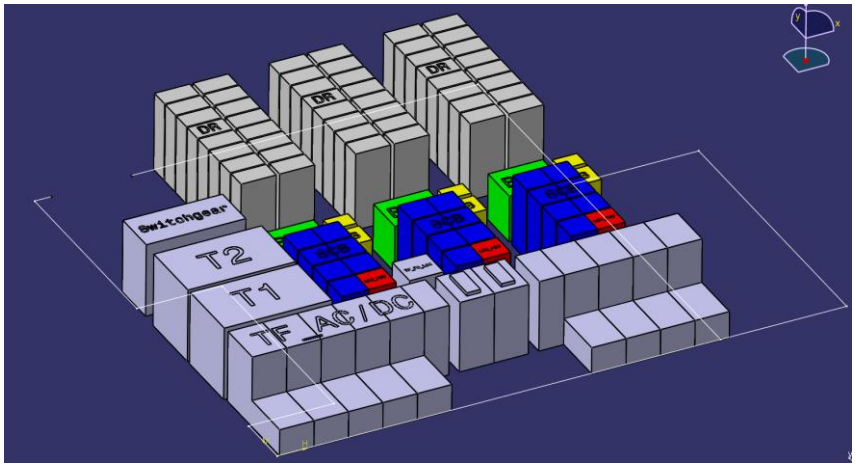
- No expected relevant criticalities
- Open items/procurement opportunities:
  - Transformers (secondary voltage)
  - Control interfaces CODAS
  - Dummy load
  - Local reactive and harmonic mitigation

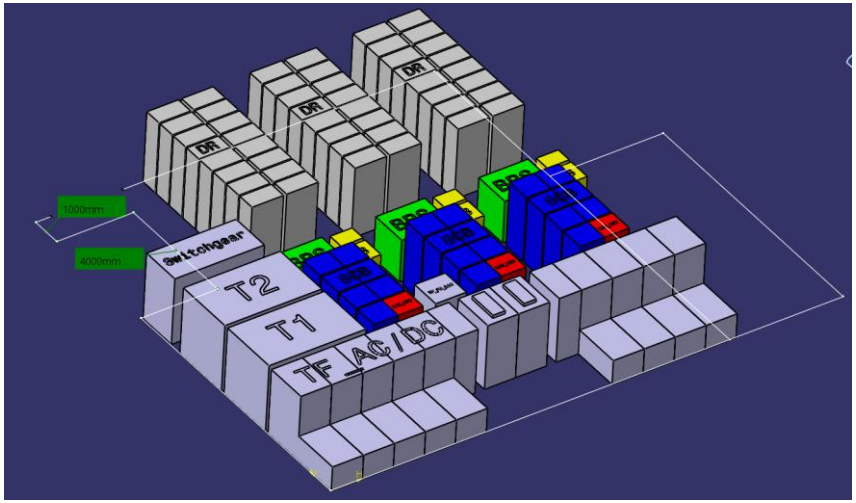
TF FDU technical issues

- Contract signed on 18/05/22 with OCEM (Italy)
- KoM held on 25/05/22
- Delivery of «mock-up» in CTF foreseen at November '23
- Delivery and installation in DTT in April '26

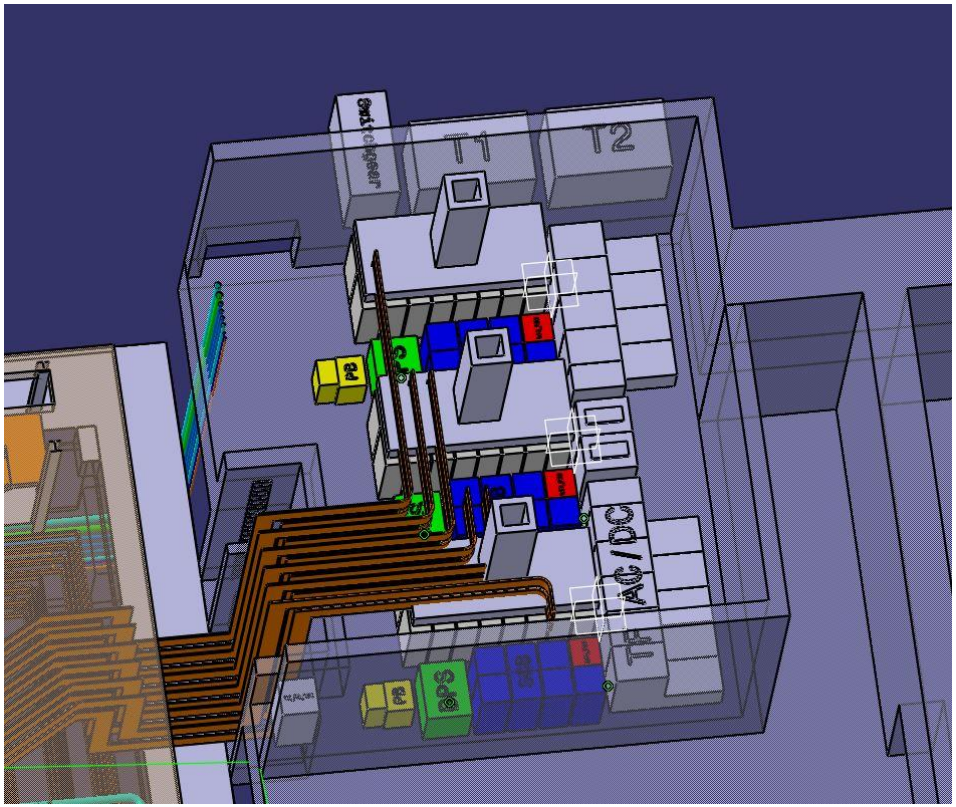
- Several novelties:
  - JT-60SA: 25.7 kA → 42.5 kA, <2.8 kV → >5.5 kV
  - Varistors
- Relevant criticalities
  - Russian current transducer
  - Russian pyrobreakers
    Problem → Opportunity
    Totally static switches: Faster (less energy in coils), safer?, better layout?
  - Cooling
  - Discharge time to be optimized according to magnet design

Layout TF PS and FDUs in Building 184

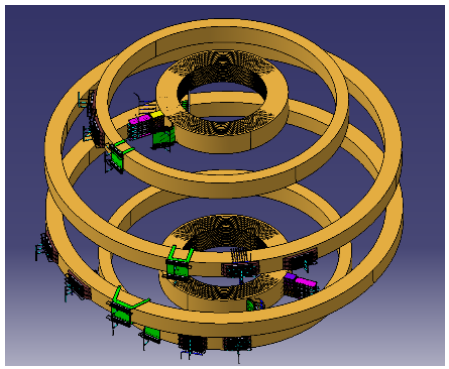




- Layout still with pyrobreakers
- DC busbars to be updated later

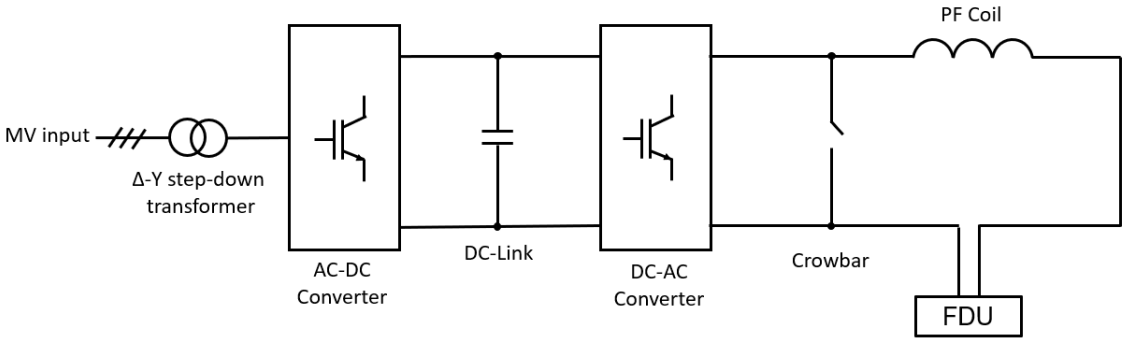


PF PS Procurement Issues



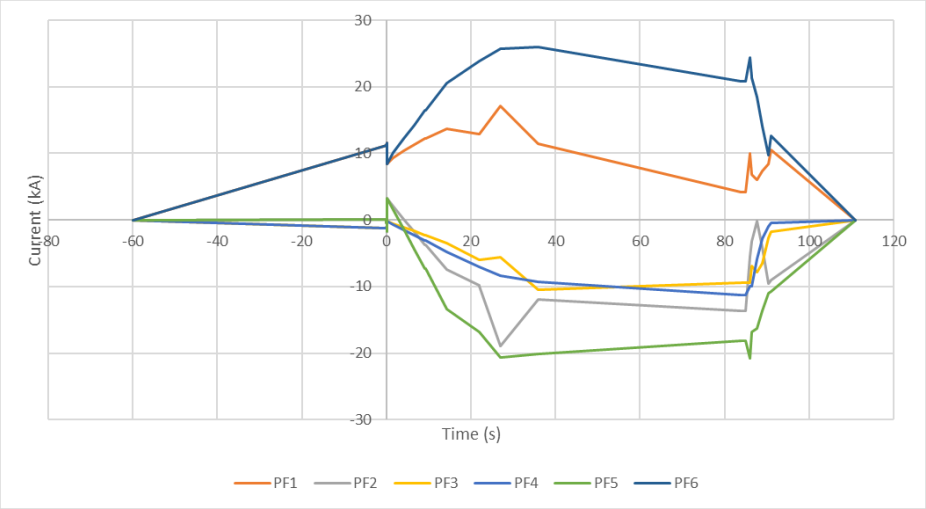
Many modifications and updates in 21/22

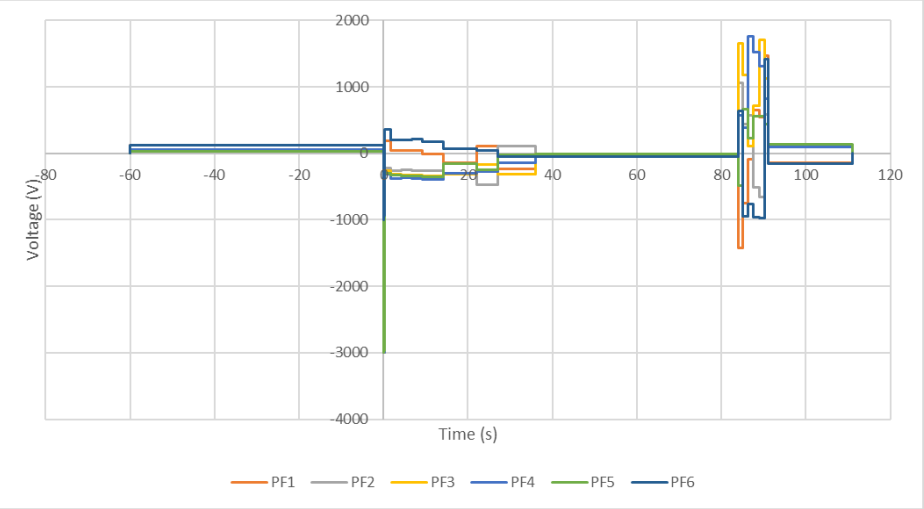
- External Panels on scenarios and magnets
- Higher voltage, no SNUs, FDUs (in crowbar?)
- Discharge τ still valid?

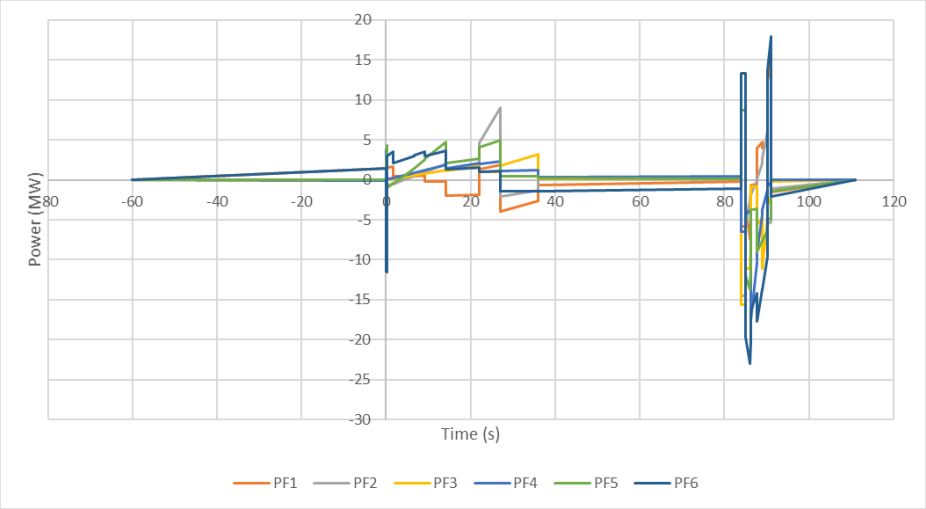


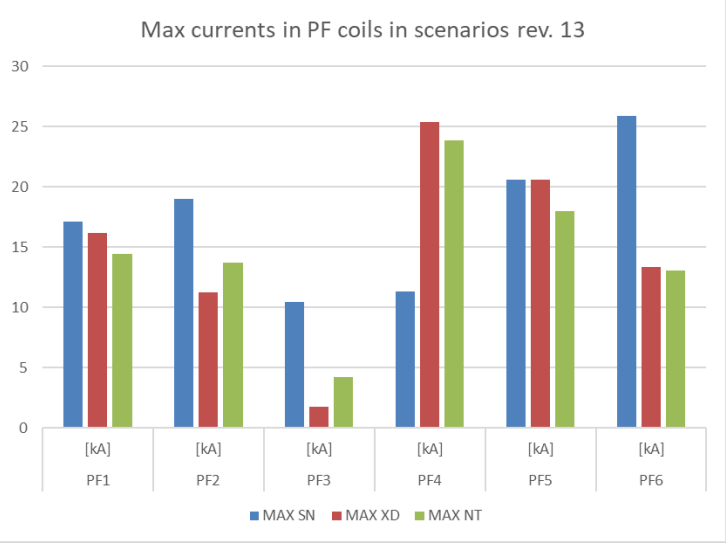
Global (PS e load)							
Quadrants (to load)		4	4	2	2	4	4
Load inductance	mH	454	298	690	690	298	454
Nominal current	kA	18.8	20.9	11.5	27.9	22.7	28.5
Max voltage on load	kV	2	3	3	3	3	2

PF PS reference scenario (TBC)

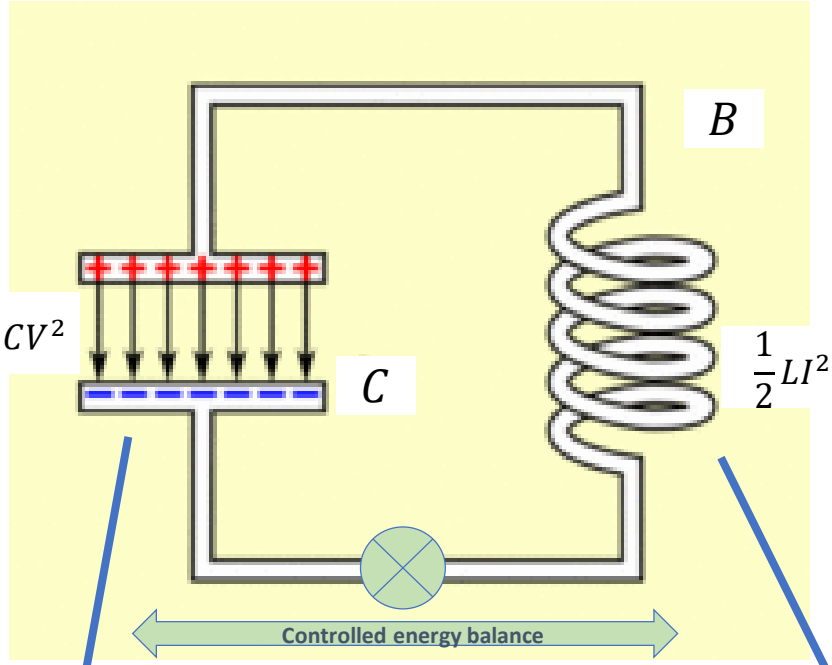


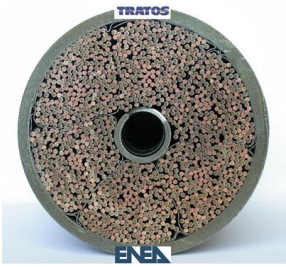






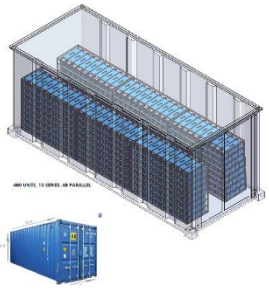
Basic (ideal) principle of storage/recovery

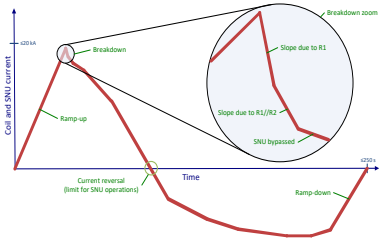




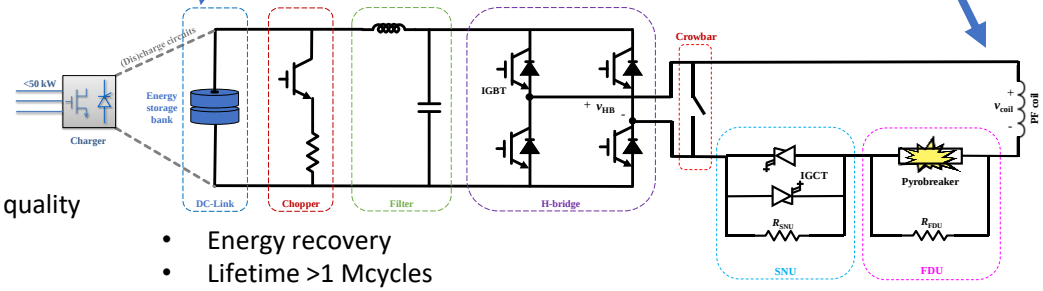
SC electrostatic energy $\frac{1}{2}CV^2$

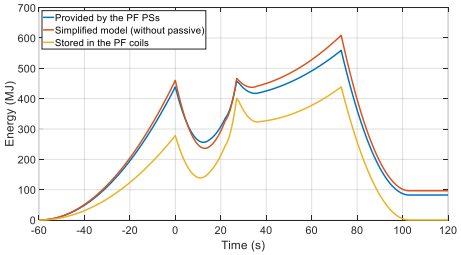
$\frac{1}{2}LI^2$ **Superconductor magnetic energy**





AC side:
- Low impact
- High power quality





- Energy recovery
- Lifetime >1 Mcycles
- No special disposal

Supercapacitors for PF and CS PSs

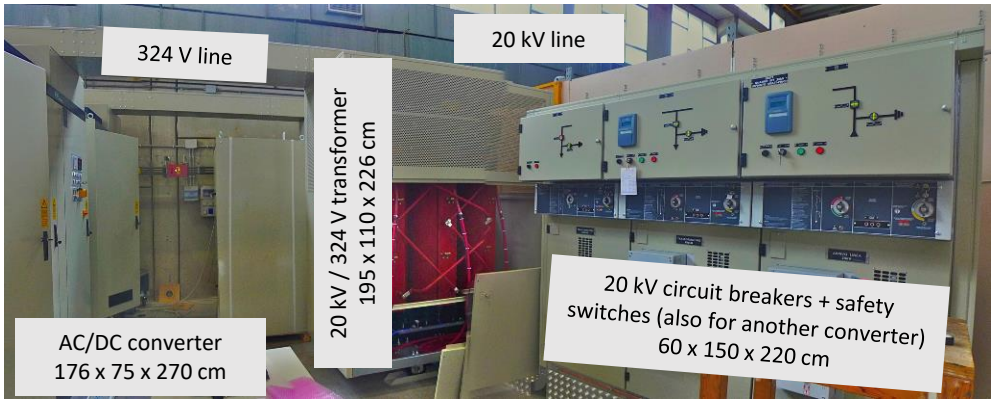
Working prototype: 2 kA, 10 s

Dimensions:
120 x 60 x 190 cm
= **1.4 m³**

Wheels to move it!

Connections: just the plug and the load

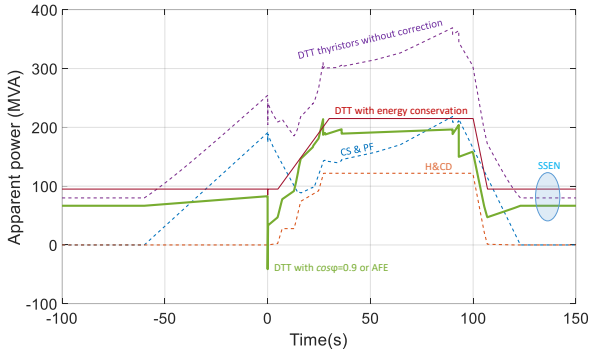
Previous system: 2 kA, 1 s



Total dimensions:
> 10 m³ (> 7 times)
+ dedicated 20-kV line
and 324-V line

Fixed installation
with many connections

Large(st) energy storage installation



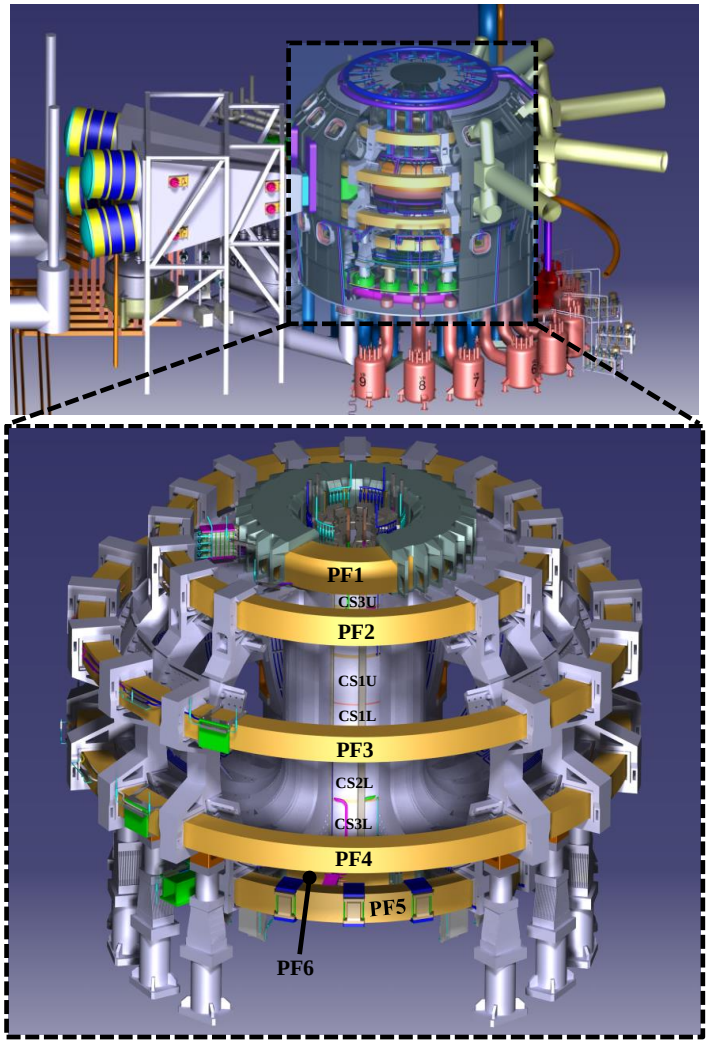
- Total Energy Storage for 12 PSs: 600 MW, 3600 MJ, 960 kWh
- Moreover, ENEA has SMESs and flywheels
- Comparison:
  - Korea: 25 MW supercap in several facilities
  - Endesa STORE, Canary Islands, Spain supercap: 4 MW, 20 MJ
  - Terna, Sicilia + Sardegna supercap: 1+1 MW, 1+1 MJ
  - Terna has some battery systems in order of 10 MW
  - DTT could be an “electrostatic lake” (Italy has 4 hydro-storage lakes at 1 GW)

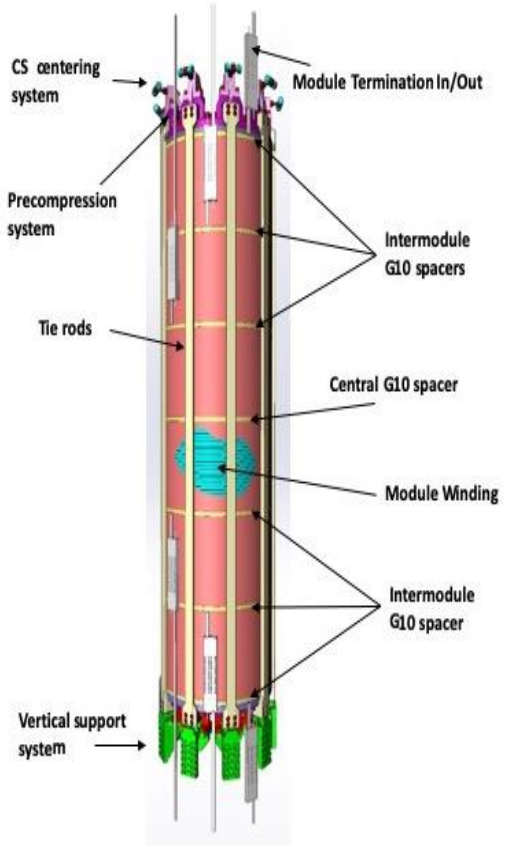
If you like to know more: www.supercap.org

PF PS Procurement Status

- Call for Tenders in Autumn 2022
  - Delivery to FCCTF: 16 months? Test of PF6
  - Coordination with CS and FDU mock-up

Central Solenoid (CS) PSs



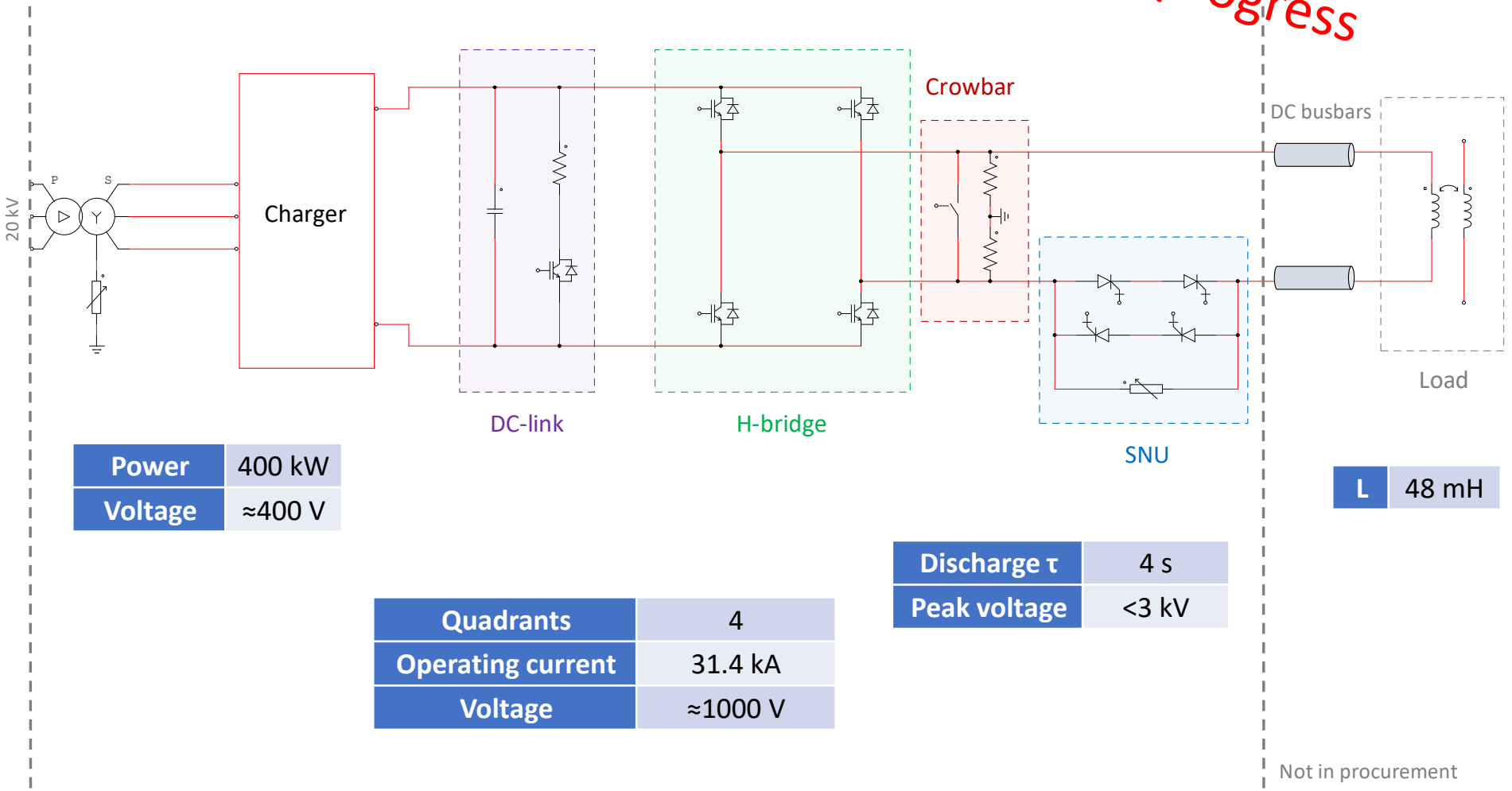


6 independent PSs:

1. CS3U (upper)
2. CS2U
3. CS1U
4. CS1L (lower)
5. CS2L
6. CS3L

CS PS reference scheme

Update in progress



Power	400 kW
Voltage	≈400 V

Quadrants	4
Operating current	31.4 kA
Voltage	≈1000 V

Discharge τ	4 s
Peak voltage	<3 kV

L	48 mH

Not in procurement

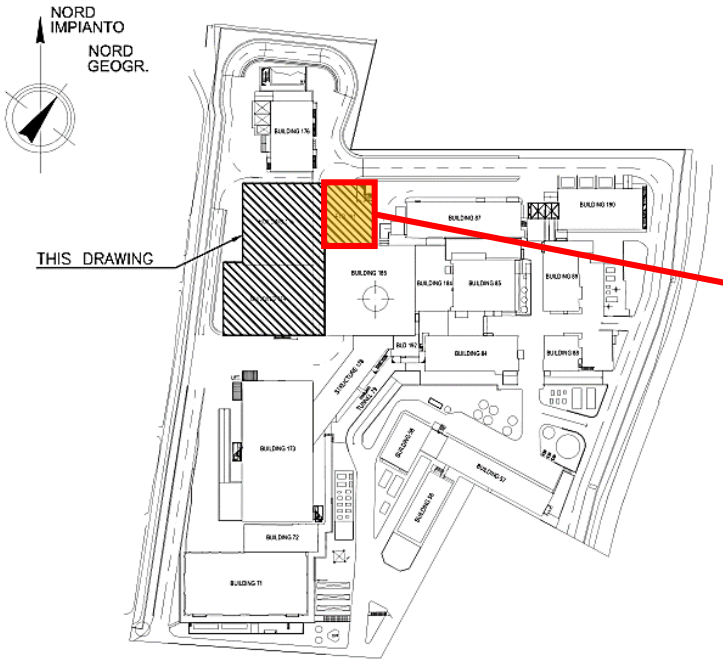
CS Procurement status

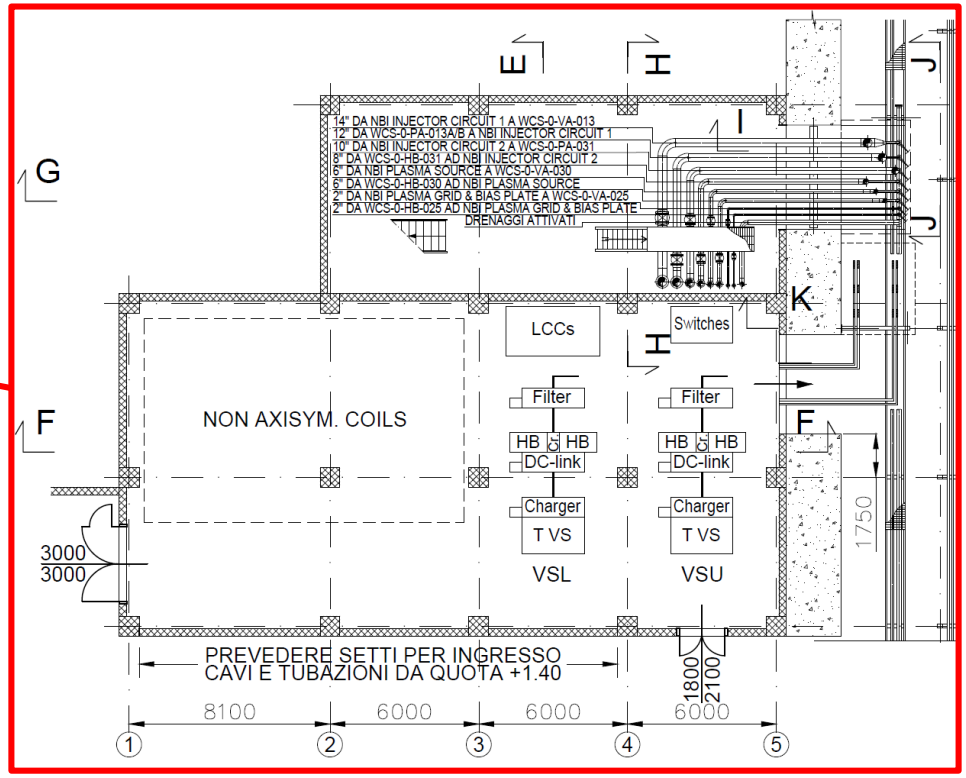
- All tender documents (including administrative) ready and approved in 2021, but frozen
  - External Panel and study ongoing
  - Higher current?

- Call for Tender in 2023
- Criticality:
  - Test of CS in FCCTF, maybe can be performed by PF PS

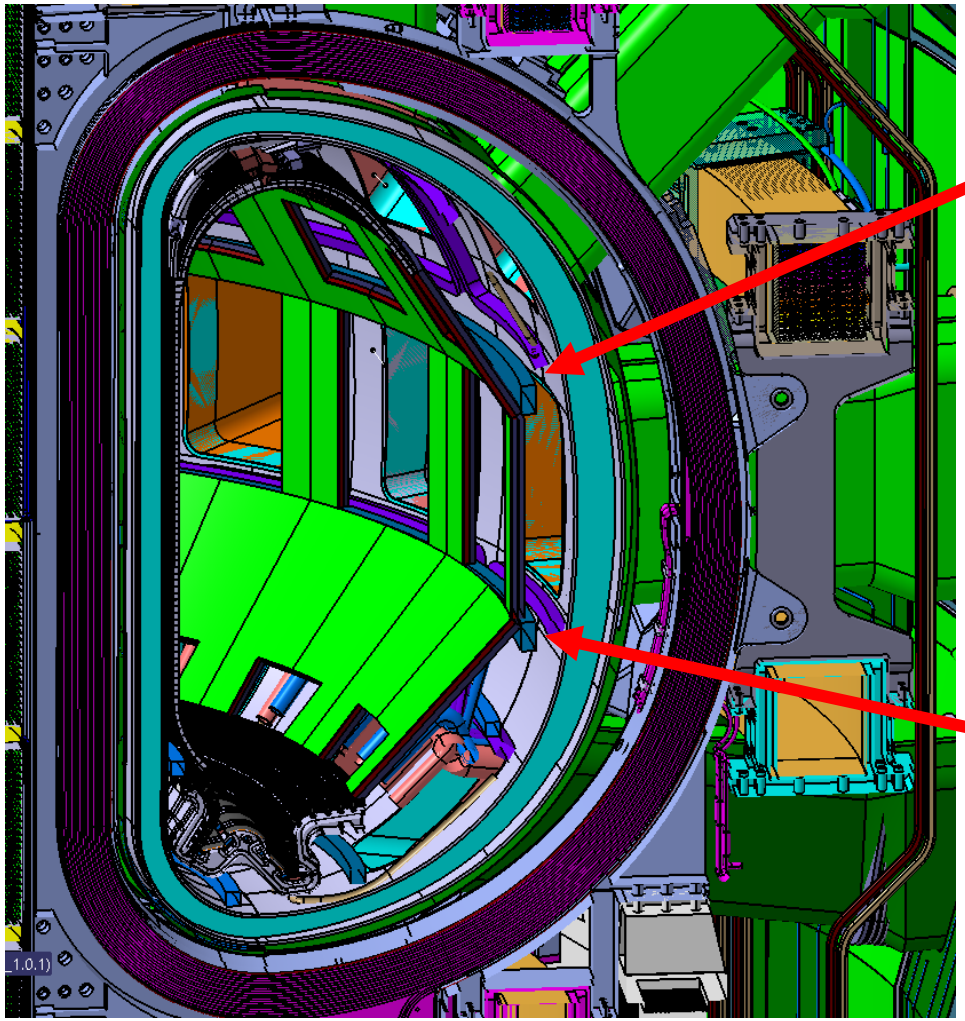
IVS PS reference location and layout

ENEA Building 191 Floor -1
(to be built)





Vertical Stabilization (VS) PSs

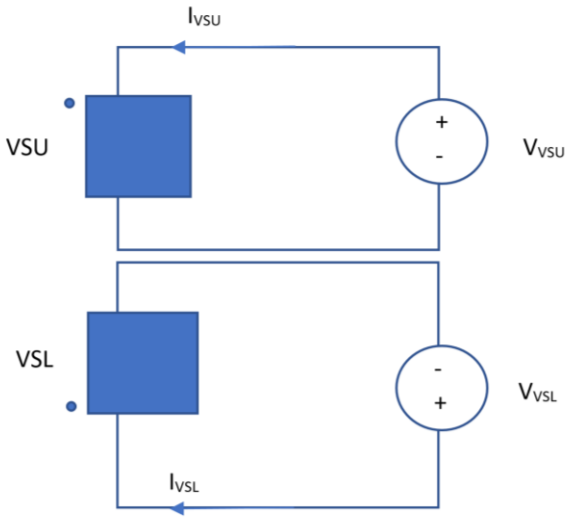


Update in progress

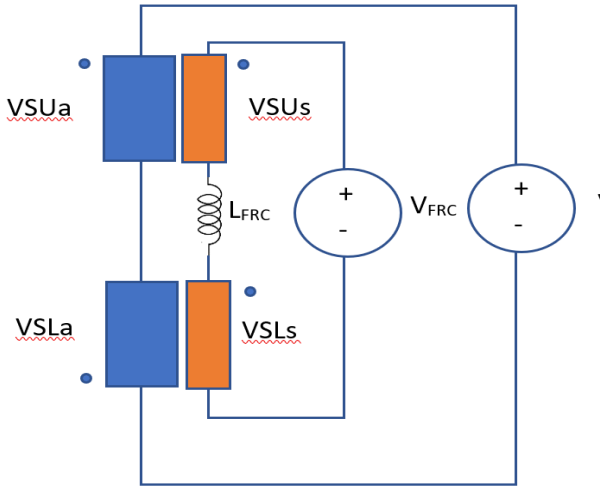
- 2 independent PSs (VSU-VSL)
- Copper
- 4 quadrants

Alterative topologies

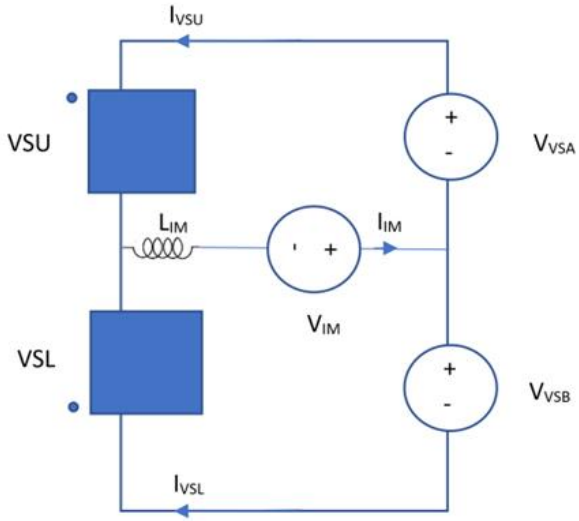
Disruption is one of the main criteria for PS design! 6 times the nominal one!



Independently fed coils
→ Sensitive to disruptions
→ Require complex protections



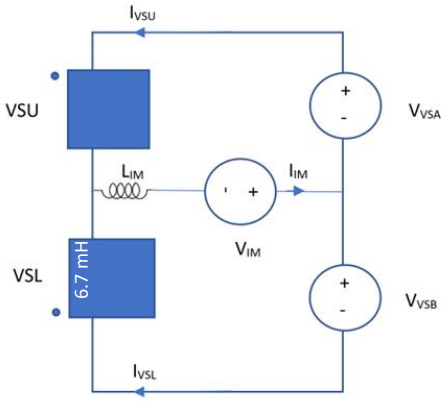
Double coupled coils
→ Problems in the available in-vessel space



Separate imbalance power supply

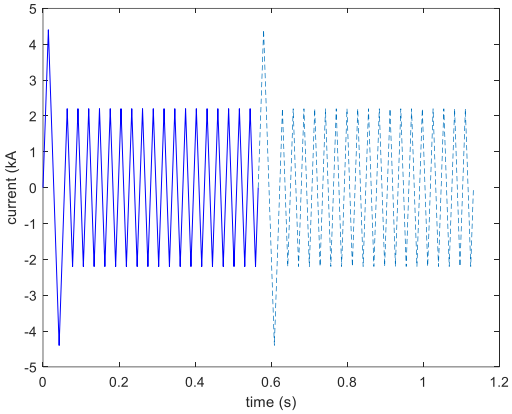
Presently selected solution

Present specifications for VS PSs



VSA and VSB: 2 identical PSs:

- 4 quadrants
- IGBT-based
- Current = 4.4 kA
- Voltage = 2.0 kV



Reference scenario

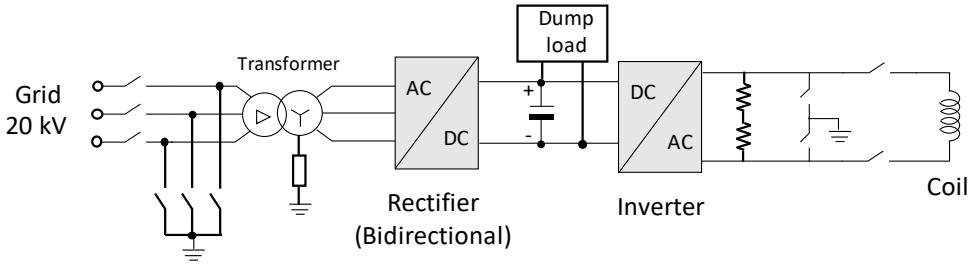
VIM PSs:

- 4 quadrants
- IGBT-based (maybe thyristors)
- Current = 6 kA
- Voltage = 2.5 kV
- Short operations (<1 s)
- High inductance and/or advanced protection

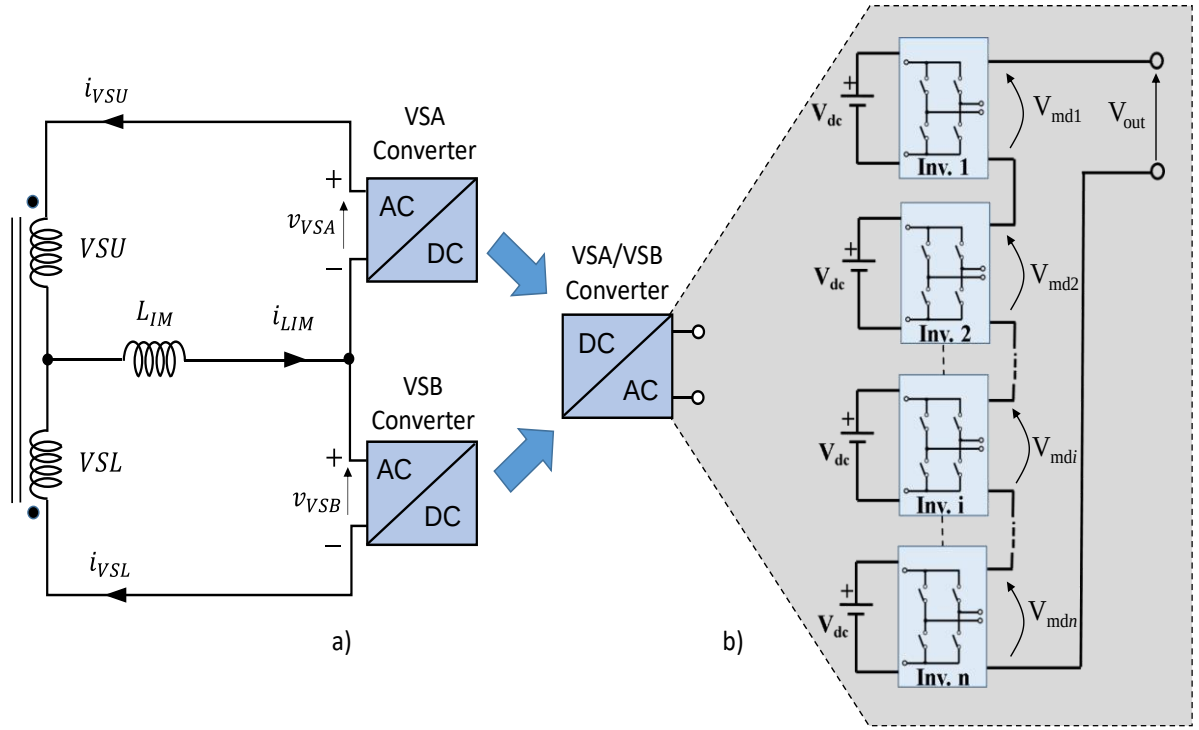
Turns might also be changed to optimize current and voltage at fixed power

High inductance assumed (L_{IM}≈100 mH)

- Study to reduce
- Recycle FTU inductors



VSS open issues and future activities

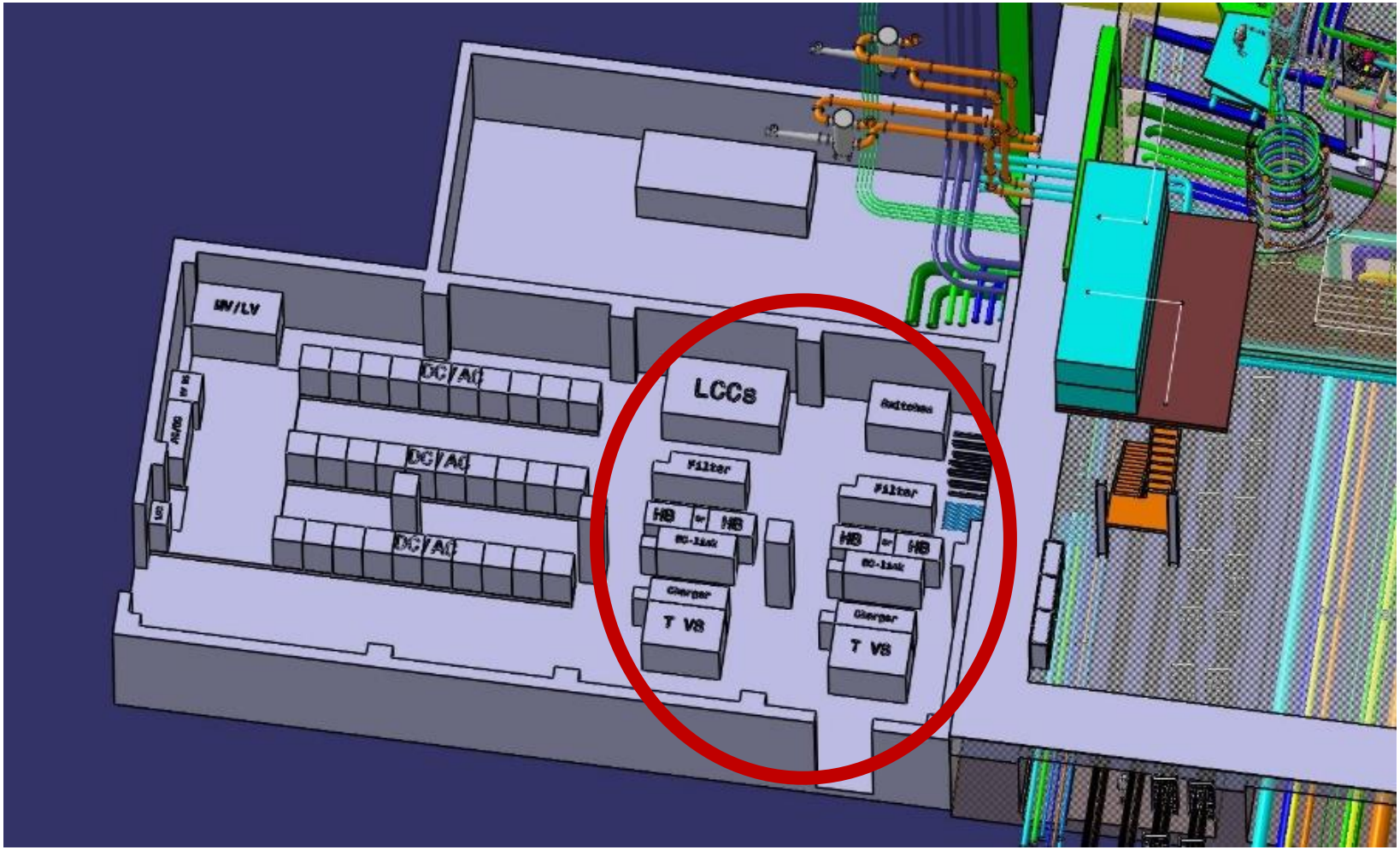


Possible reduction of PSs: 3→2

But control more complicated:

- Conjunction of slow and fast control in the same PS
- HIL simulation

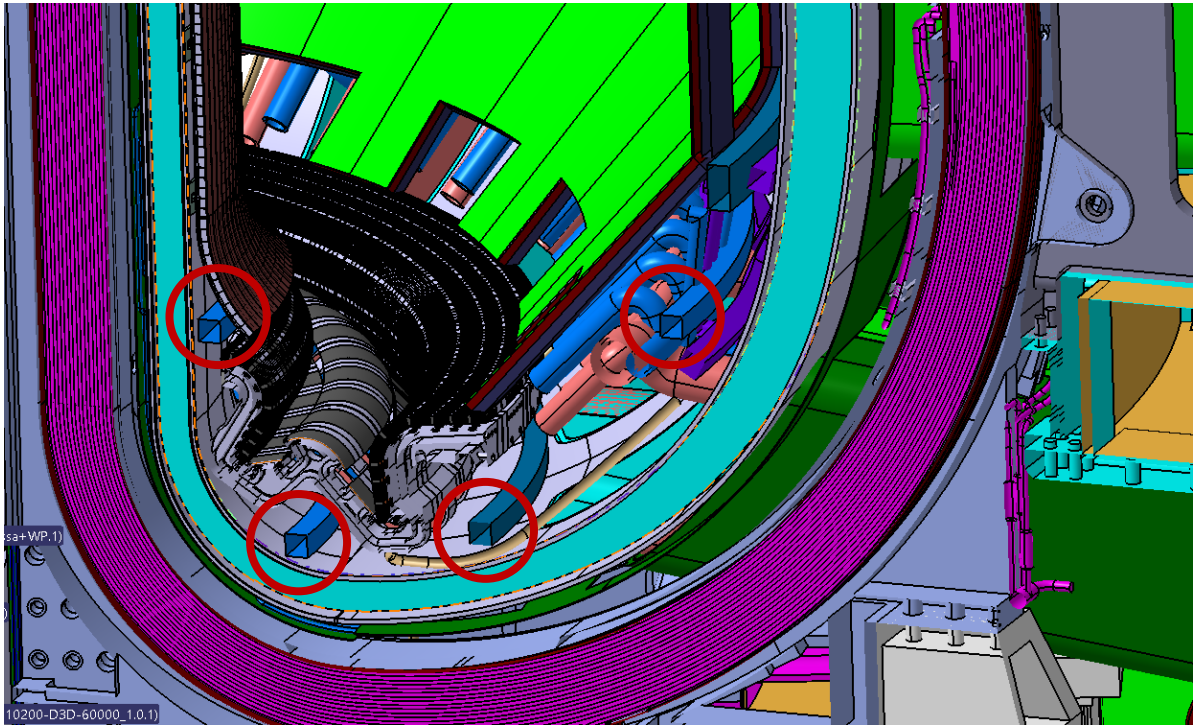
VS PS layout (2 PSs, but with higher power)



VS Procurement status

- Call for Tender could wait >2023
- Now PNRR: we should launch the Call for Tender early

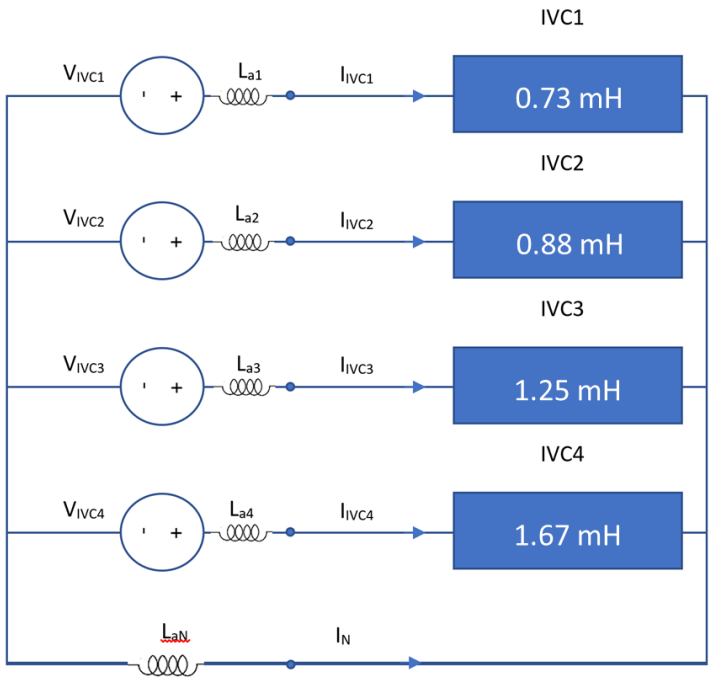
Divertor (DIV) PSs



Update in progress

- 4 independent PSs
- Copper
- 4 quadrants

DIV: 2021 selected solution



Disruption is one of the main criteria for PS design

↓

Separate imbalance branch

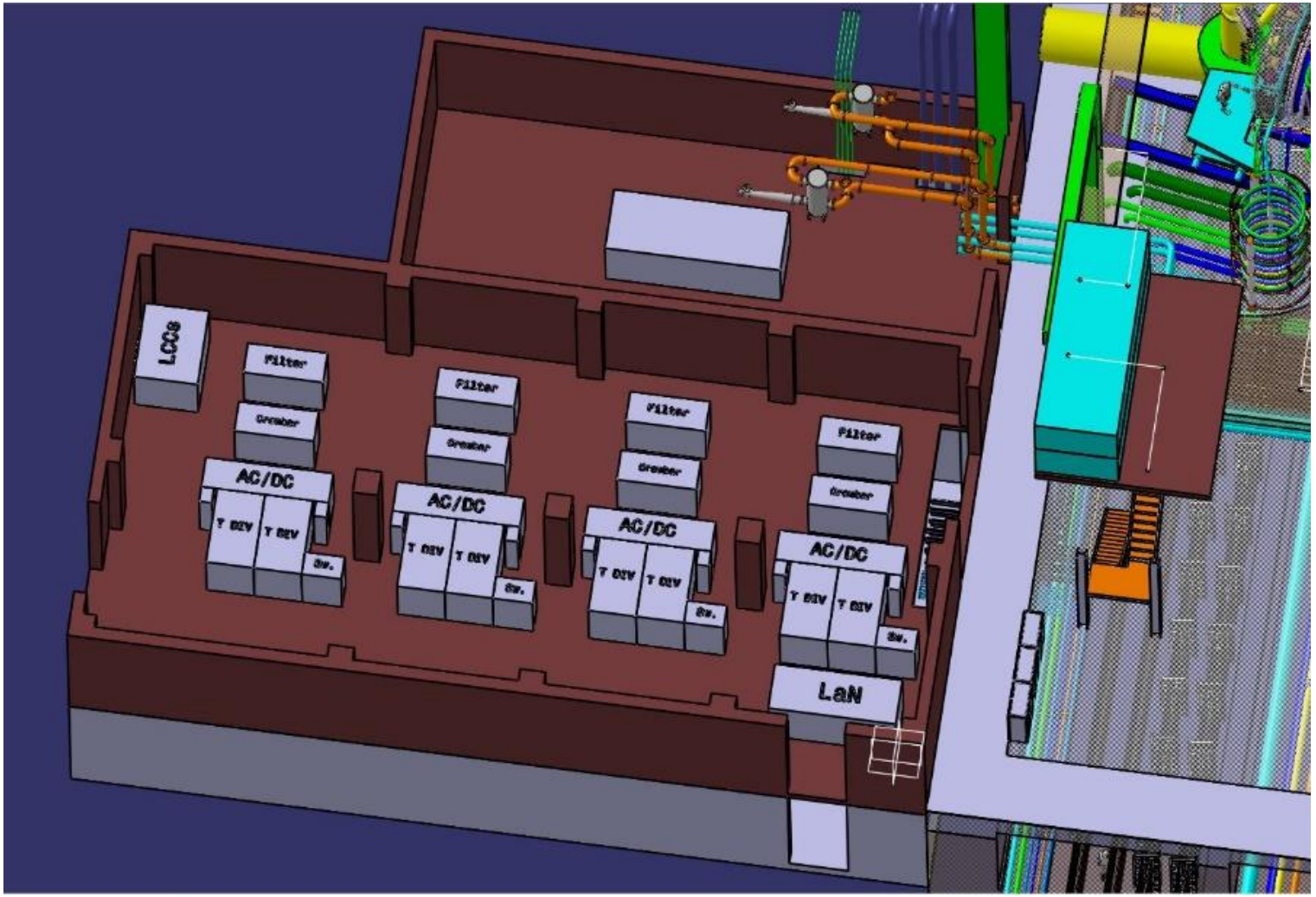
Maximum control speed: 4 Hz

- Thyristor converters (maybe, choice mainly based on costs)

Open issues and future activities:

- Possible update by other groups: 4 → 3 coils
- Turns to be optimized
- Inductance to be optimized
- Fast circuit breakers necessary for overcurrent?

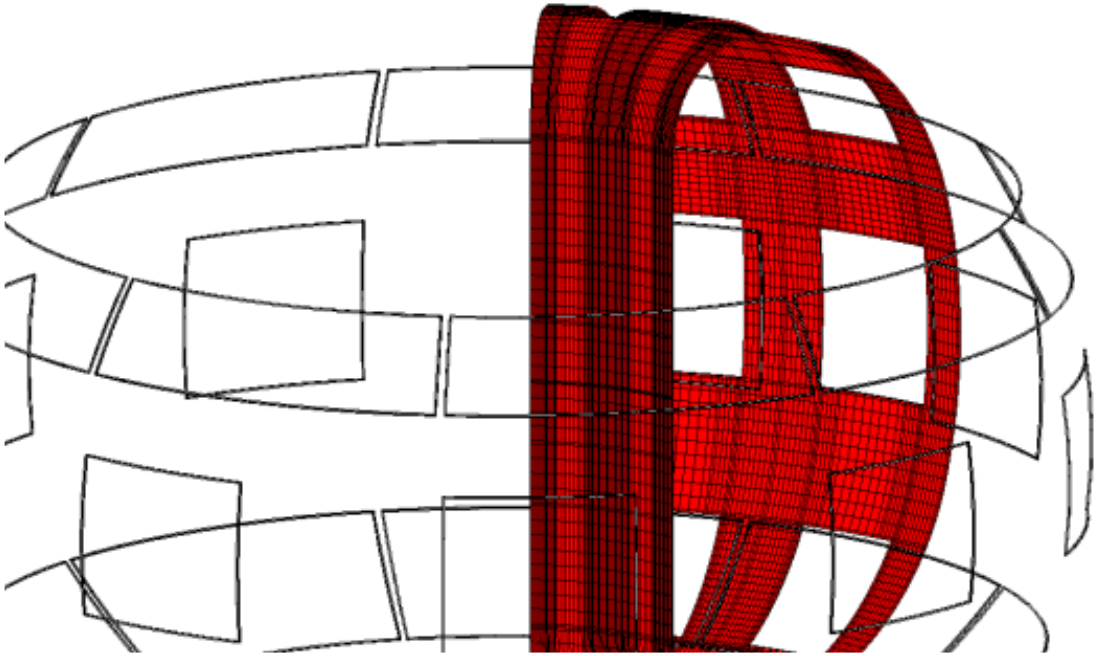
DIV PS layout (with good margin)



DIV PS Procurement status

- Now PNRR
- For Call for Tender we could wait >2023

Non-Axisymmetric (NA) PSs



- 27 independent
- Copper
- 4 quadrants

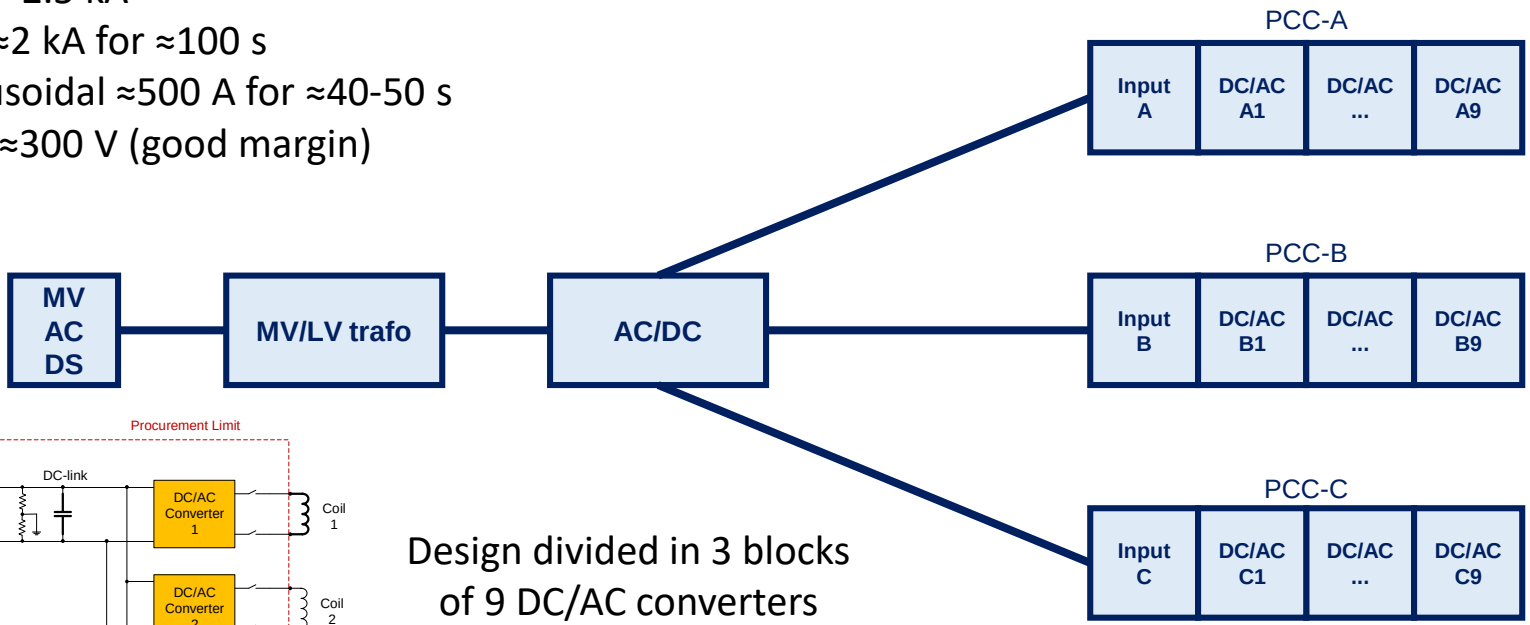
Update in progress

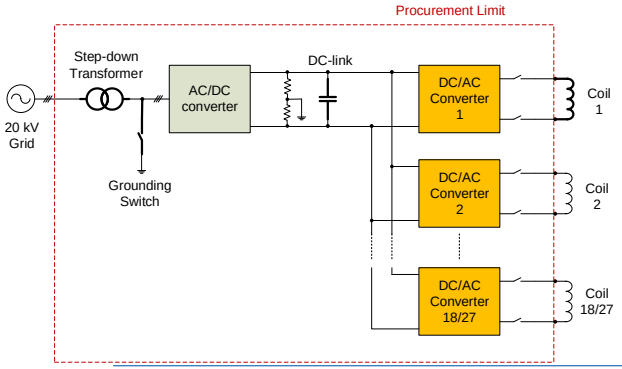
NAS specifications and reference scheme

18 → 27 identical PSs:

- Single input power: 4 MW (TBC)
- Output:
  - 4 quadrants
  - IGBT-based
- Current ≈2.5 kA
  - DC ≈2 kA for ≈100 s
  - Sinusoidal ≈500 A for ≈40-50 s
- Voltage ≈300 V (good margin)

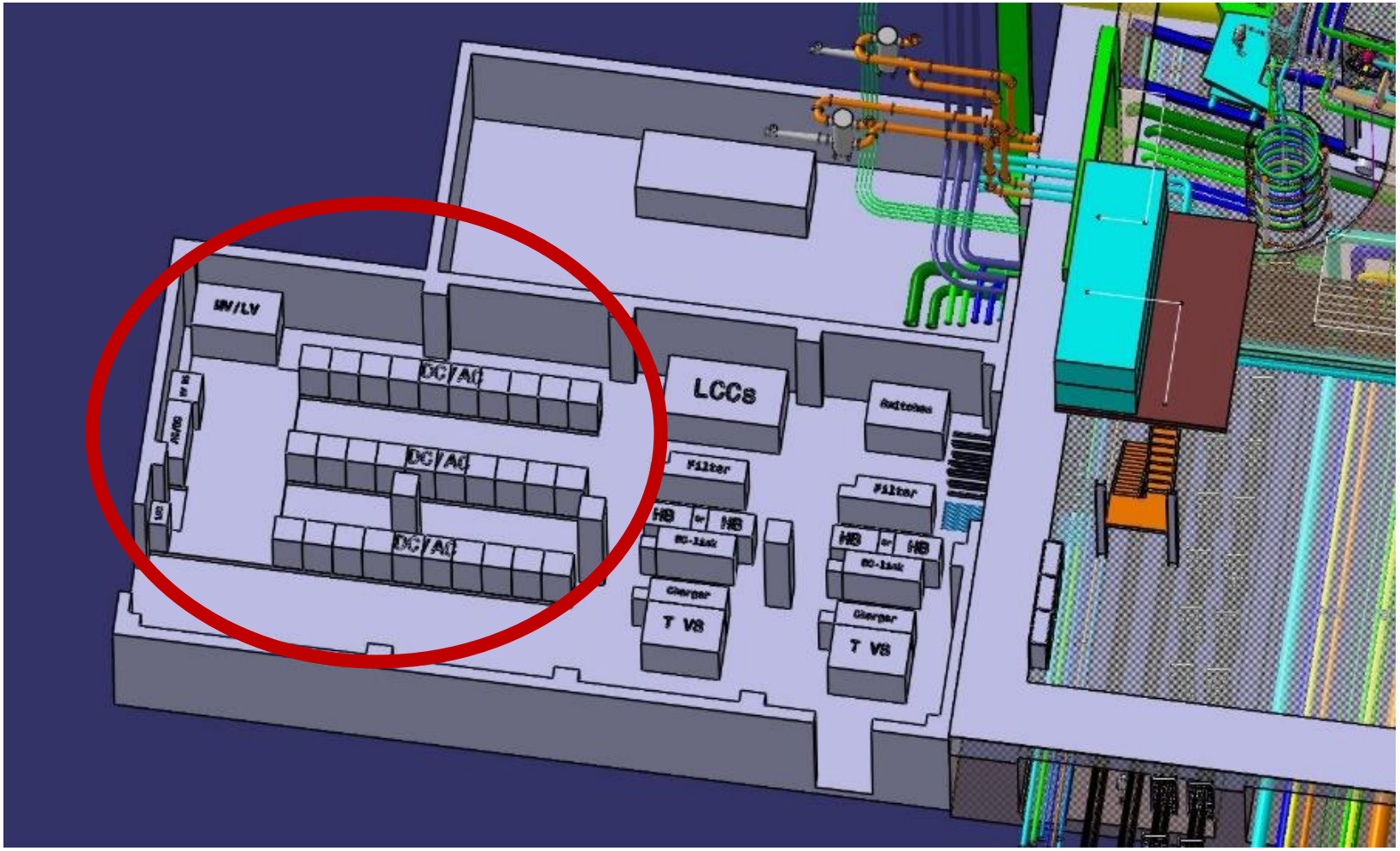
- Discussions to increase turns and/or current
  - kAt: ≈30 kAt → >>50 kAt
- Disruption analysis still preliminary





Design divided in 3 blocks of 9 DC/AC converters

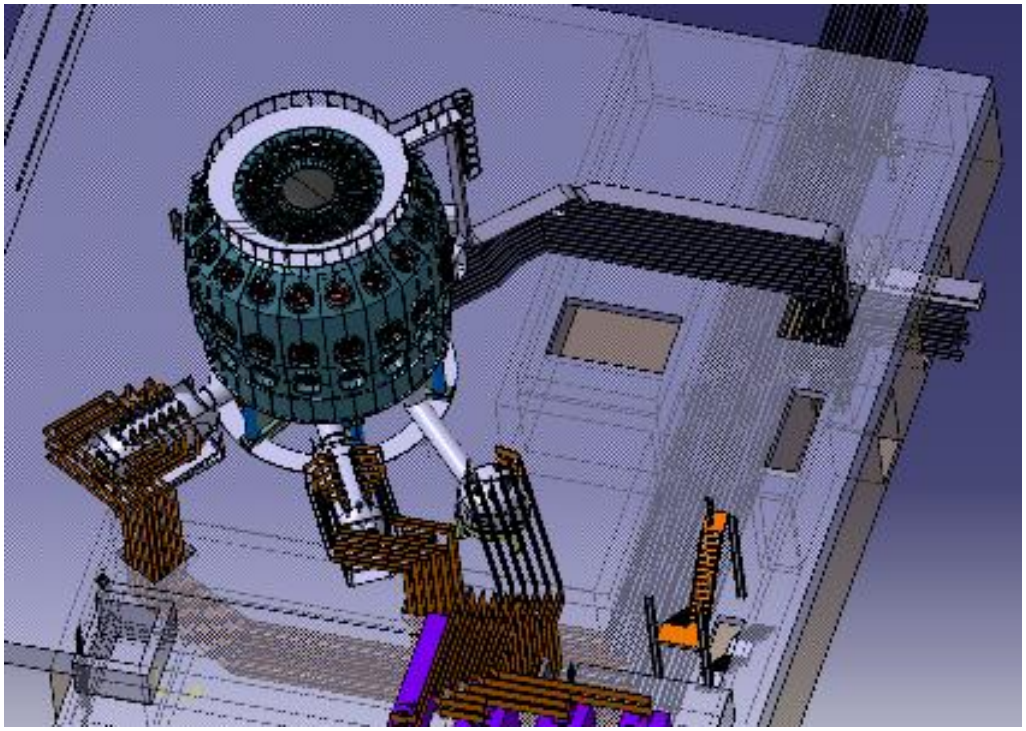
NAS layout


LV/LV
DC/AC
DC/AC
DC/AC
LCCs
Switches
Filter
Filter
HB
HB
HB
HB
Charger
T VS
Charger
T VS

NAS Procurement status

- Now PNRR
- For Call for Tender we could wait 2023

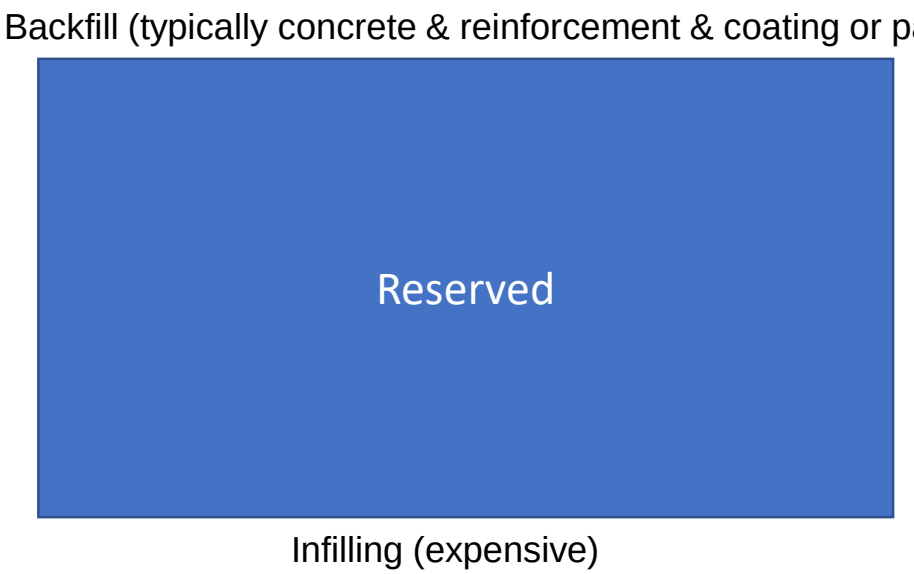
DBS DC Busbars (or cables)

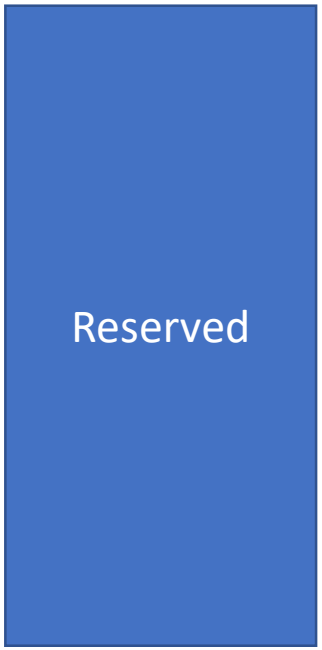


- Call for Tender >2023
- HTS busbars? PNRR

Discussion on busbar penetrations

- Issues: neutrons, heat dissipation, electrical insulation, structural (seismic)
- Option: Increase dimensions at least in penetrations
- Final filling could be optimized and implemented later
- Contacts with other tokamaks





CSP Control System PSs

- Control System for PSS
- Activities are ongoing with CODAS
  - To define standard interfaces
  - To develop prototypes/demonstrators
  - Maybe integrate them in PROTO-SPHERA
- Hardware-in-the-loop (HIL)

Other PS Components

- Several minor components
- When possible included in other procurements, as TF dummy load
- No criticalities

Thank you for your attention!

For more info please contact:

https://www.dtt-project.it/

http://www.afs.enea.it/lampasi

http://www.supercap.org

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