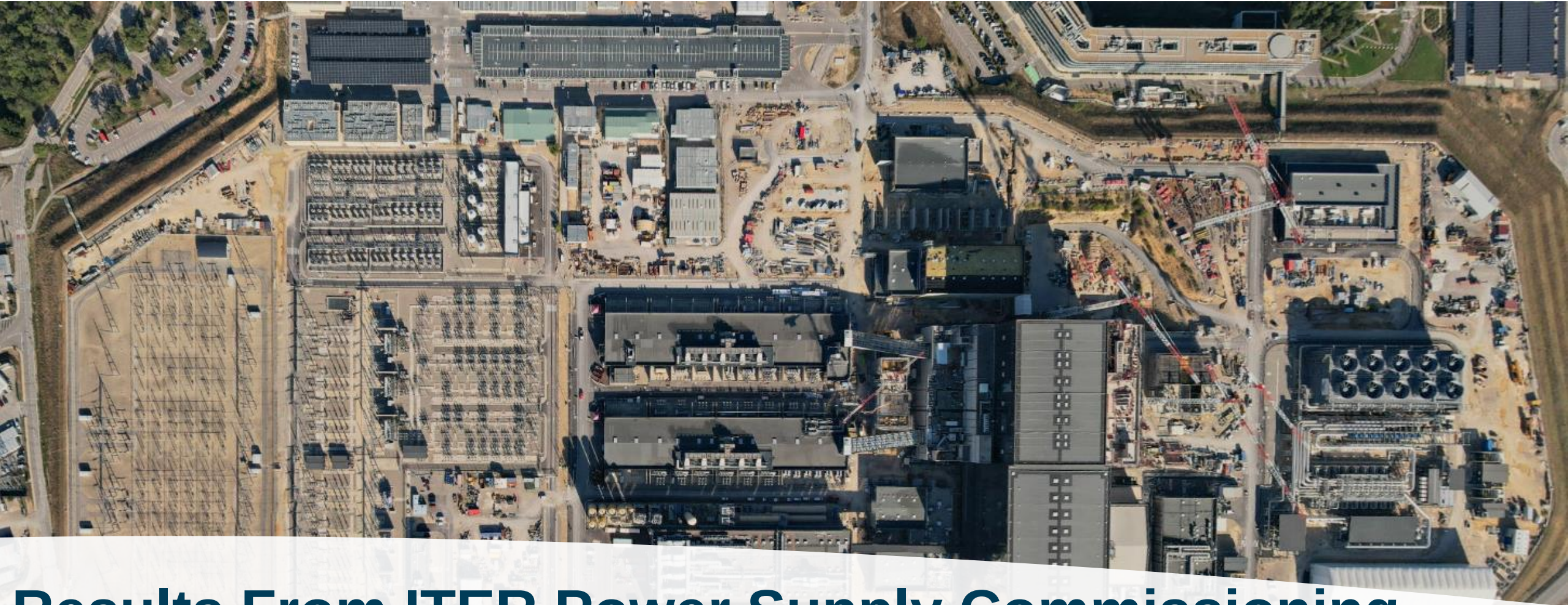


Results From ITER Power Supply Commissioning and Future Development

34th Symposium on Fusion Technology

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22 September 2026 Renjing.Fan@iter.org

china eu india japan korea russia usa

1. ITER Ex-Vessel Coil Power Supplies (ECPS) Introduction and Commissioning.

1.1 ITER ECPS Overview.

1.2 Stage 1 Reactive Power Compensation and Harmonic Filtering (RPC & HF) Systems.

1.3 Superconducting Coil Power Converter Circuits.

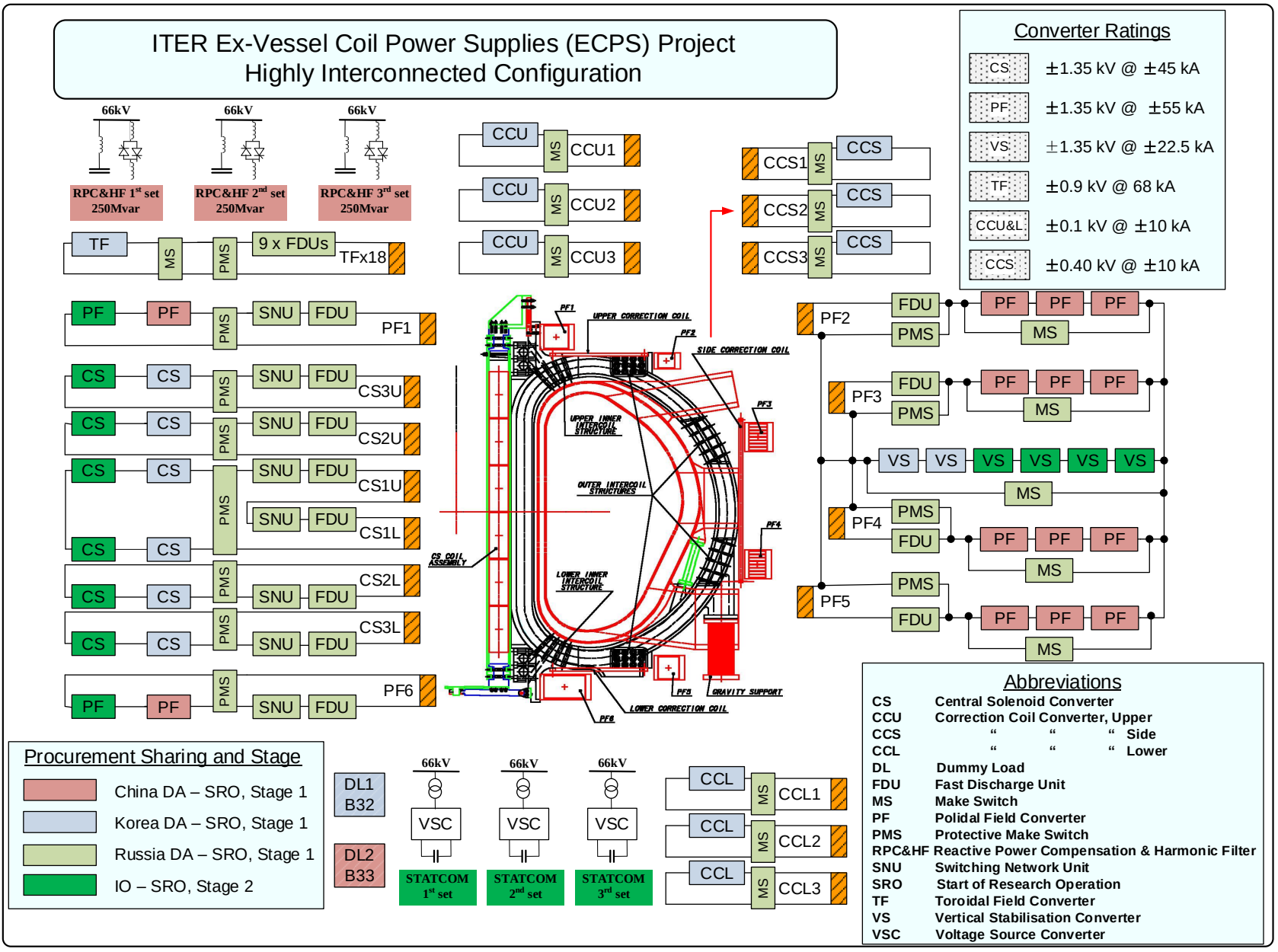
2. ITER In-Vessel Coil Power Supplies (ICPS) Introduction and Future Development.

2.1 ITER ICPS Overview.

2.2 Edge Localized Mode (ELM) Power Supplies.

2.3 Vertical Stability 3 (VS3) Power Supply.

2.4 IO Static Magnetic Field (SMF) Test Facility.



Systems	Supplier	Stage
RPC&HF Systems	One Procurement Arrangement with CNDA	SRO
Stage 2 RPC (STATCOM TBD)	To Be Determined (TBD)	SRO
Stage 1 Main Coil Power Converter Systems	Two Procurement Arrangements with CNDA & KODA	SRO
Stage 2 Main Coil Power Converter Systems	Two Task Agreements with CNDA & KODA	SRO
DC Switches & Busbars	One Procurement Arrangement with RFDA	SRO

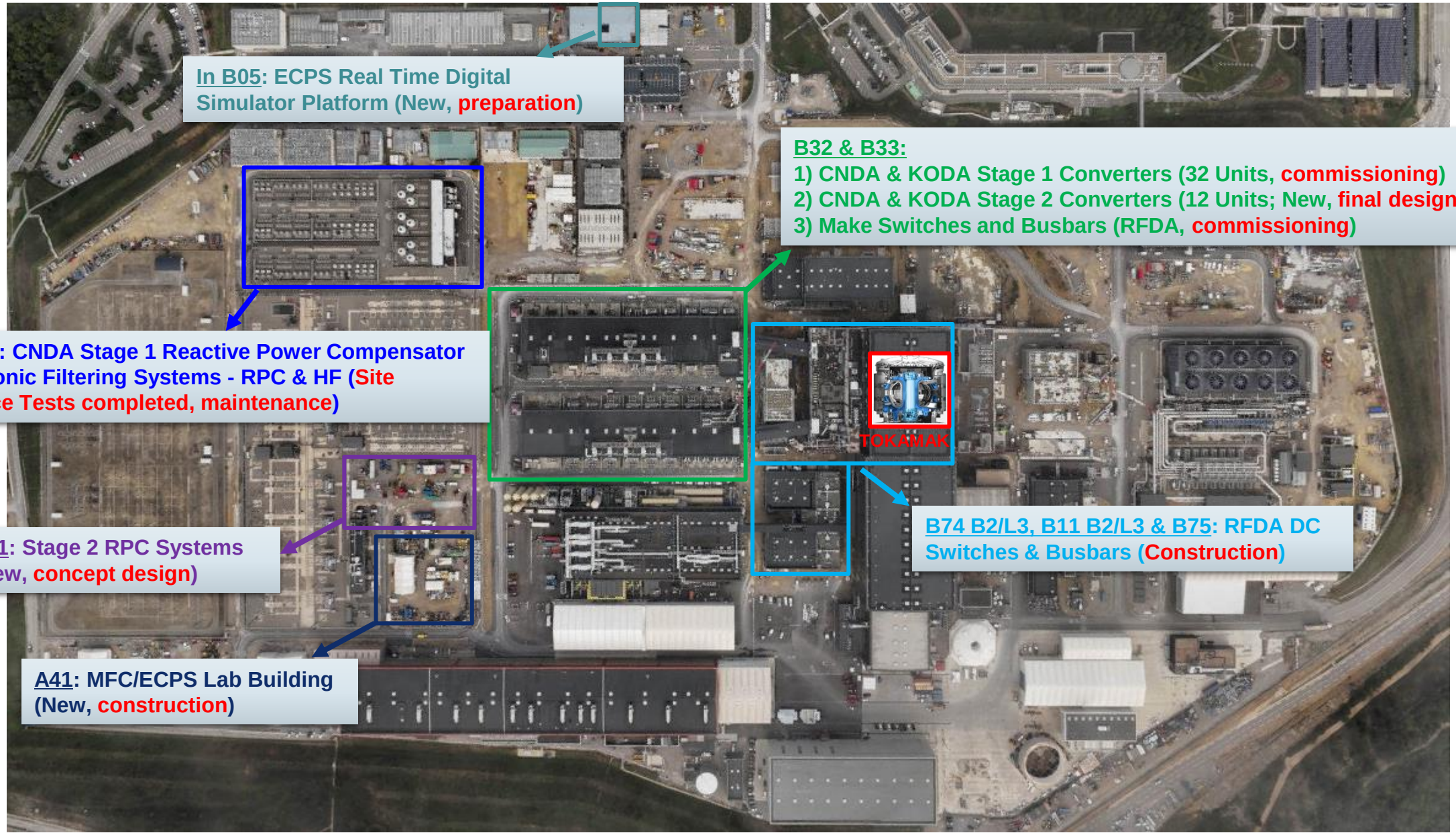
1) RPC & HF Systems: 750 Mvar;

2) Power Converters: up to 68 kA rating;

3) 120 switches: up to 70 kA rating;

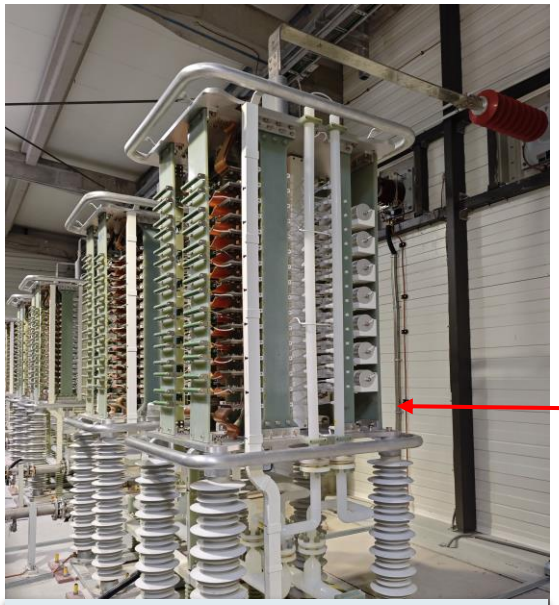
4) DC Busbars: around 10 km length.

1.1 ITER ECPS Overview - Highly Interconnected Configuration

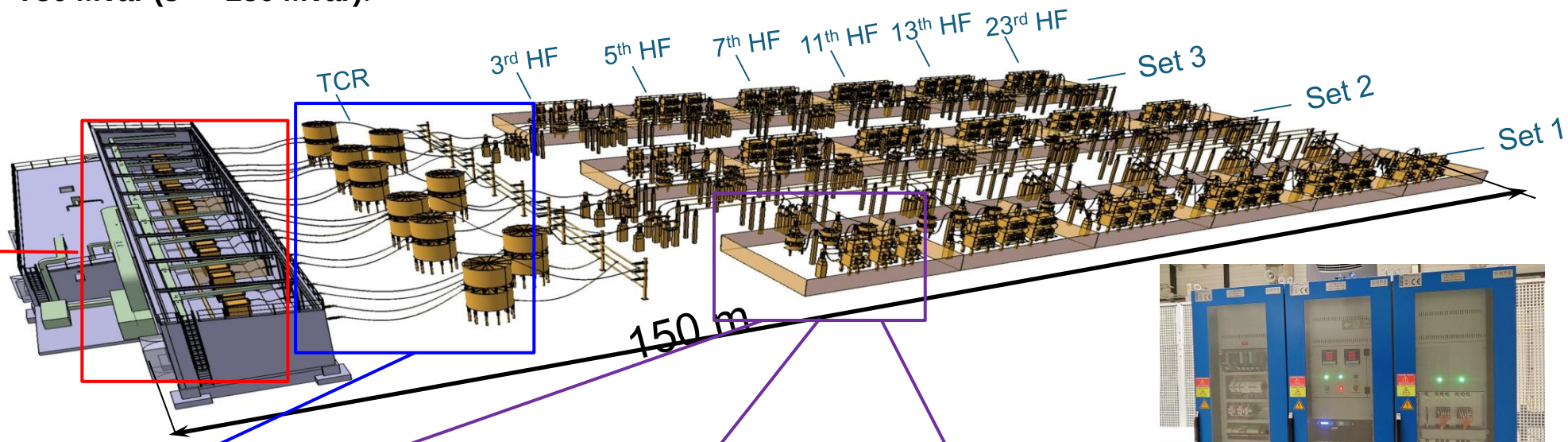


1.1 ITER ECPS Overview - Geographical Scope

Static Var Compensation (SVC) technology, supplied through CNDA in-kind contribution, with a total capacity of **750 Mvar (3 × 250 Mvar)**.



Light-Triggered Thyristor Valve Banks





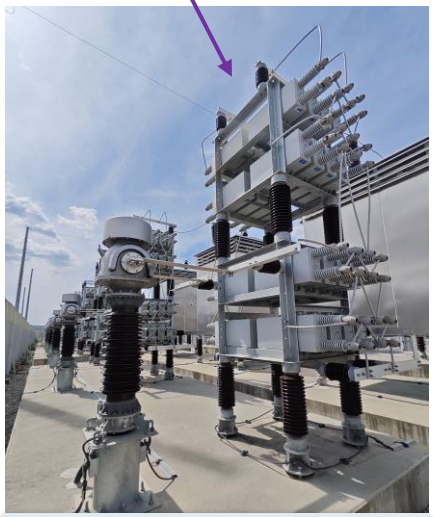
Thyristor Controlled Reactors (TCR)



H3 Resistors



H3 Filter Reactors



H3 Capacitor Banks

Local Cubicles

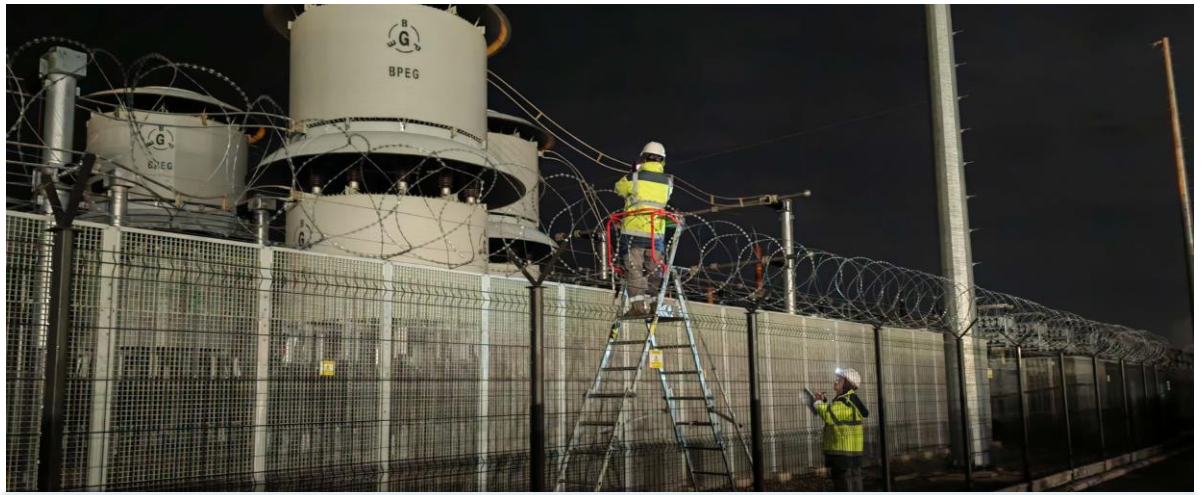


Cooling Water System

1.2 Stage 1 RPC&HF System - Overview

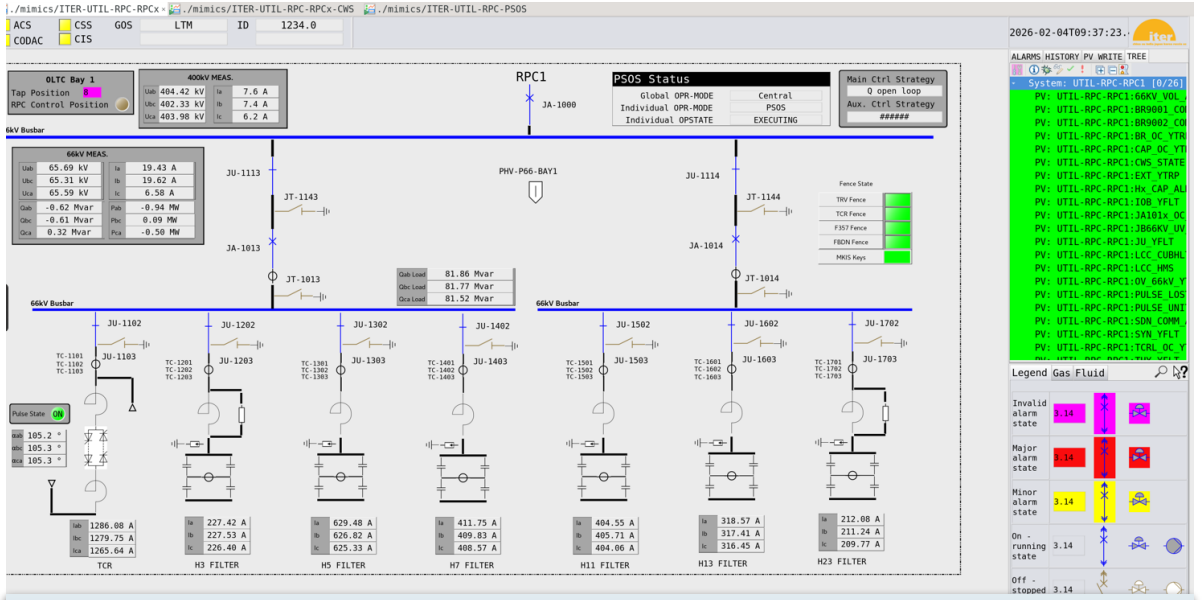


RPC & HF systems - site overview



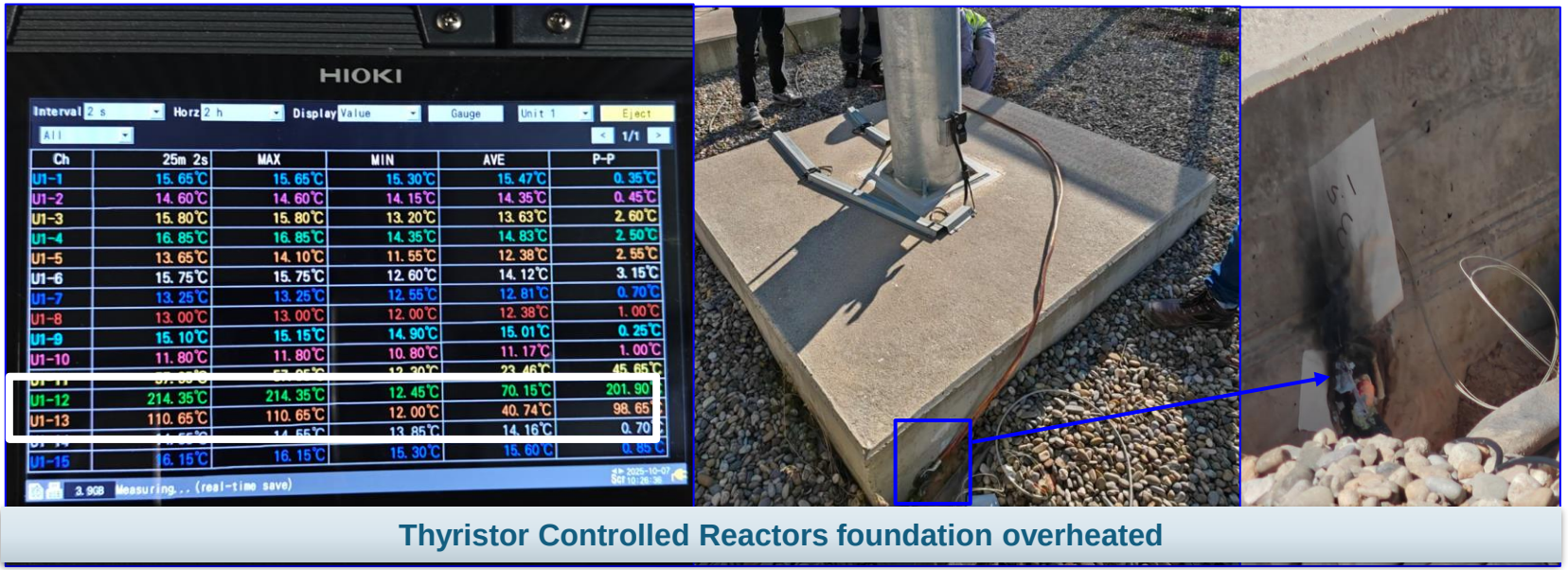
24 hours continuous operation test

- RPC & HF systems entered the preservation and maintenance phase after SAT completion in Nov. 2024, with periodic HV energizations starting from 2025.
- More than 200 commissioning procedures, trouble shooting reports and commissioning reports were approved.
- Safety Preparation: Third-party safety regulatory inspection, Emergency Response Team (ERT) fire drill and evacuation exercise, Lockout/Tagout (LOTO), Mechanical Key Interlock System (MKIS), etc.
- Zero safety incidents involving major equipment damage, zero safety accidents resulting in lost workdays.



Human-Machine Interface (HMI)

1.2 Stage 1 RPC&HF System – Commissioning Status



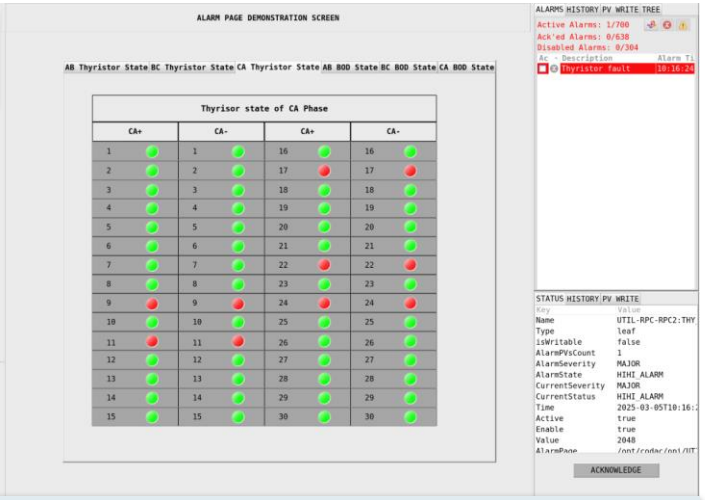
Thyristor Controlled Reactors foundation overheated



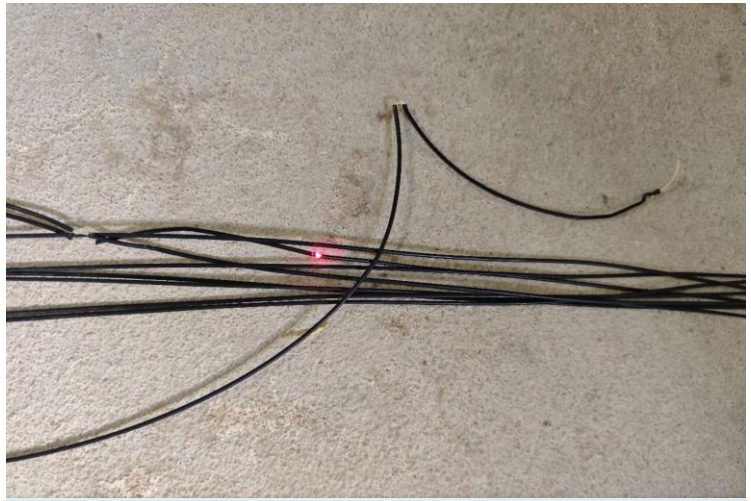
Fence earthing wire overheated to 220℃

Optical fibres protection





Thyristor state fault in second RPC&HF system



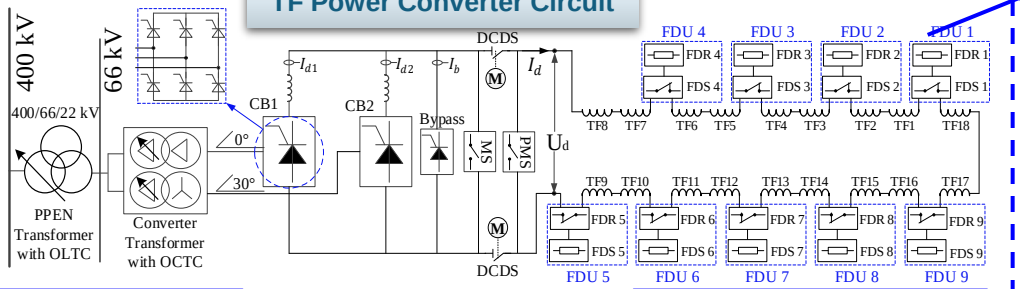
The fibres were damaged due to rat bites

Lessons learned

- Avoid or optimize the earthing loops on site to prevent circulating currents induced by the electromagnetic fields around the reactors.
- All vulnerable optical fibres should be adequately protected with conduits from rat-induced fibre damage.
- Always keep spare optical fibres available during installation.

1.3 Power Converter Circuits - Typical Topologies at ITER

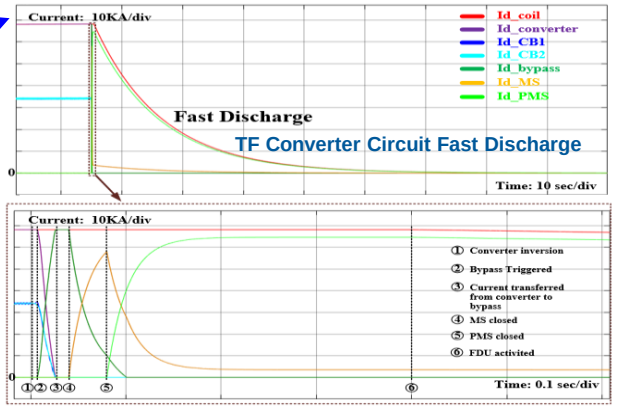
TF Power Converter Circuit



CC: Correction Coil
CS: Central Solenoid
PF: Poloidal Field
TF: Toroidal Field
VS: Vertical Stability

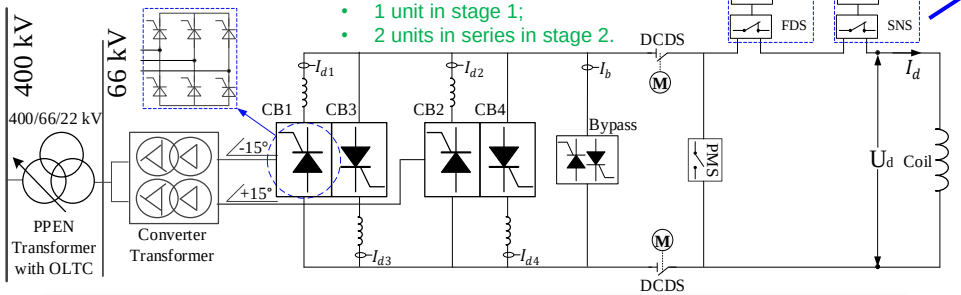
FDU: Fast Discharge Unit
FDR: Fast Discharge Resistor
FDS: Fast Discharge Switch
SNU: Switching Network Unit
SNR: Switching Network Resistor

CB: Converter Bridge
DCDS: DC Disconnector
DCES: DC Earthing Switch
MS: Make Switch
PMS: Protective Make Switch

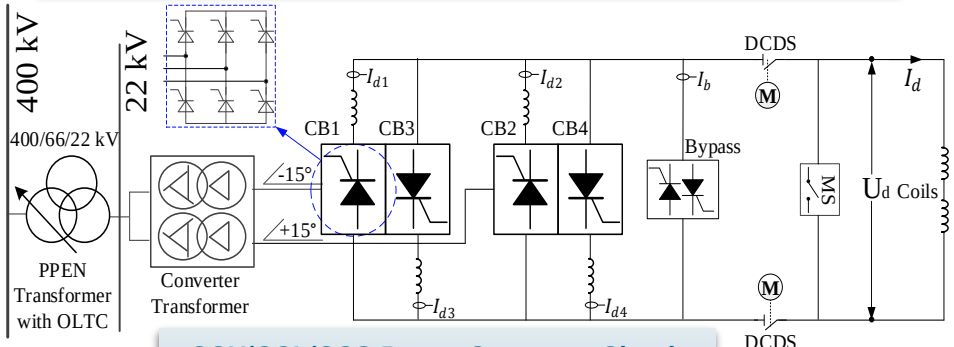


PF1/PF6/CS2U/CS2L/CS3U/CS3L Power Converter Circuit:

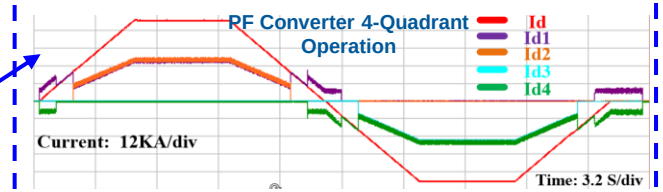
- 1 unit in stage 1;
- 2 units in series in stage 2.

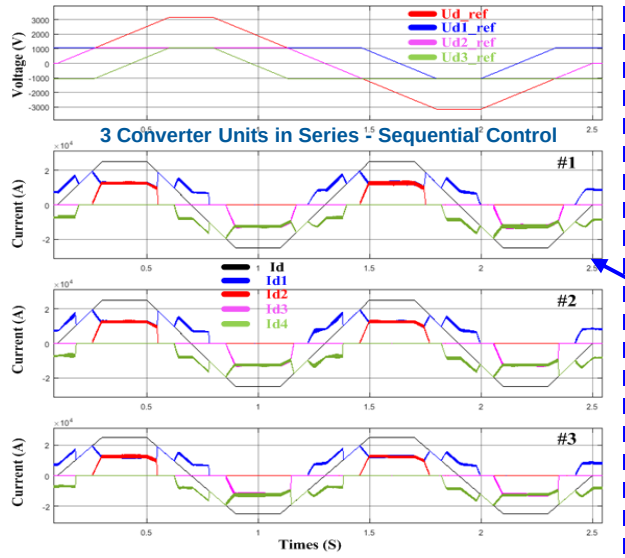


Stage 1 PF1/PF6/CS2U/CS2L/CS3U/CS3L Power Converter Circuit

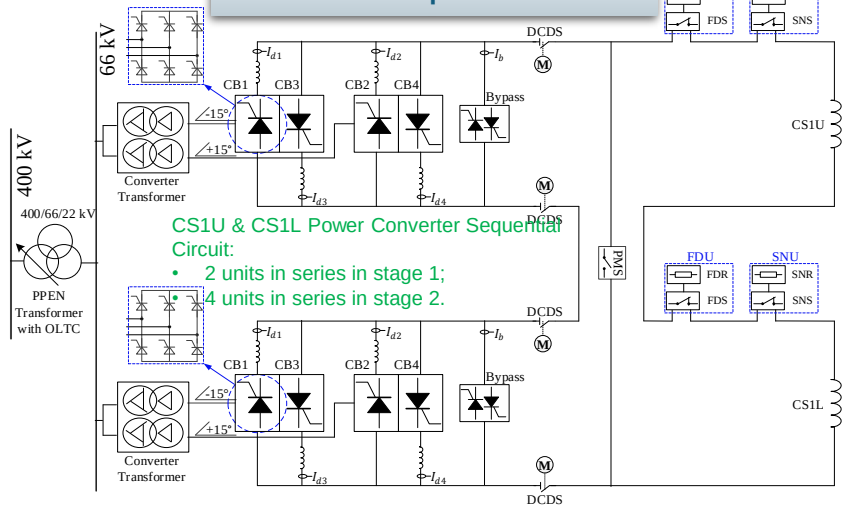


CCU/CCL/CCS Power Converter Circuit



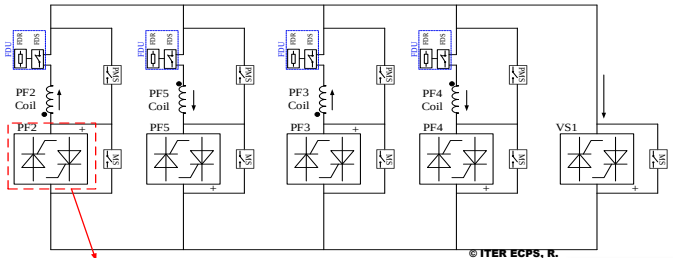


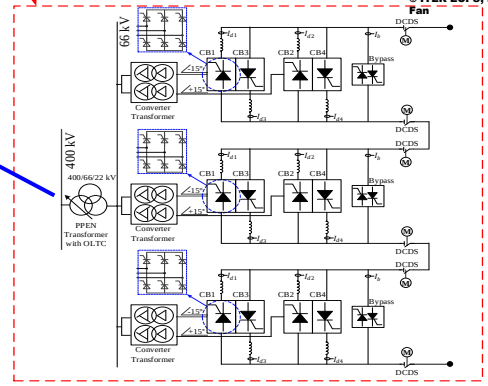
Stage 1 CS1U & CS1L Power Converter Sequential Circuit



CS1U & CS1L Power Converter Sequential Circuit:

- 2 units in series in stage 1;
- 4 units in series in stage 2.





PF2-5 and VS1 Interconnected Power Converter Circuit

PF2-5 Converters:
- 3 units in series.

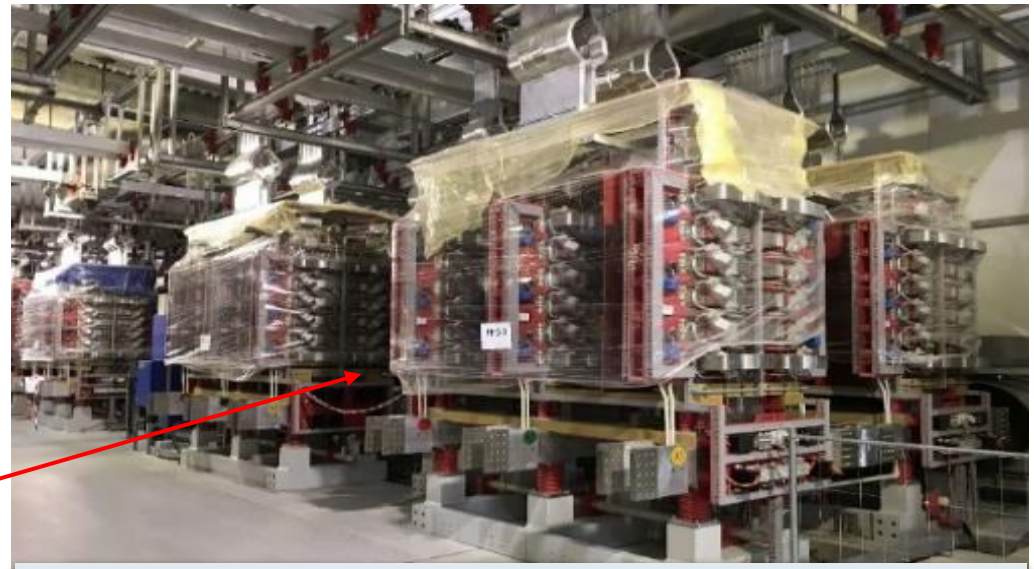
VS1 Converters:
- 2 units in series in stage 1;
- 6 units in series in stage 2.



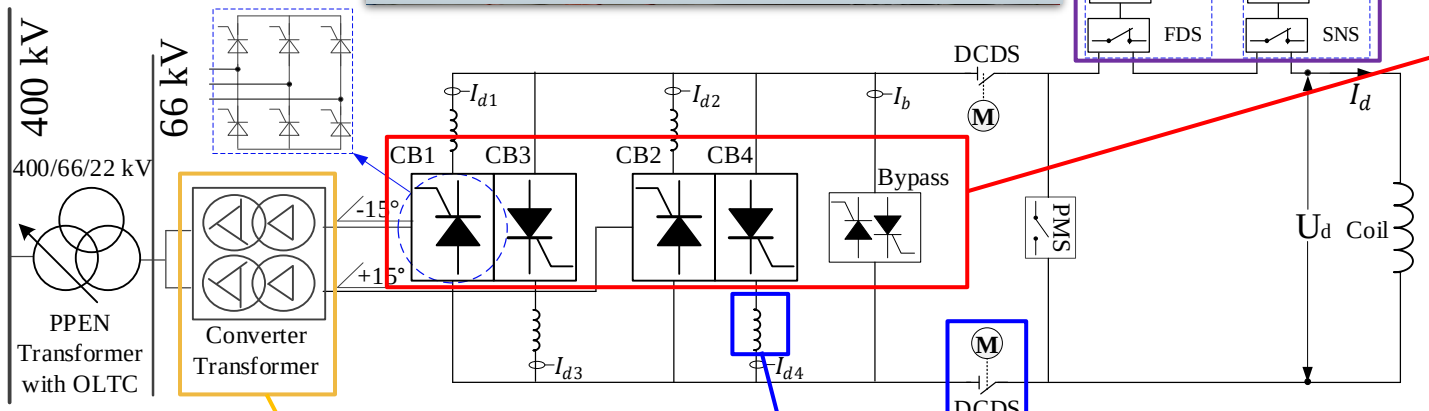
Local Cubicles



DC Switches



Converter Bridges and Bypass





Converter Transformer



DC Reactor, DCDS and DCES

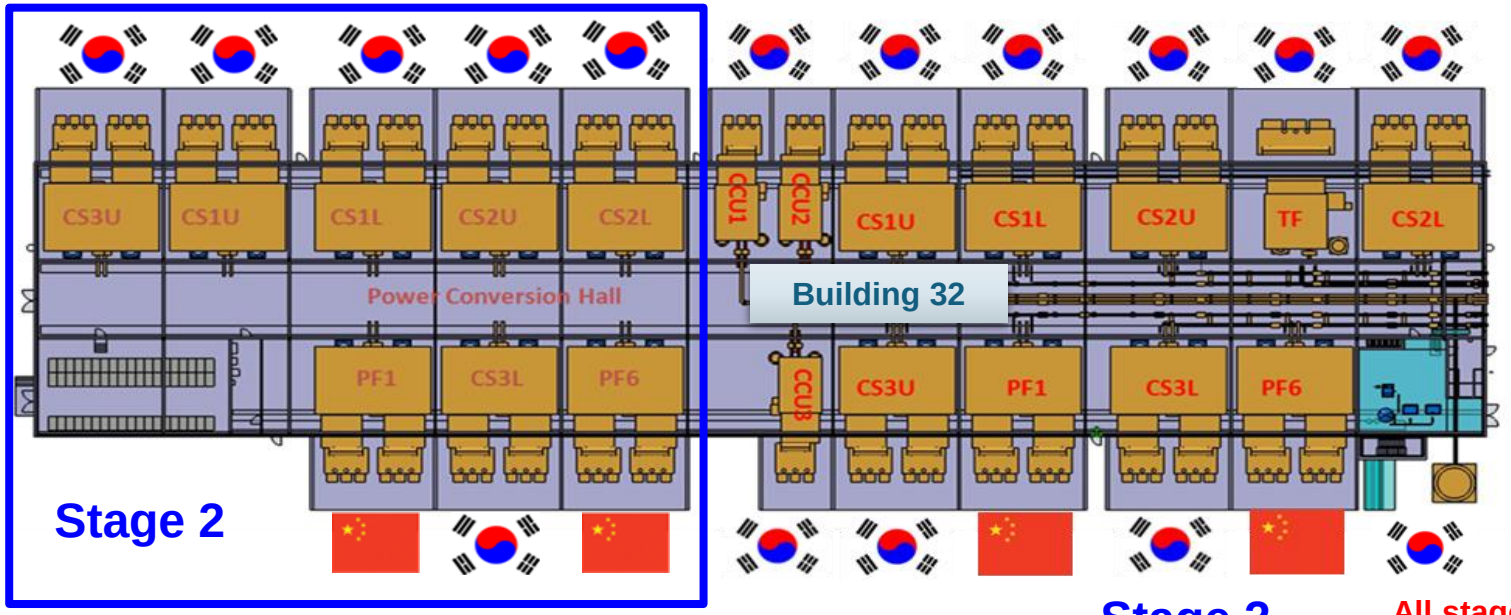


Cooling Water System



Dummy Load

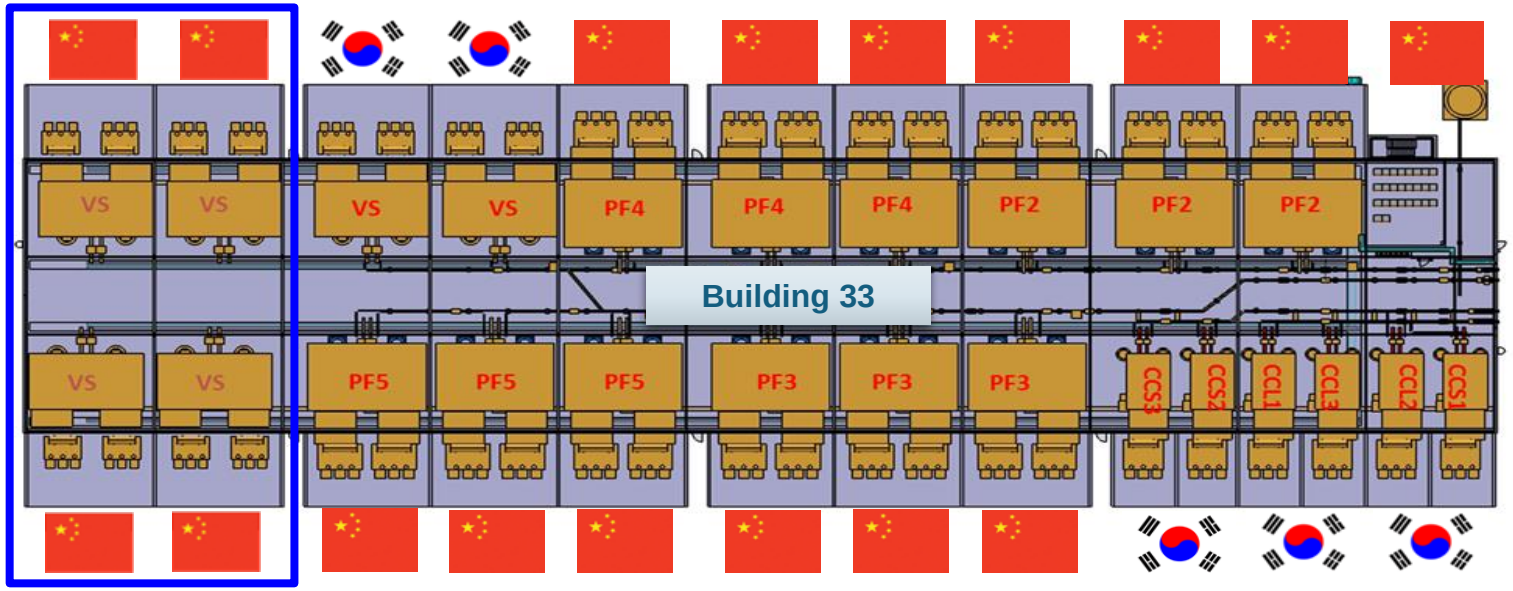
1.3 Power Converter Circuits - One Typical Configuration



Parameters	TF converters	CS converters	CCU/L converters
AC input voltage, kV	66	66	22
Rated DC current (continuous duty), kA	±68	±45	±10
Rated DC voltage (on-load), kV	±0.65/0.16	±1.05	±0.085
Voltage response time, ms	40	40	40
Quantity (stage 1), units	1	6	6
Quantity (stage 2), units		**6**	

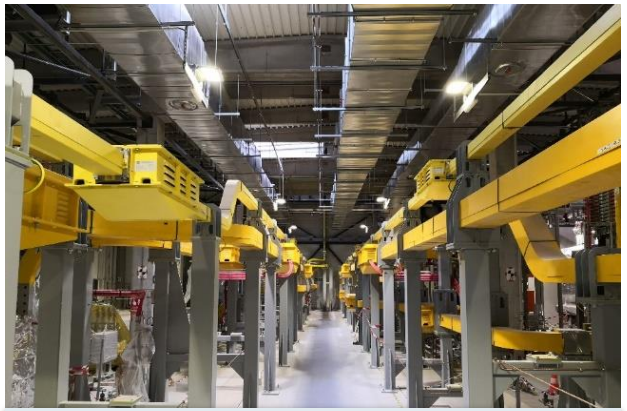
All stage 1 Power Converters were installed by Italian Companies.

Parameters	PF converters	VS converters	CCS converters
AC input voltage, kV	66	66	22
Rated DC current (continuous duty), kA	±55	±22.5	±10
Rated DC voltage (on-load), kV	±1.05	±1.05	±0.3
Voltage response time, ms	40	20	40
Quantity (stage 1), units	14	2	3
Quantity (stage 2), units	**2**	**4**	



1.3 Power Converter Circuits – AC/DC Power Converters

DC Busbars



DC Busbars

PF/CS DC Switches

TF DC Switches



FDU Main Circuit Breaker

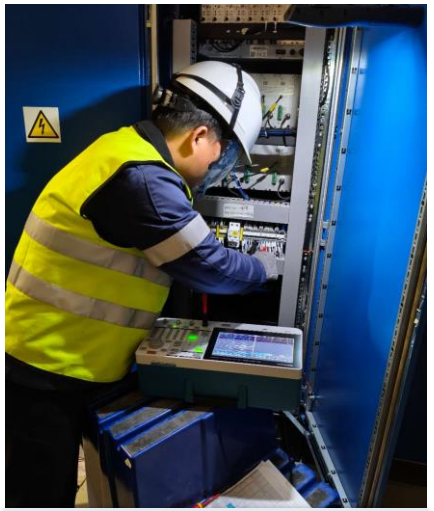
- Approximately **320,000 components** are being installed.
- Approximately **10 km DC Busbars**.
- **120 DC Switches** rated up to 70 kA.

1.3 Power Converter Circuits – DC Switches and Busbars



Regulatory inspection

Regulatory inspection and punch list resolution



Low Voltage test



Light Load test



Safety – Fire drill before energization

High Voltage test started with 66kV line and Converter Transformer first energization

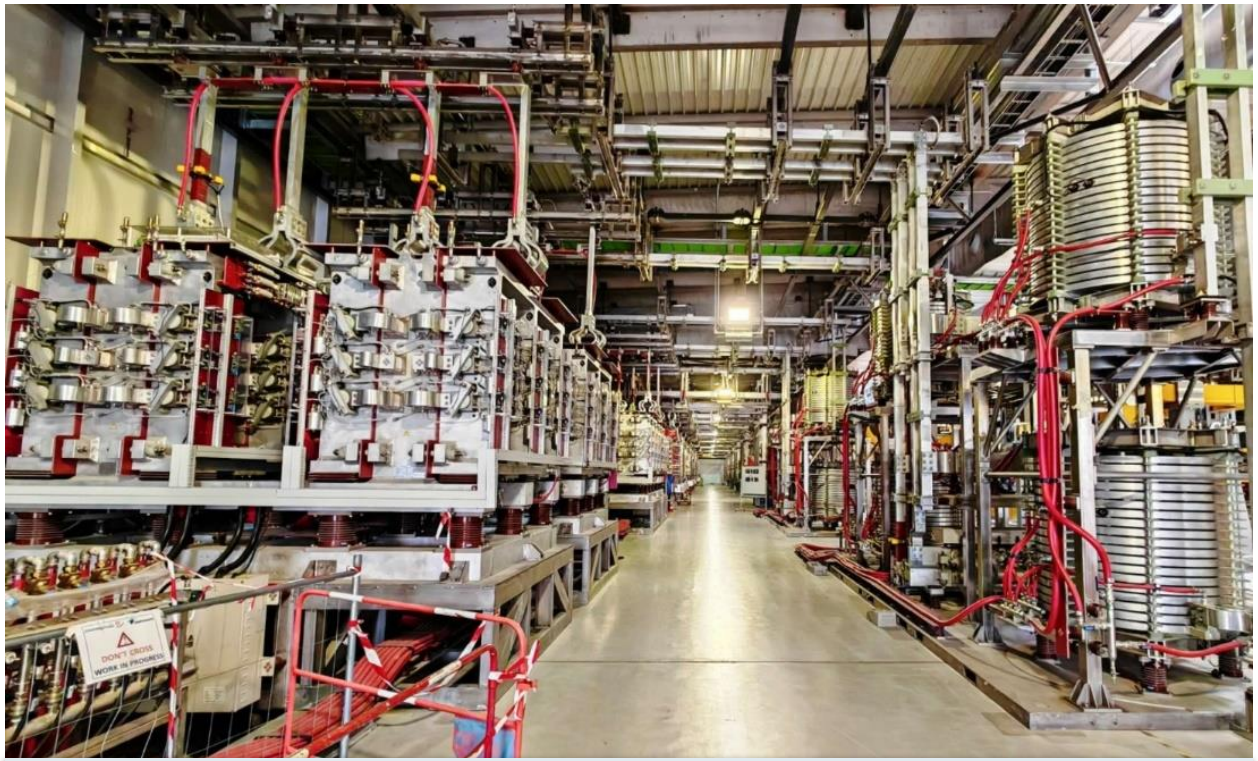


Temporary control room for Converter High Voltage functional test

1.3 Power Converter Circuits – Commissioning Sequence



Stage 1 AC/DC Power Converters from CNDA



Stage 1 AC/DC Power Converters from KODA

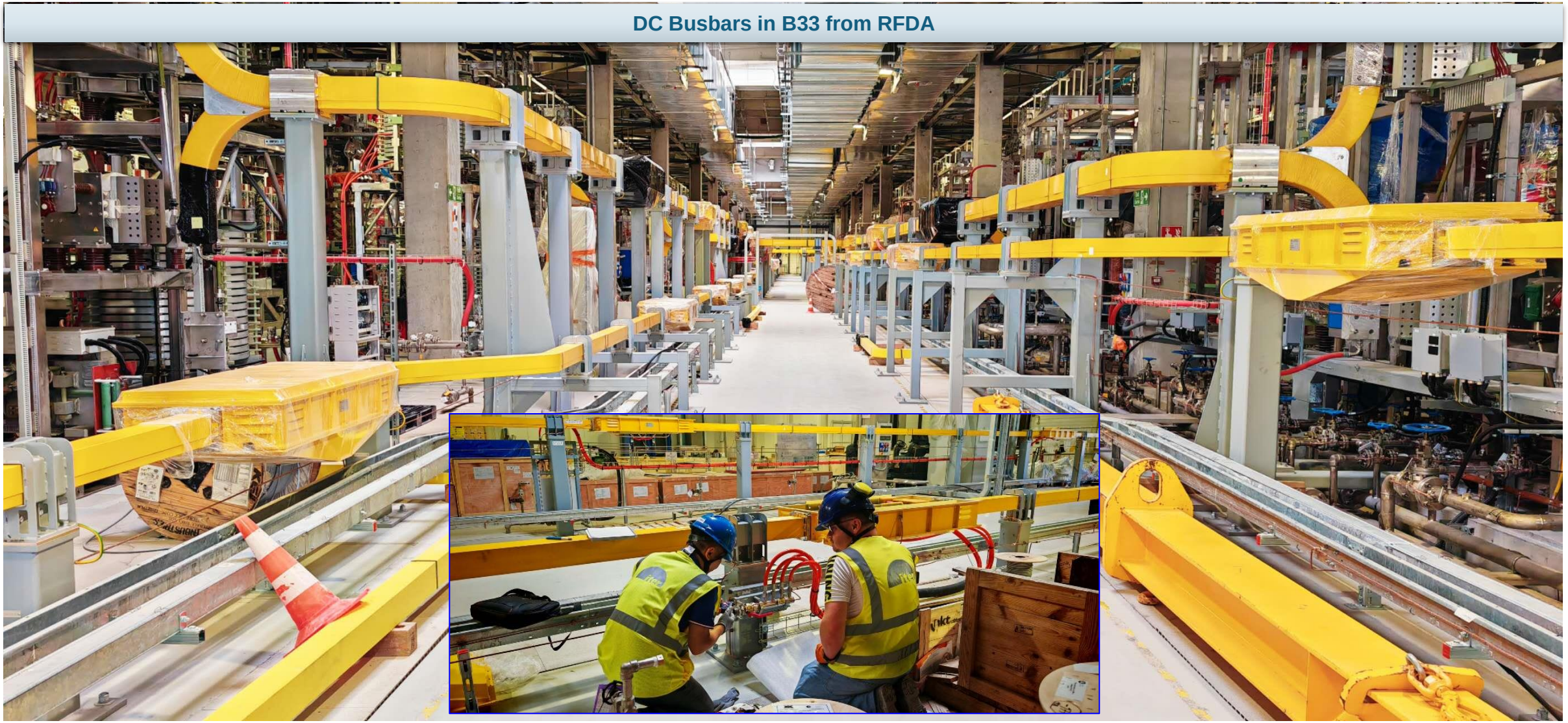
Commissioning of PF Power Converters by ASIPP – CNDA In-Kind Contribution

- After approximately 17 months of work since 17 Sep. 2024, the Low Voltage (LV) commissioning of the 14 stage 1 PF Power Converters was successfully completed on 12 Feb. 2026. High Voltage (HV) commissioning is progressing safely in phases, with all 14 lines and 5 Converter Transformers energized at 66kV.

Commissioning of TF/CS/VS1/CC Power Converters by DAWONSYS - KODA In-Kind Contribution

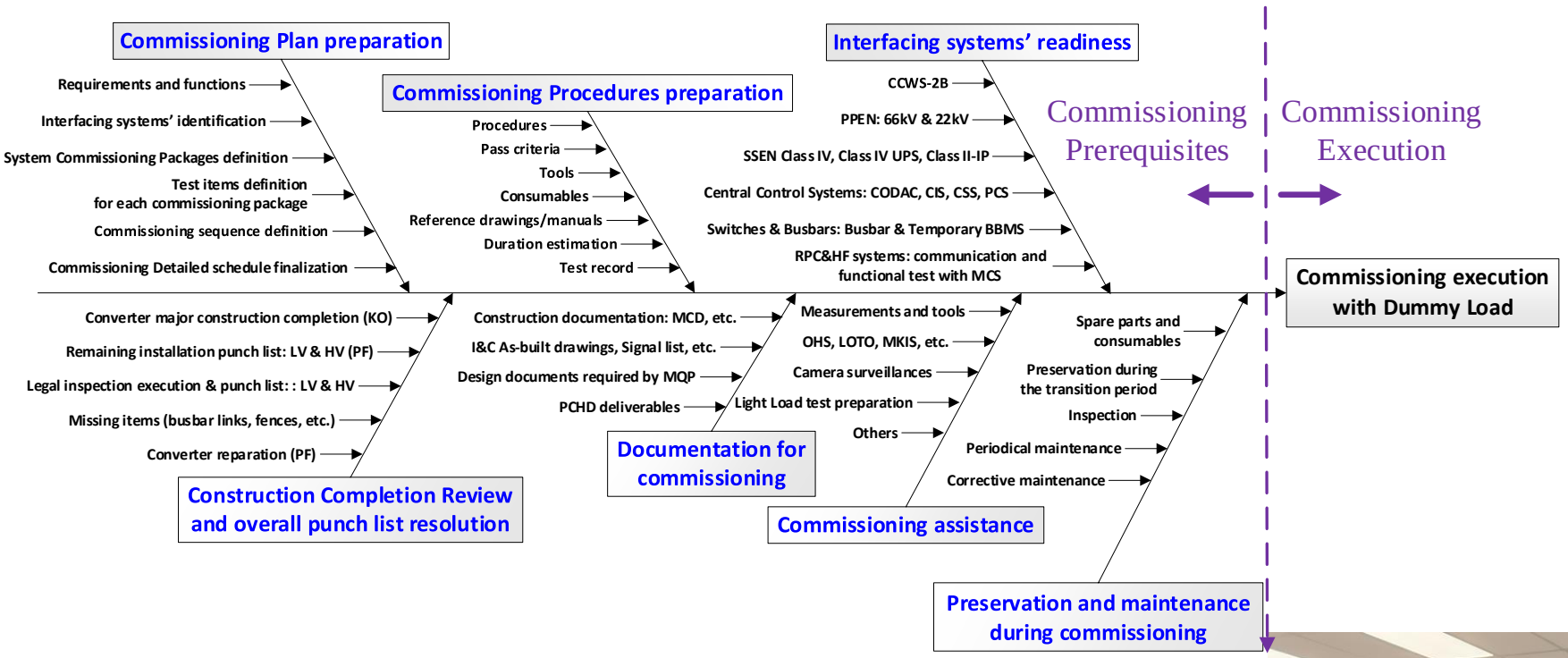
- After approximately 16 months of work since 19 Dec. 2024, the low-voltage commissioning of the 18 TF/CS/VS1/CC Power Converters was complete as of 21 Apr. 2026. The remaining HV commissioning punch-list items are being resolved.

DC Busbars in B33 from RFDA



Commissioning of DC Busbars in B32 & B33 by IO - RFDA In-Kind Contribution

- As of May 2026, the DC Busbar Monitoring System in B32 and B33 had been tested and was ready for the Power Converter HV tests..



Management challenge

- With ITER activities accelerating, multiple international stakeholders work in parallel in the same area for installation, commissioning, etc.

Close collaboration with a systematic roadmap among Domestic Agencies (DA), Suppliers, Contractors, and ITER Organization.

Technical challenges

- Unique and complex operation and protection functions.
- Majority and variety of components are bespoke.
- Tremendous physical and functional interfaces.

The Hardware-in-the-Loop (HIL) testing approach is being widely used to address technical challenges, mitigate risks, train engineers, and enhance the reliability of commissioning and operation of the large Ex-Vessel Coil Power Supply Systems.



The HIL test platform is being developed by integrating real controllers from different suppliers

1. ITER Ex-Vessel Coil Power Supplies (ECPS) Introduction and Commissioning.

1.1 ITER ECPS Overview.

1.2 Stage 1 Reactive Power Compensation and Harmonic Filtering (RPC & HF) Systems.

1.3 Superconducting Coil Power Converter Circuits.

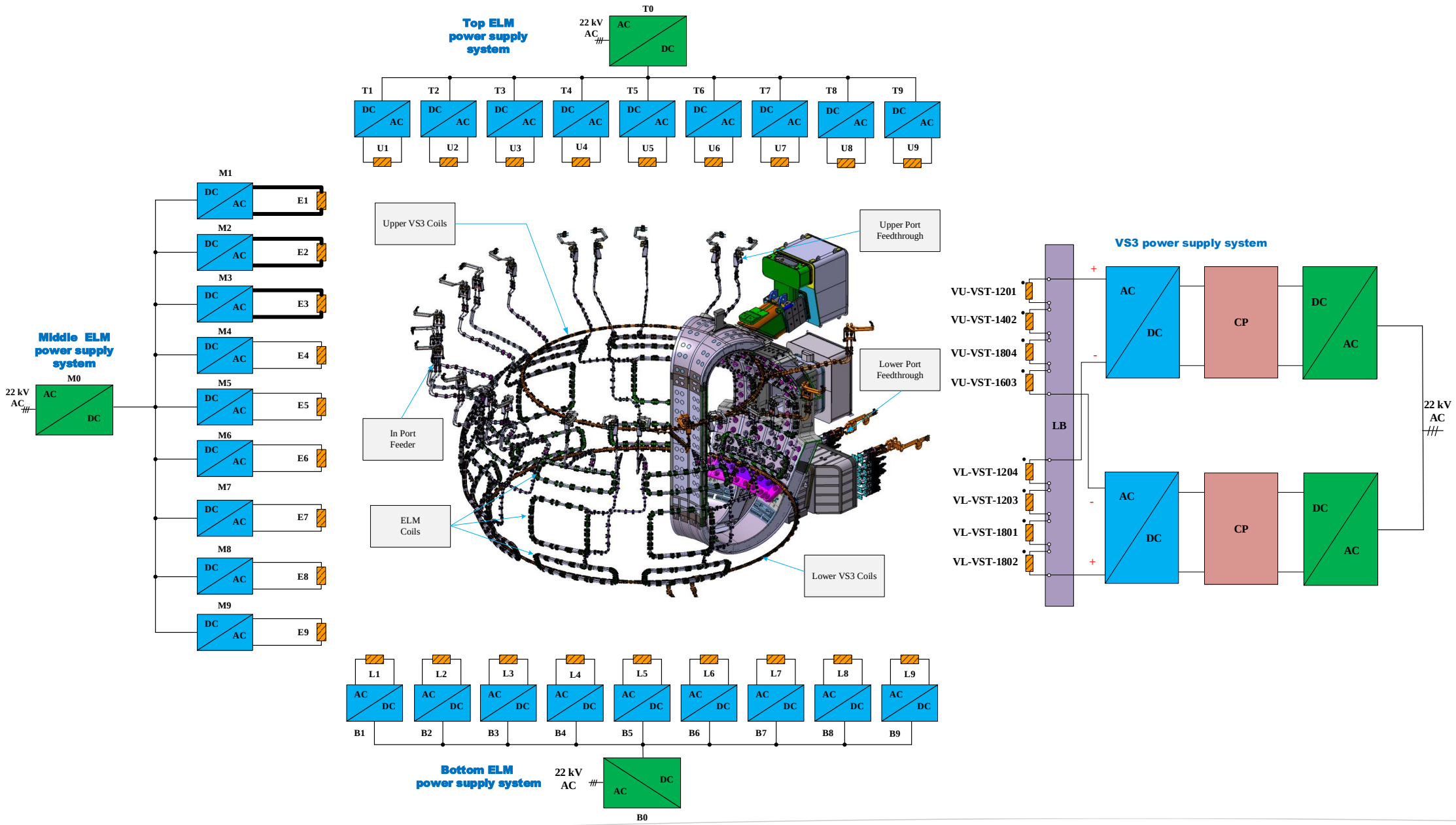
2. ITER In-Vessel Coil Power Supplies (ICPS) Introduction and Future Development.

2.1 ITER ICPS Overview.

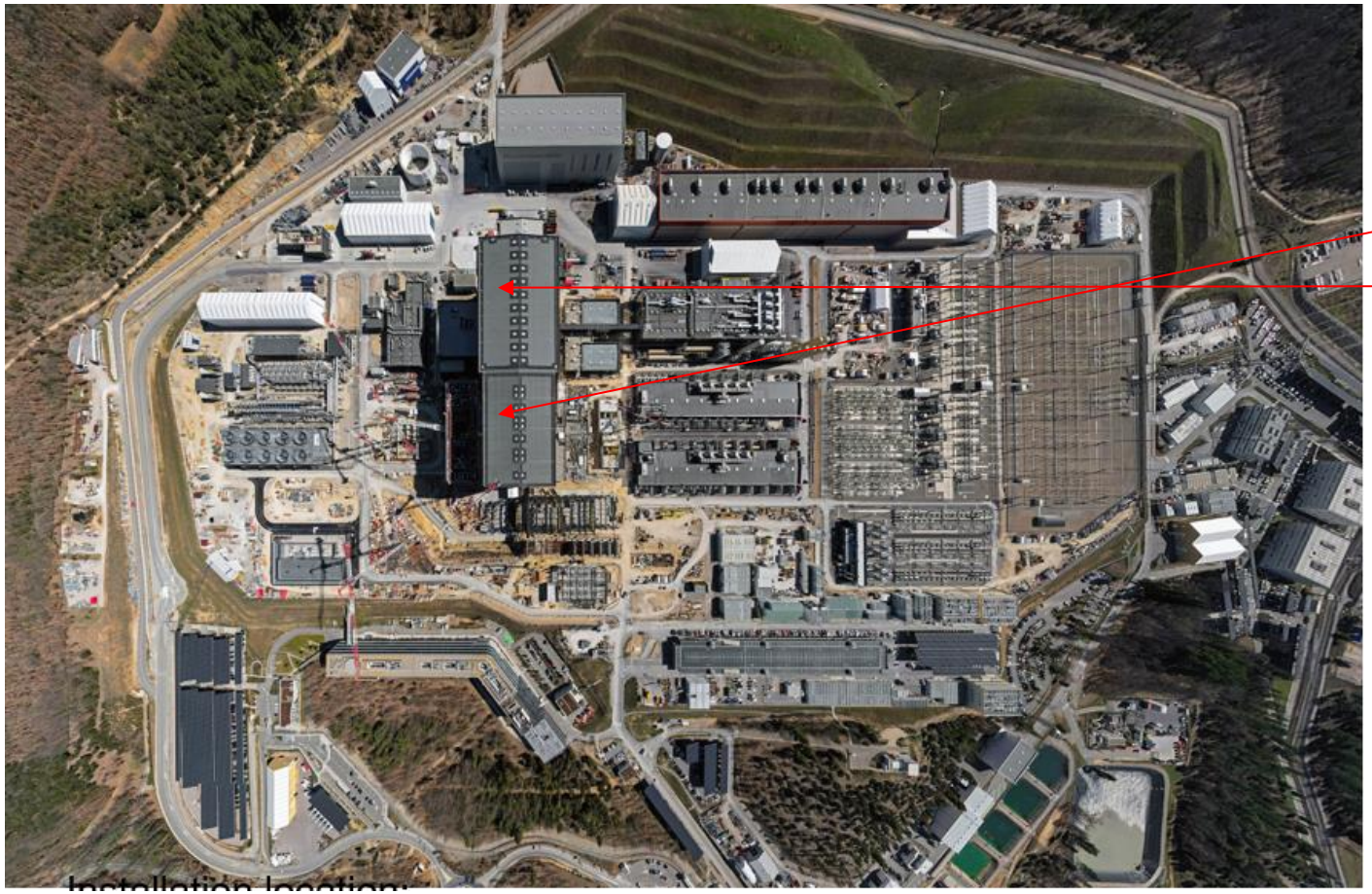
2.2 Edge Localized Mode (ELM) Power Supplies.

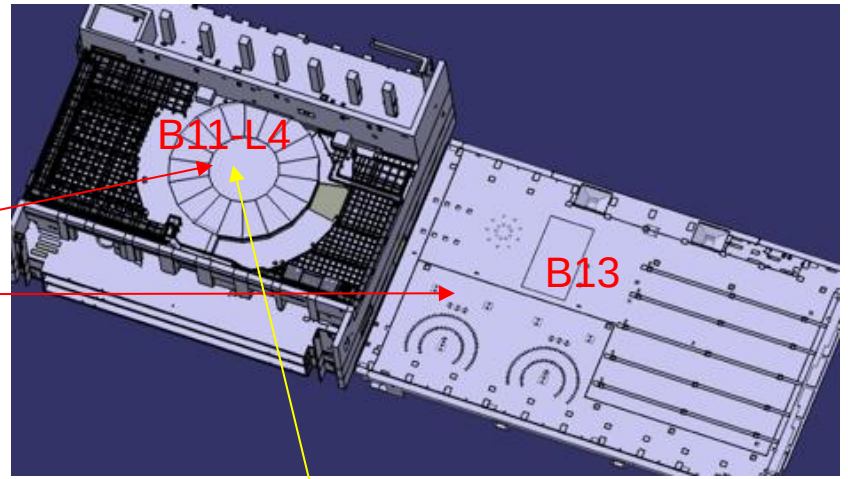
2.3 Vertical Stability 3 (VS3) Power Supply.

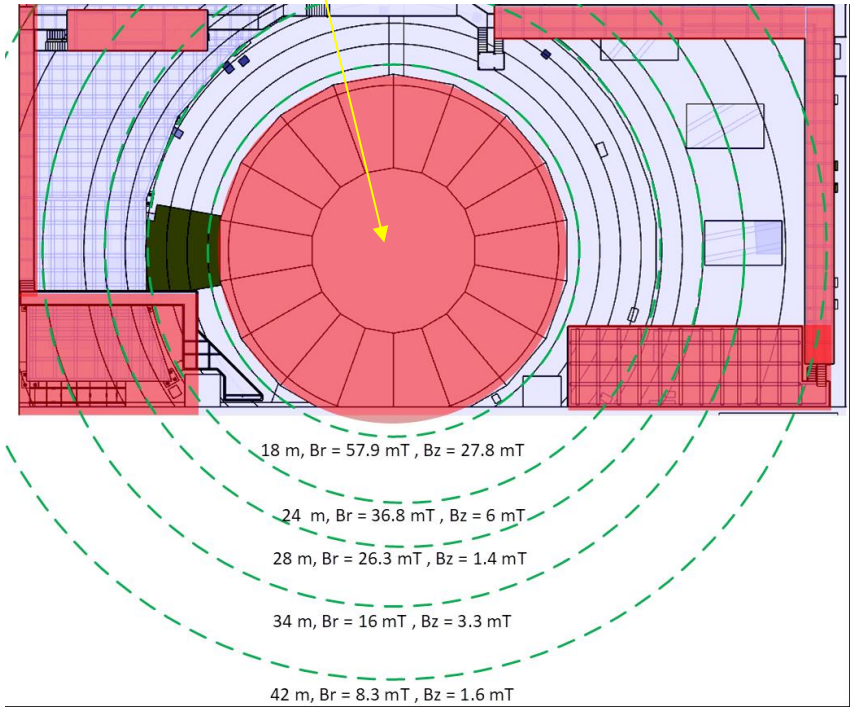
2.4 IO Static Magnetic Field (SMF) Test Facility.



2.1 ITER ICPS Overview - System Level Configuration

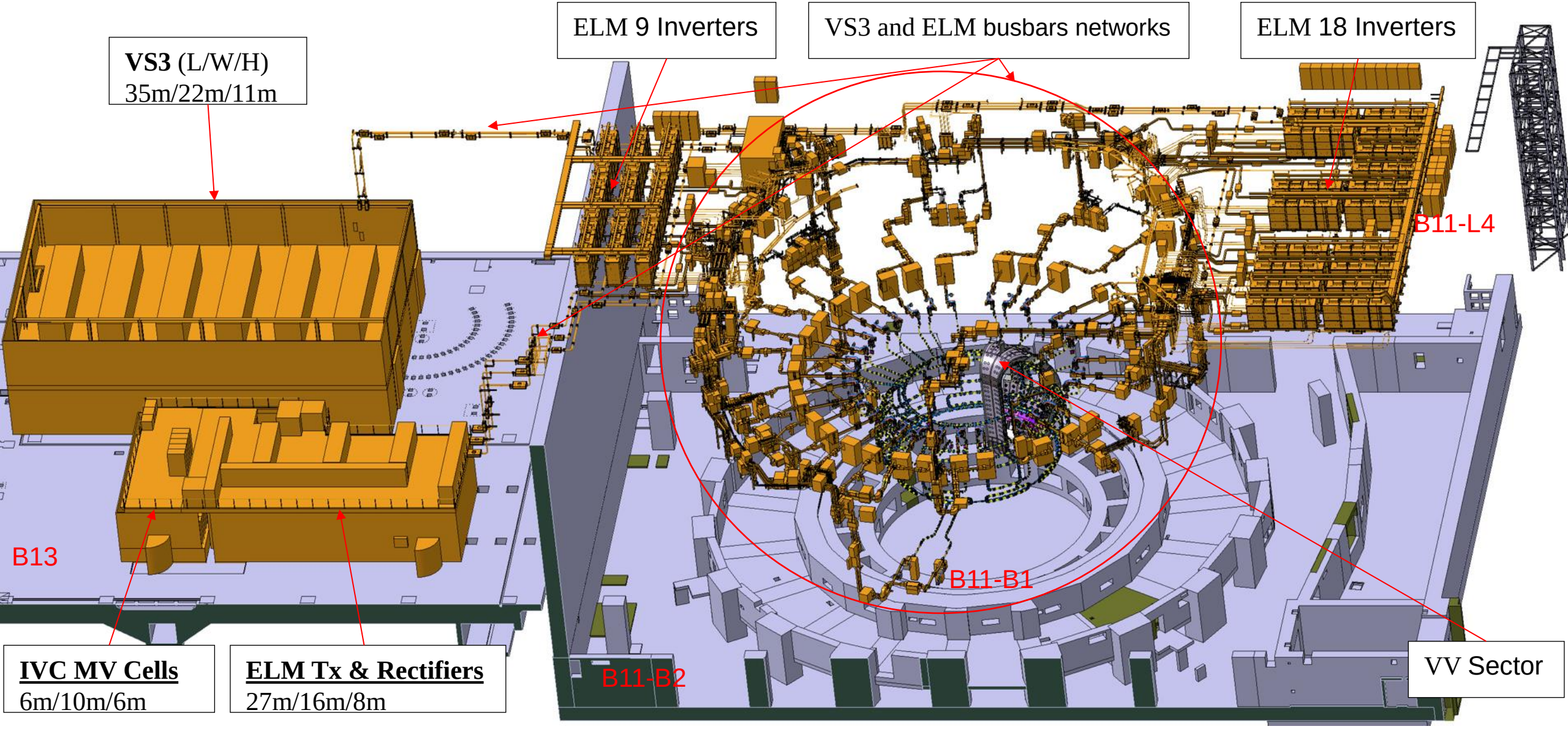






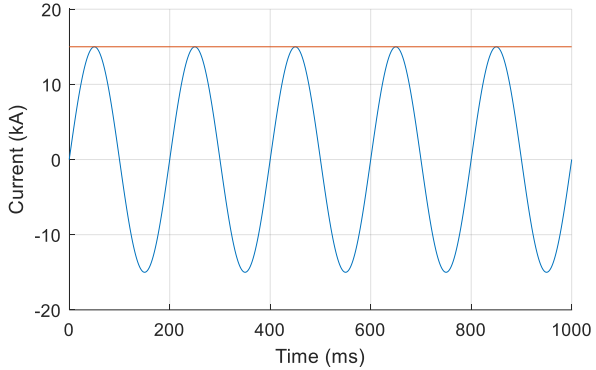
Location: B11-L4 (Tokamak Building Level 4) and B13 (Assembly Building)

Magnetic field: 40mT on the radius of 24m of B11-L4. lower than 5mT in B13

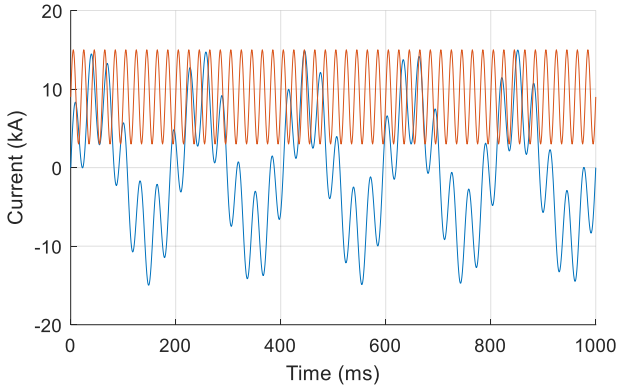


2.1 ITER ICPS Overview - Layout

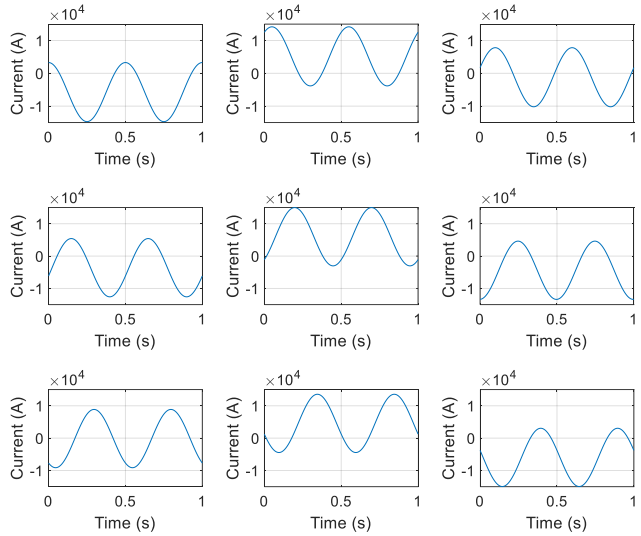
ELM dc or ac



ELM ac + RWM (Resistive Wall Mode) ac

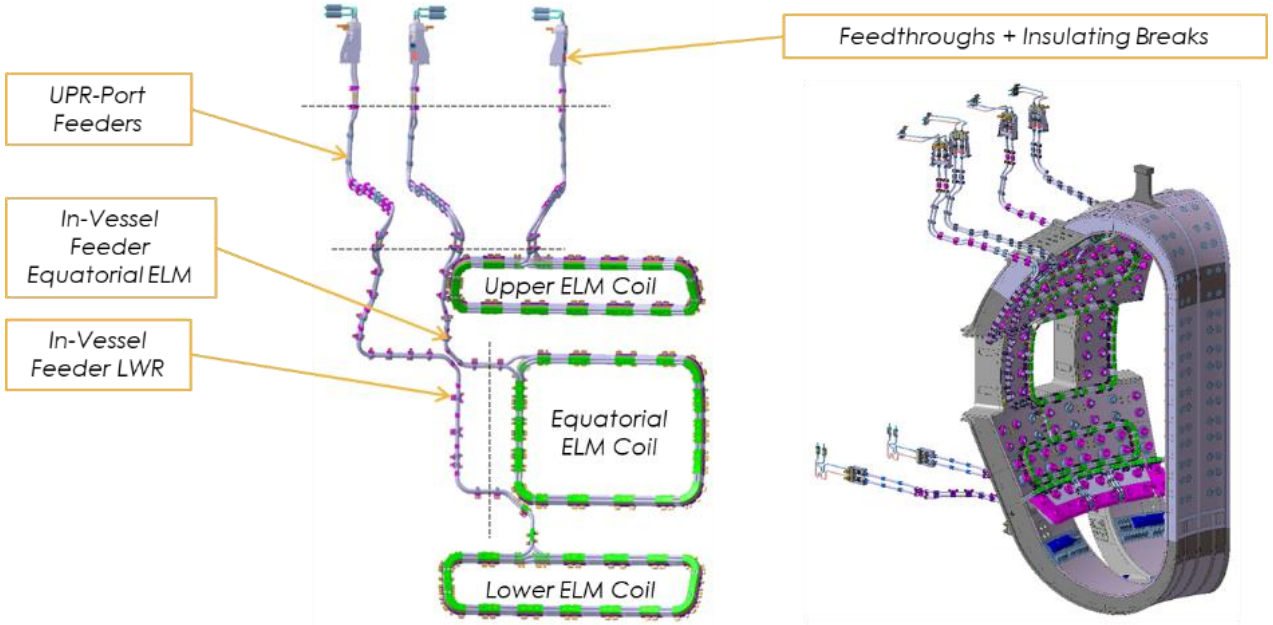


ELM ac + EF (Error Field) dc



$$i_{ELM}(t) = I_{ELM}\cos\{n_{ELM}[\Delta\Phi_k - (\Phi_j - \Phi_{ref})] + 2\pi f_{ELM}t\}$$

$$i_{RWM}(t) = I_{RWM}\cos\{[\Delta\varphi_k - (\Phi_j - \Phi_{ref})] + 2\pi f_{RWM}t\}$$



$$i_{EF} = I_{EF}\cos\{n_{EF}[\Delta\varphi_k - (\Phi_j - \Phi_{ref})]$$

f_{ELM}: 0 or 1 ~ 5 Hz

f_{RWM} : 5 ~ 50 Hz

$\Delta\Phi_{top} = 66°$, $\Delta\Phi_{middle} = 0°$, $\Delta\Phi_{bottom} = 52°$

$\Delta\varphi_{top} = 66°$, $\Delta\varphi_{middle} = 0°$, $\Delta\varphi_{bottom} = 52°$

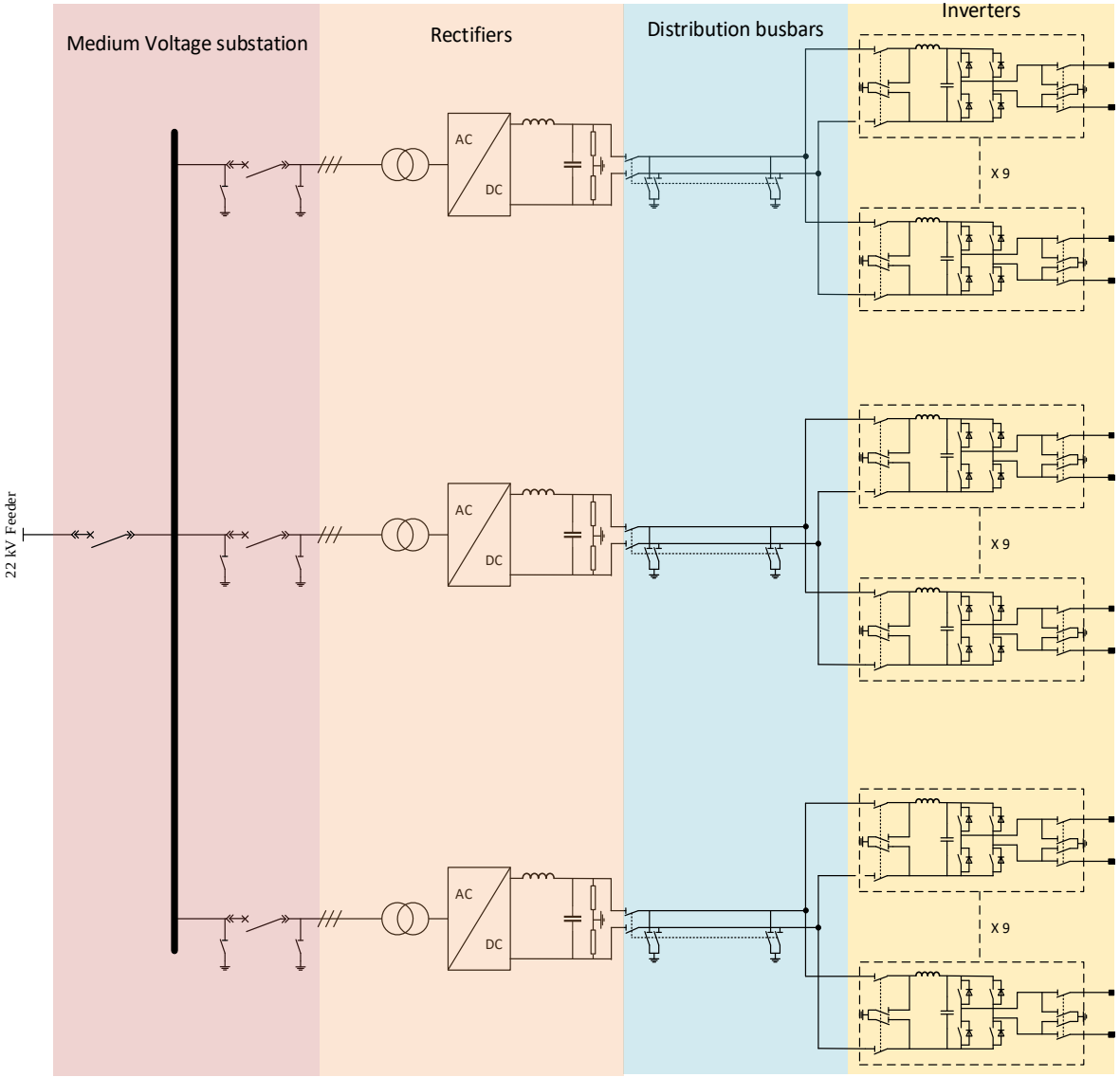
n_{ELM}=3 or 4, n_{EF}=1 or 2

$\Phi_j - \Phi_{ref} = (j-1) \times 40^o$, j =1, ..., 9

Coil Parameters:

- 15kA continuous, 300V.
- Rdc: 2.1-2.6 mΩ.
- Ldc: 178 – 239 uH.

2.2 ELM Power Supplies - Function, Typical Current Waveforms, Main Parameters

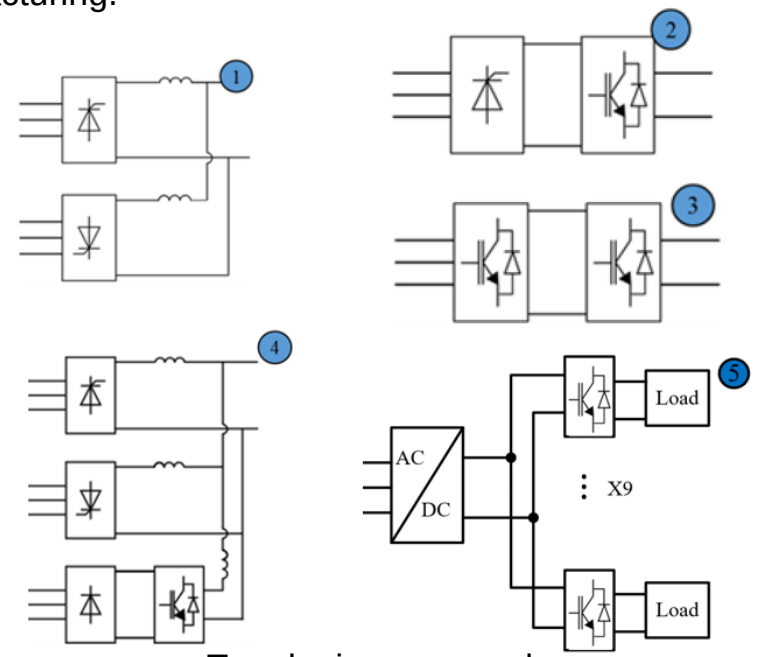


Topology:

- Each group: One IGBT rectifier (~ 6MVA) + nine IGBT inverters(~4.5MVA).
- 22kV transformers and rectifiers placed in B13 (<5mT).
- Each distribution busbar network: 350 V, 15 kA.

Considerations for the selection of topology:

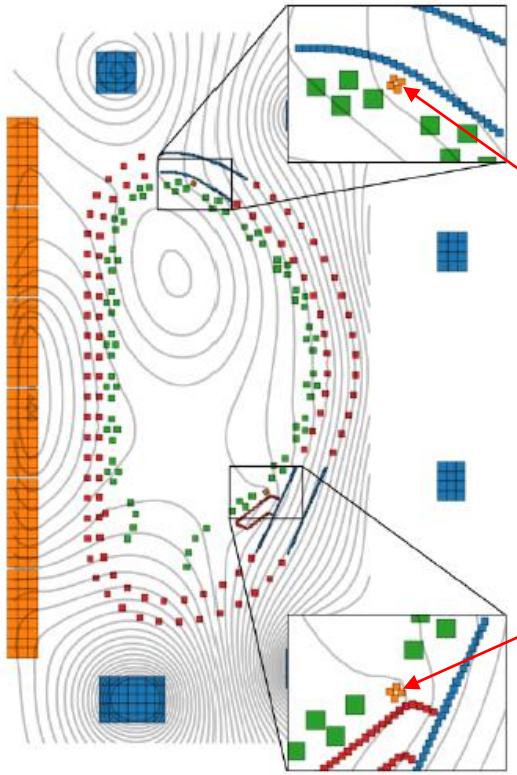
- Cost, mass, size (system level)
- Magnetic field (equipment locating)
- Reactive power at the supply point.
- Low frequency current into the supply.
- Modular design and manufacturing.
- ELM coil unique operation.



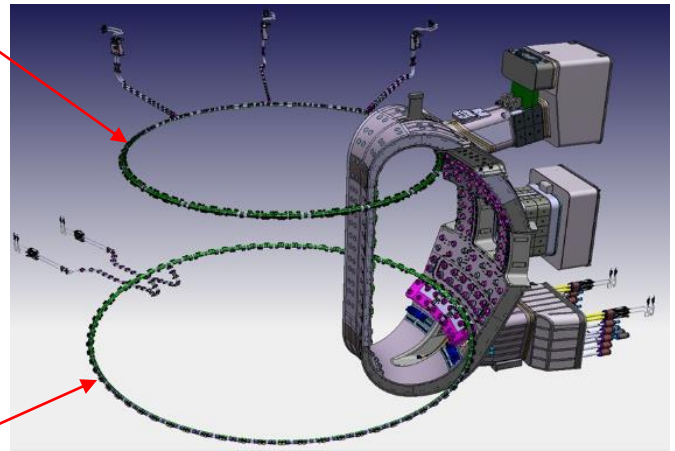
Topologies surveyed

2.2 ELM Power Supplies - Power Conversion Topology Selection and Consideration

- Anti-series connection.
- Control the vertical position of the plasma current.
- Peak current (0.3s) : ±80 kA up to 3 times consecutively every **10s.**
- DC RMS continuous noise current rms : 4 kA.
- ± 2.4kVdc.

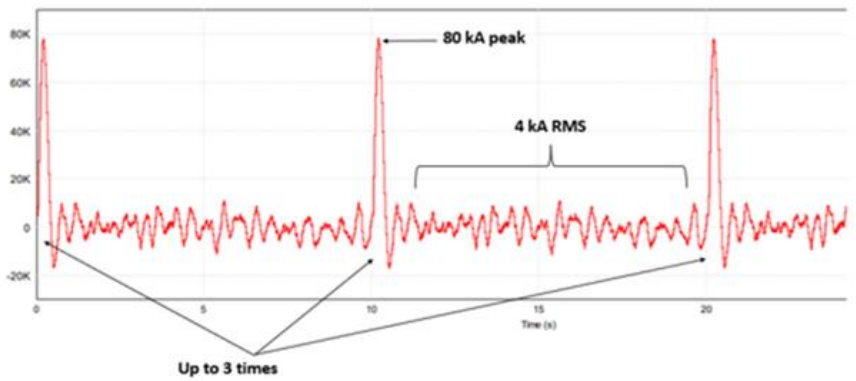


VS Upper coil : 4 Turns



VS Lower coil : 4 Turns

6-turn operation



$$I = I_{vde} + I_{noise}$$

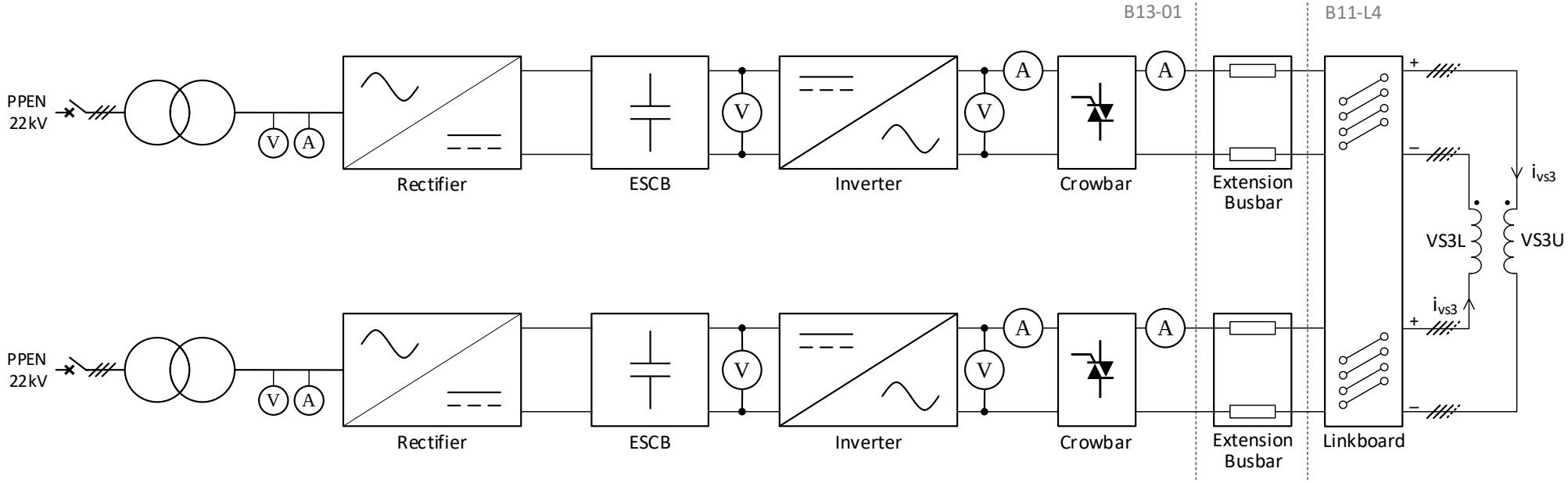
$$I_{vde} = A\left(\varepsilon^{-t/\tau_1} - \varepsilon^{-t/\tau 2}\right)$$

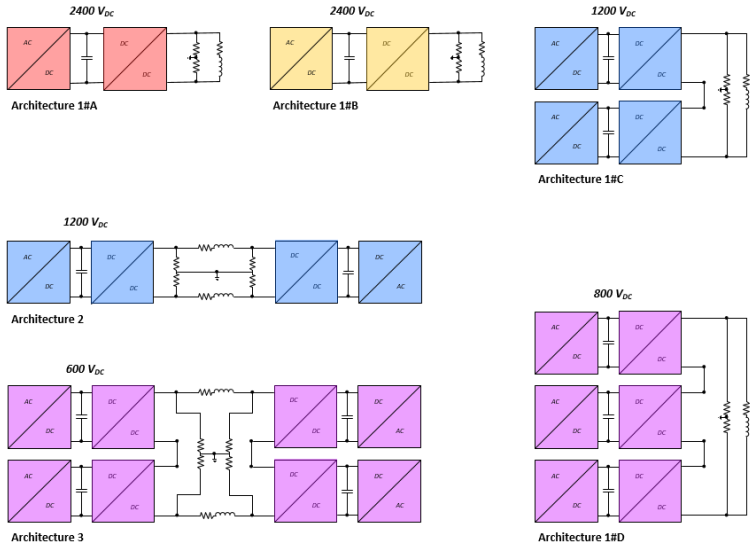
$$I_{noise} = I_{noise_rms}\sqrt{2}\sin(2\pi ft)$$

A = 99200 A
τ1 = 0.304 sec
τ2 = 0.016 sec
$I_{noise\ rms}$ = 2907 A
f = 30 Hz

Coil + feeder + VV @ operating temperature	DC mΩ / mH	30Hz mΩ / mH
8 turns in anti-series	14.0 / 1.33	49.7 / 0.493

2.3 VS3 Power Supply - Function, Typical Current Waveforms, Main Parameters





Topologies surveyed

Topology:

- "Push-pull" to split the PS in two identical halves.
- Each half: IGBT 3.5MVA charger + 12.5MJ Energy Storage + 96MVA IGBT inverter.

Considerations for the selection of the topology:

- Cost, mass, size
- Voltage stress on the insulation of the coil and the busbars.
- Modular design and manufacturing.
- Full power testing in factory.
- Safety and protection.
- 1700V IGBT for the rectifier and inverter.

2.3 VS3 Power Supply - Power Conversion Topology Selection and Consideration

At ITER premises, a Static Magnetic Field Laboratory has been set up to test and qualify all materials to be installed in the reactor and exposed to Static Magnetic Field. It aims to fulfil not only the IO internal demand, but also requests coming from customers willing to test and qualify their products for the Fusion Global Market .

The Laboratory is unique in Europe for its technical features, and it is providing:

- Static Magnetic Field to test equipment from 0 to 275mT with stability and linearity of 5% in all axis without limitations.
- Coil water cooled and stabilized 20±3 °C for better field stability.
- A testing capacity of 1m^3 (max D 1mx1mx1m) and 300Kg in automatic mode (Rail#1) and 1000Kg in manual mode (Rail#2).
- The Laboratory has achieved in 2026 the ***Accreditation ISO 17025 - FR COFRAC*** a seal of quality for its activity.



D'ACCREDITATION

COMITE FRANCAIS

cofrac ESSAIS

Laboratoire SMF (Static Magnetic Field)

Route de Vinon de verdon
13115 Saint-Paul-Lez-Durance

est accrédité
is accredited

par la section Laboratoires
by Laboratory section

selon la norme NF EN ISO/IEC 17025 et les règles d'application du Cofrac sous le numéro

in compliance with ISO/IEC 17025 standard and the Cofrac rules of application under n°

1-7540

Pour : des activités d'essais
For: test activities

Les activités couvertes et la validité de l'accréditation ainsi que les sites concernés sont précisés dans la ou les attestation(s) en vigueur qui lui a (ont) été délivrée(s) (visible sur www.cofrac.fr).
Durant cette période, l'organisme s'engage à respecter à tout moment les exigences de l'accréditation.

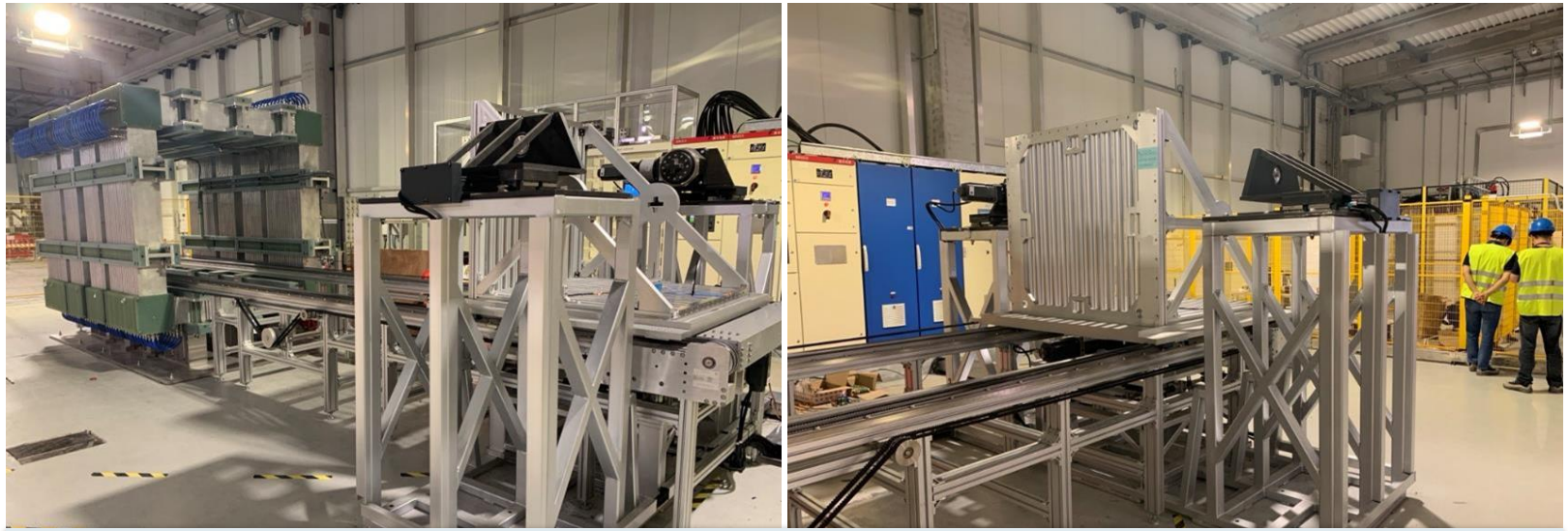
The activities covered and the validity of accreditation as well as concerned sites are stipulated in the accreditation certificate(s) in force which has (have) been issued with it (visible on www.cofrac.fr).
During this period, the organisation undertakes to abide at all times by the requirements of the accreditation.

Le Directeur Général
General Director

Dominique GOMBERT

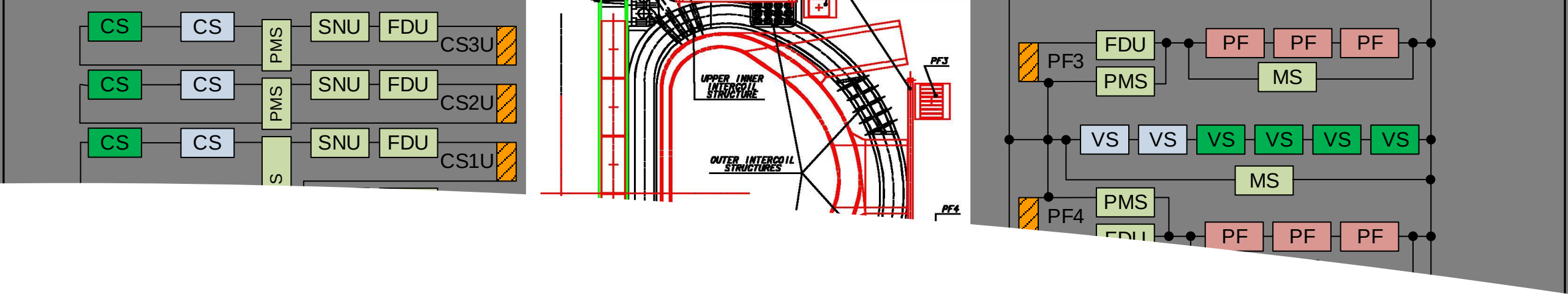
6 – Rév. 03 – Janvier 2019

Accreditation Certificate



Static Magnetic Field test facility

2.4 IO Static Magnetic Field (SMF) Test Facility



Thank you!

iter

china eu india japan korea russia usa