Progress in the ITER Electron Cyclotron H&CD High-Voltage Power Supply System: Architecture, Qualification Process and Commissioning Results

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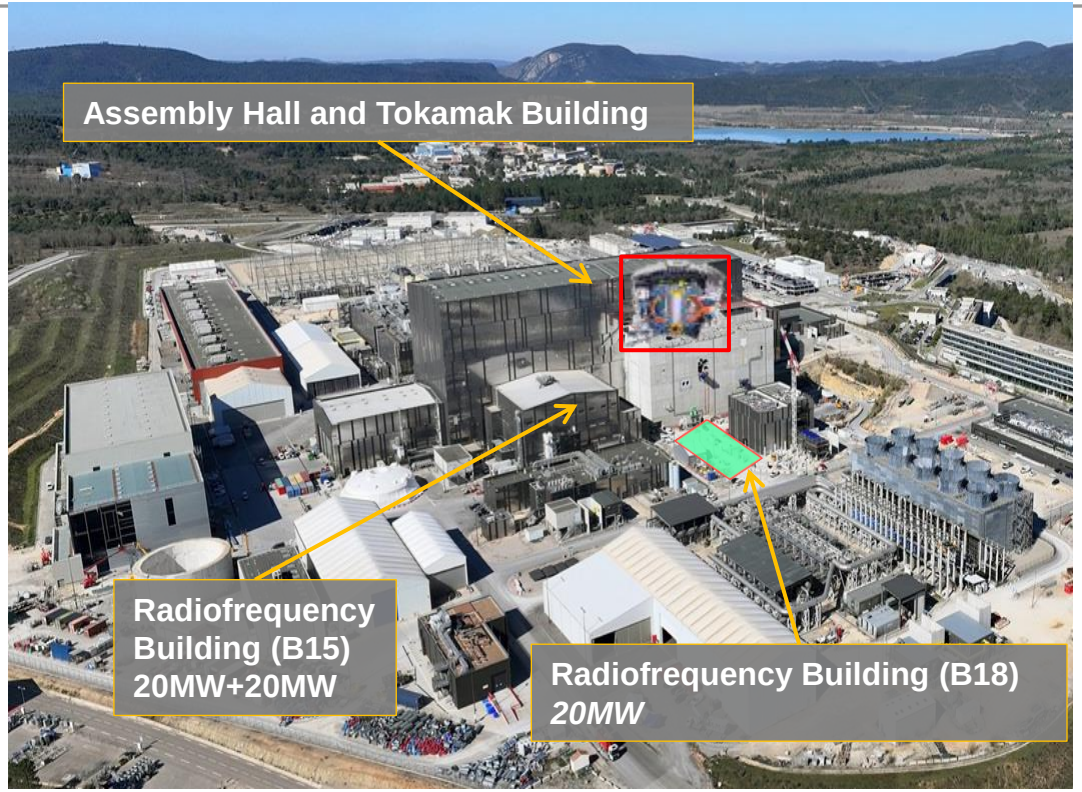
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Why EC Heating System Matters

- EC System Function
  - *Plasma Startup*
  - *Plasma Heating*
  - *Current Drive*
  - *NTM suppression*
  - *Sawtooth control*
- 60 MW Gyrotron RF power to tokamak:
  - 40MW for SRO Phase from B15 cluster ;

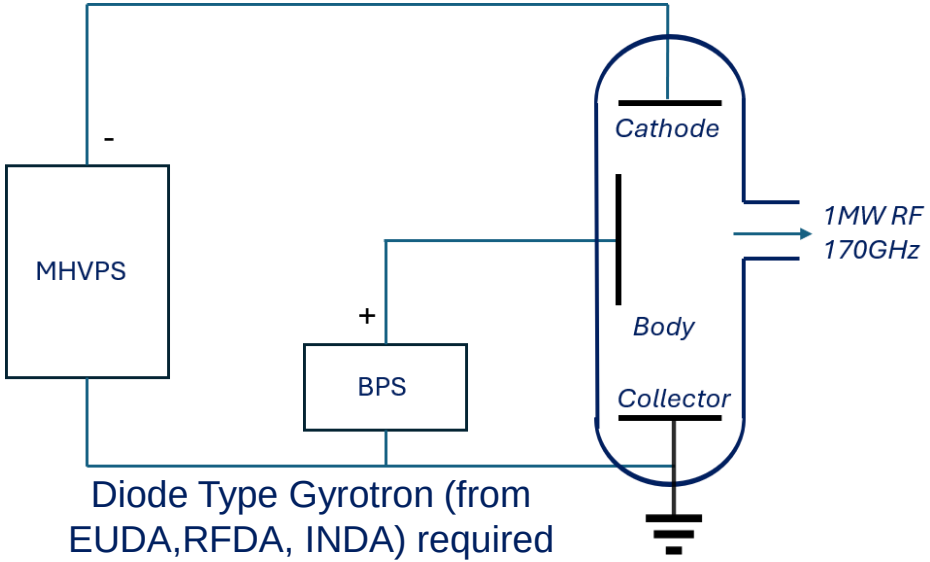
    20MW (South part)
    20MW (North part)
  - 20MW of RF power for DT Phase from B18



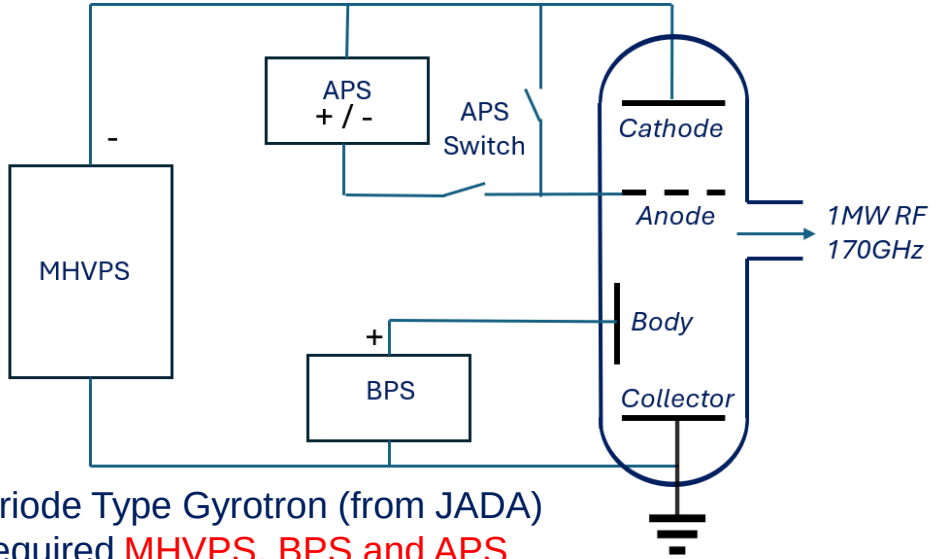
ITER is becoming the largest gyrotron-based RF heating facility ever constructed

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EC HVPS System Overview :- Gyrotron Prospective



Diode Type Gyrotron (from EUDA,RFDA, INDA) required MHVPS and BPS



Triode Type Gyrotron (from JADA) required MHVPS, BPS and APS

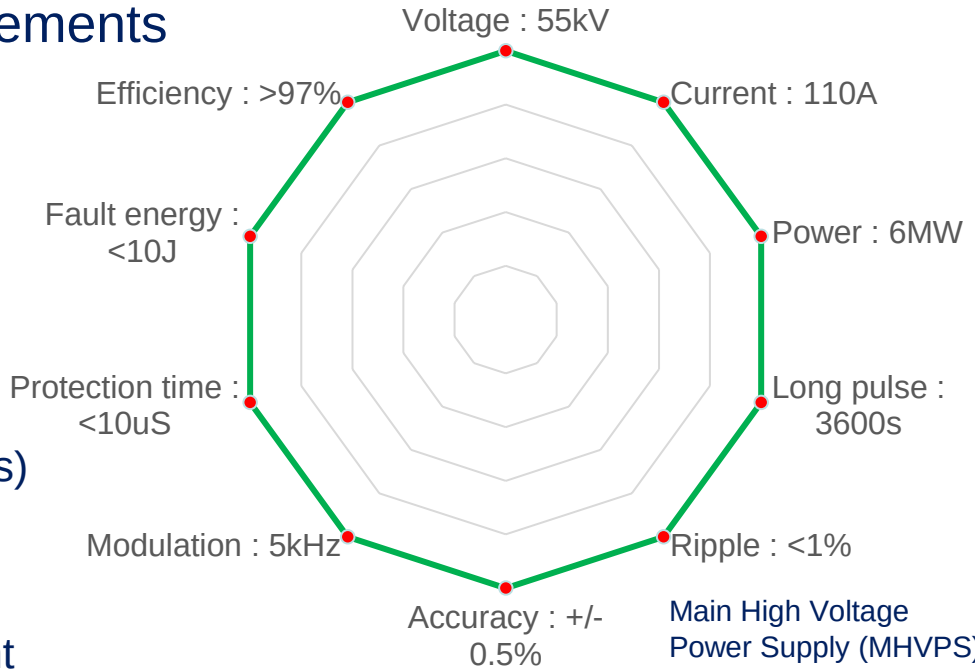
- HVPS technical requirements are governed by the Gyrotron operation requirement
- HVPS performance directly impact the gyrotron output power, efficiency and stability
- RF power deposition inside the plasma need modulating HVPS
- Gyrotron protection should be ensured by HVPS.

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What Makes HVPS Challenging

Gyrotrons (1MW, CW Operation) performance driven by HVPS performance : Impose Strict Power Supply Requirements

- Dynamic Response
- Fast Protection
- Power Density
- Availability
- Scalability
- Control ; Local, Remote (Two Modes)



Main High Voltage Power Supply (MHVPS)

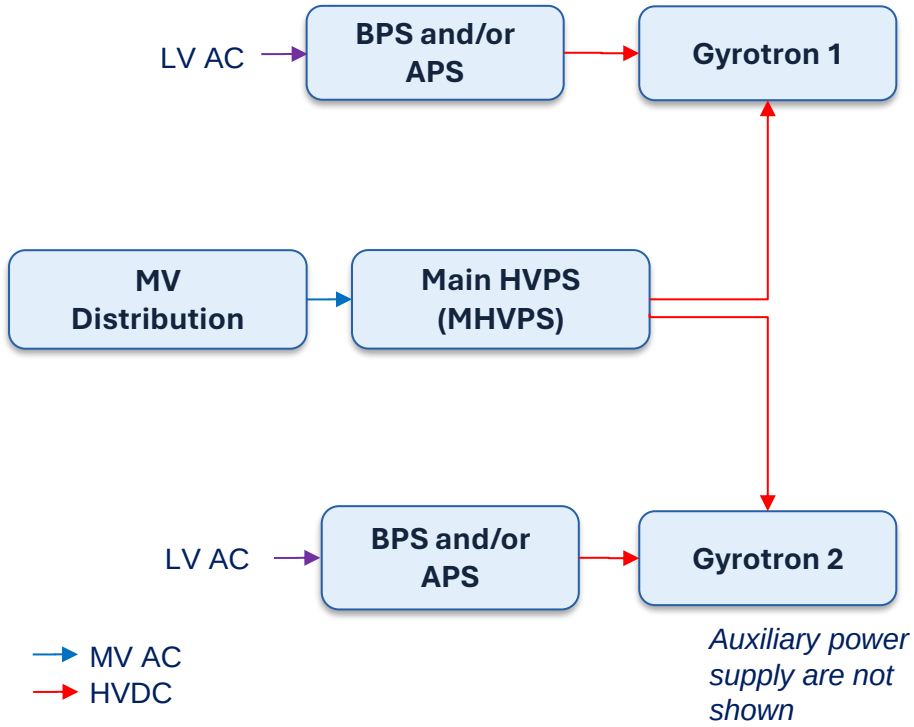
BPS 35kV/100mA and
APS -20kV,+10kV / 600mA
Also have similar performance requirement

HVPS Should Design - Manufacture – Installation and Commissioning should treat for Plant Level System with High Availability for large scale fusion system including scalability

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Overall HVPS Architecture

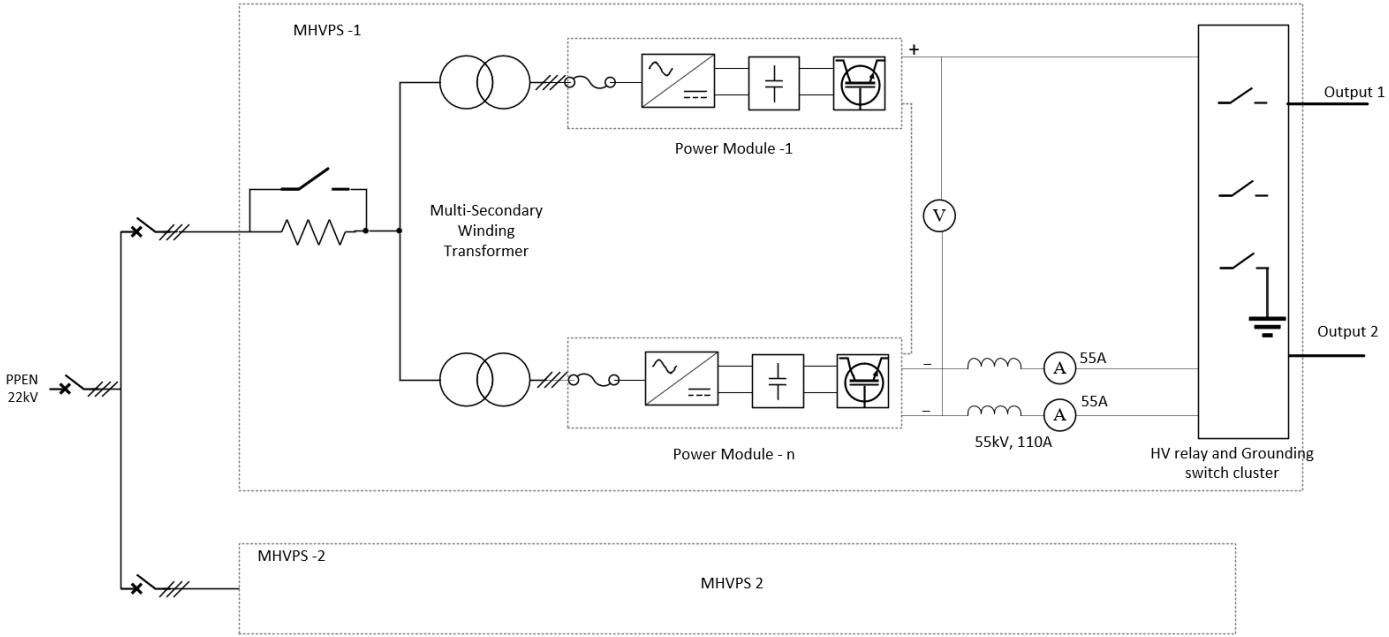
- One complete Power Supply set provides Electrical power for Two Gyrotrons
  - One MHVPS between Two Gyrotrons
  - Trade-off between the loss of 2MW RF power (in case of only one gyrotron has fault) to the CAPEX, Nominal rating, floor space and cooling requirement
  - APS and BPS are implemented one-per-gyrotron basis for operational flexibility



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MHVPS Topology

- Pulse Step Modulator (PSM) Technology selected as the baseline technology for the ITER MHVPS
  - Modular construction, Low stored energy, better voltage regulation, fast dynamic response…… Proven technology

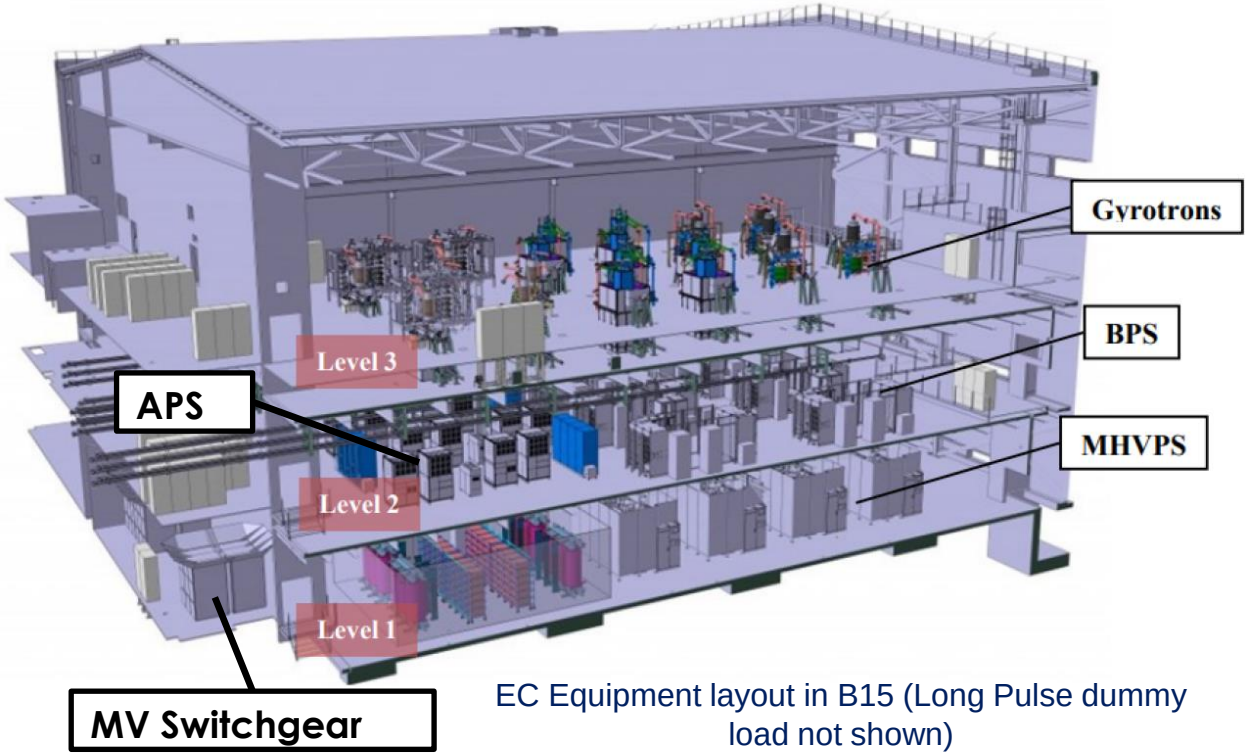


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Layout Integration of HVPS in EC Building 15

Layout Objective

- Maintain segregation
  - HV High power system
  - HV Low power System
  - Gyrotrons
- Minimized cable length
  - Vertically stacked layout



EC Equipment layout in B15 (Long Pulse dummy load not shown)

EC Equipment layout in B18 is side by side with the identical layout objective

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High Voltage Safety Architecture

HAZARDOUS ENERGY



22kV AC

55kV DC

STORED ENERGY

REMOTE ENERGIZATION

1

PHYSICAL SEGREGATION

Physical Separation among different HVPS to provide operation, commissioning and maintenance

2

CONTROLLED ACCESS

Authorized personal only

Safety interlock involved software-based interlock and passive mechanical interlock

3

INTERLOCKING

Electrical power flow chain from source to load : *protection system signal interlock and mechanical key transfer*

4

SAFE STATE

ISOLATE and GROUND

The input to Source and Output to load is grounded

SAFE ACCESS

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HVPS Procurement and Implementation

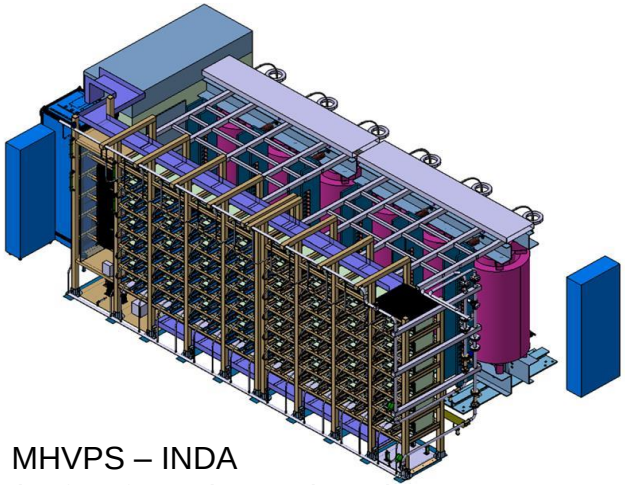
	EUDA	INDA	JADA
B15-South 20MW	8 MHVPS 16 BPS	4 MHVPS	8 BPS and APS

Additional Power Supply for the 20MW of SRO phase in B15-north (12 sets) and 20MW of DT (12 sets) phase in B18 are under design stage

- European and Indian MHVPS design share the functional PSM concept while different in implementation



MHVPS - EUDA



MHVPS – INDA
(Safety fence is not shown)

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HVPS Procurement and Implementation

- BPS from EUDA is based on Enhance PSM concept
- APSBPS from JADA is based on the off-the-self HVPS with MOSFET based switch for dynamic control and protection



APS and BPS from JADA



Gyrotron auxiliary power supply and control system



BPS for Diode type Gyrotron

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HVPS Conformance and Commissioning Strategy

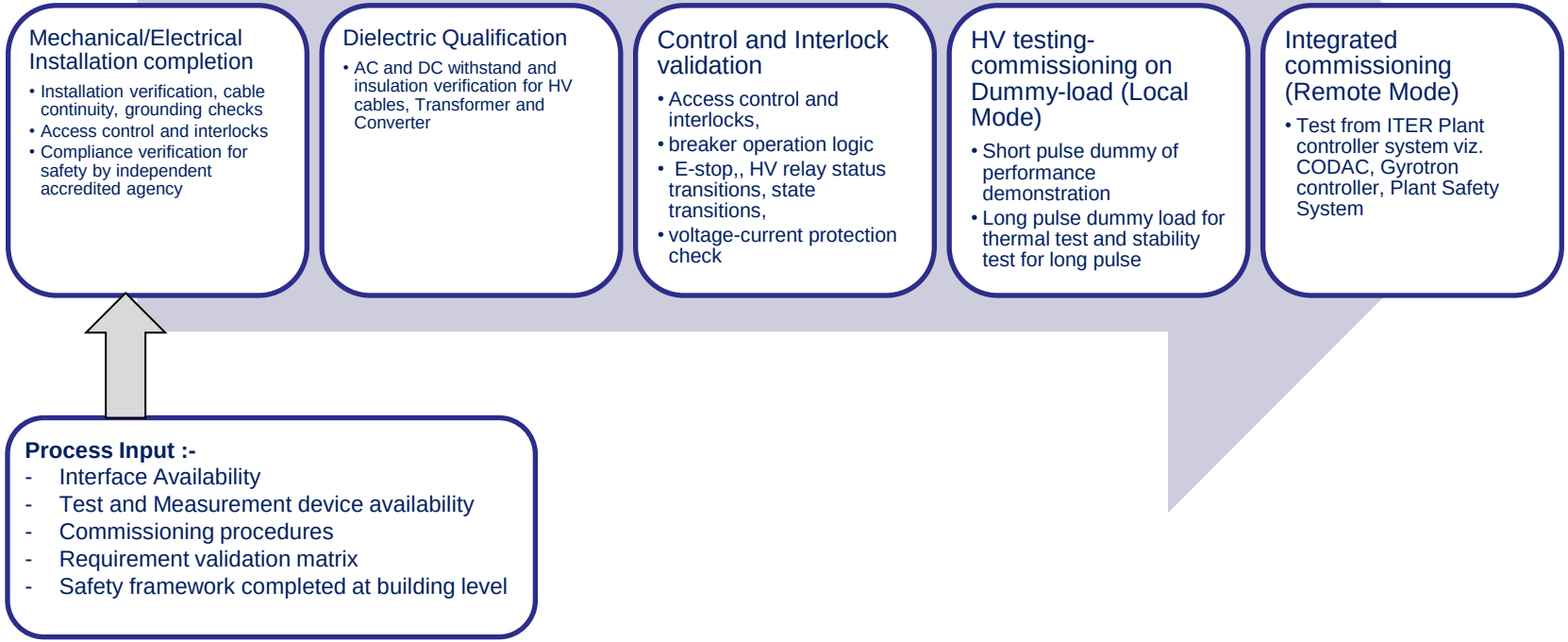
Conformance for Safety

- Important to demonstrate compliance with the safety requirement of applicable standard ;
  - EC HVPS comprises MV distribution equipment, power electronics, HV insulation system, Proetction and Safety system. no single international standard can fully demonstrate compliance of the complete installation.
- Conformance is therefore established through progressive accumulation of evidence obtained during: Design verification factory testing, installation verification and safety checks during commissioning
- The commissioning process is therefore an essential part of the conformance process case rather than a final operational formality.

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HVPS Conformance and Commissioning Strategy

Progressive Commissioning Strategy



Evidence accumulates for conformance checks while electrical risk is increased progressively.

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Site Acceptance Test Results (EUDA and JADA HVPS)

Parameter	Requirement	Measured/verified	Status
Voltage Regulation	± 0.5%	-0.43% to +0.15%	Pass
Voltage ripple	<1% (550V)	328 V @ 55 kV	Pass
Modulation	1kHz, 5kHz desirable	1kHz, 5kHz demonstrated	Pass
Fault energy	<10J (< 100mAs)	2mC	Pass
Protection response	<10uS	Demonstrated	Pass
Safety function	Required	Verified	Pass
Control Integration	Required	Verified	Pass
Long Pulse operation 2MW ; 1 Hours 6MW 15 sec	Thermal performance, Power quality and efficiency measurement, Stability verification for ITER operation pulse		Pass

MHVPS nominal parameters demonstrated at 55 kV and 110 A (55 A × 2 output).
BPS and APS also demonstrated requirement compliance during SAT

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EC HVPS System Current Status

20MW Gyrotron RF power HVPS Status (SRO Phase): -

- 8 HVPS Sets (MHVPS + BPS) from EUDA are installed : Two Sets are commissioned. One set ownership is with ITER.
- One Long pulse dummy and associated feeder line are installed and commissioned
- 8 APS-BPS from JADA are installed ; Two sets are commissioned
- Four MHVPS from INDA will be delivered by Dec'2028
- First Complete HVPS chain (MHVPS+APS+BPS) successfully integrated, commissioned and connected with Triode type Gyrotron. Gyrotron HV conditioning is currently in progress. A dedicated provision for MHVPS No-load operation has been implemented to support the gyrotron conditioning.

40MW Gyrotron RF power HVPS Status (SRO, DT Phase): -

- 24 HVPS sets (12 for SRO Phase and 12 for DT Phase) are under design phase, Delivery for first Two HVPS sets are planned for Mid'2028. Subsequent sets will be delivered in phased approach at regular interval.

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Thank You

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