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ITER Coil Power Supply and Distribution System

Jun TAO for Coil Power Supply Team

ITER Organization

Acknowledgments

Many thanks to the Chinese, Korean and Russian Federation DAs for the contribution to the Design of the ITER Coil Power Supply and Reactive Power Compensation System!

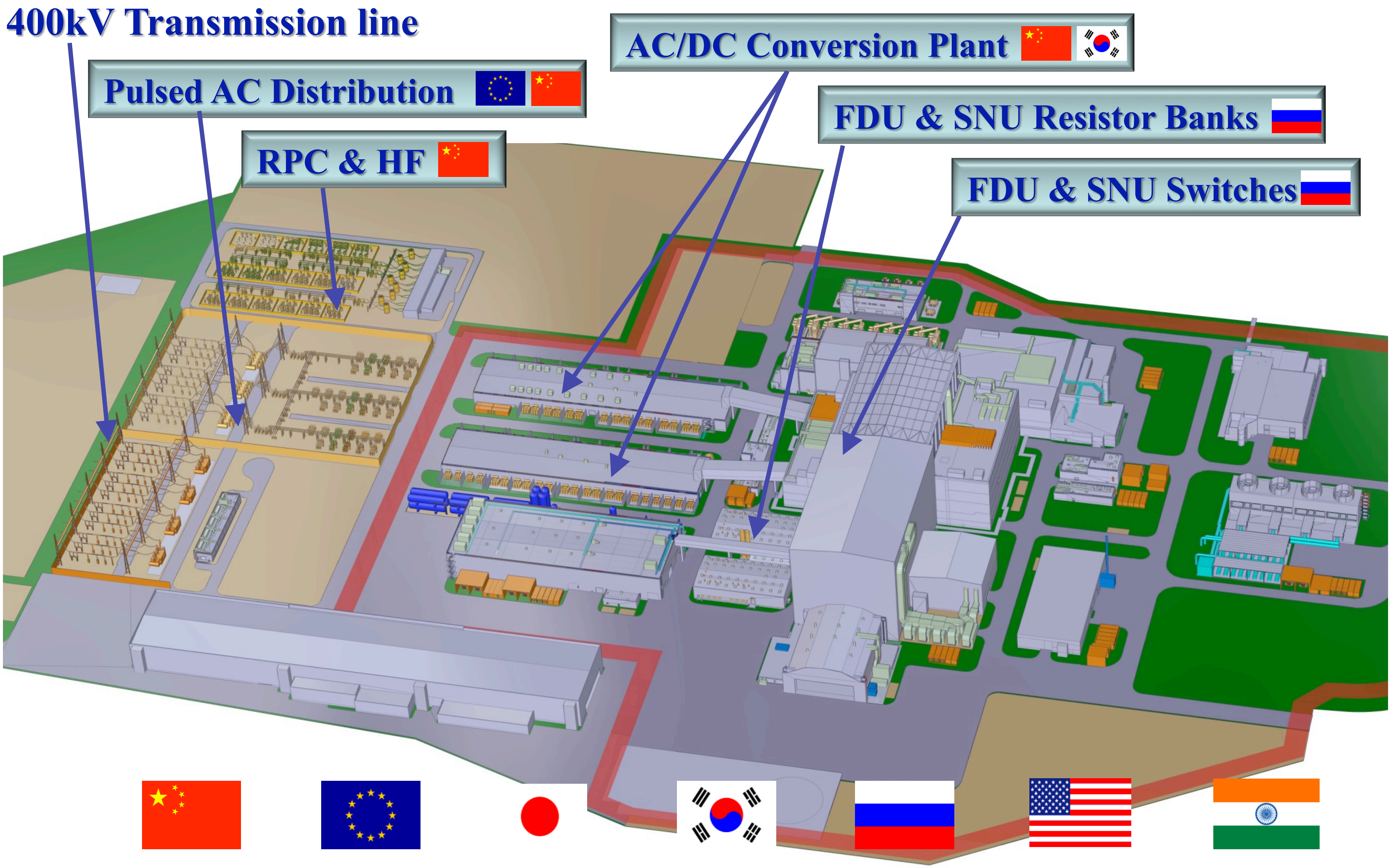
Outline

- **Introduction**
- **AC Distribution and Pulsed Load**
- **Coil Power Supply System (CPSS)**
- **Reactive Power Compensation and Harmonic Filtering (RPC & HF)**
- **Conclusion**

Main Components of Coil Power Supply and Distribution (CPSDS)

- **AC Pulsed Distribution ----- 3×300MVA**
  - To distribute the AC power to the Coil Power Supply System (CPSS)
- **AC/DC Conversion Plant ----- ~2GVA installed power**
  - To provide controlled DC power to the superconducting magnets
- **SNU (Switching Network Unit) ---- Up to 45kA and 8.5kV**
  - To generate a high loop voltage for plasma initiation
  - To extract a very large amount of power (2 GW)
- **FDU (Fast Discharge Unit) ----- Up to 68kA and 10kV**
  - Protection for superconductive magnets
  - Huge energy to be dissipated
- **RPC & HF (Reactive Power Compensation and Harmonic Filtering) ---- 3×250Mvar**
  - Dynamic reactive power compensation to minimise the voltage variation and reduction of the reactive power demand
  - Reduction of the harmonic distortion

ITER Site and Main CPSDS Components



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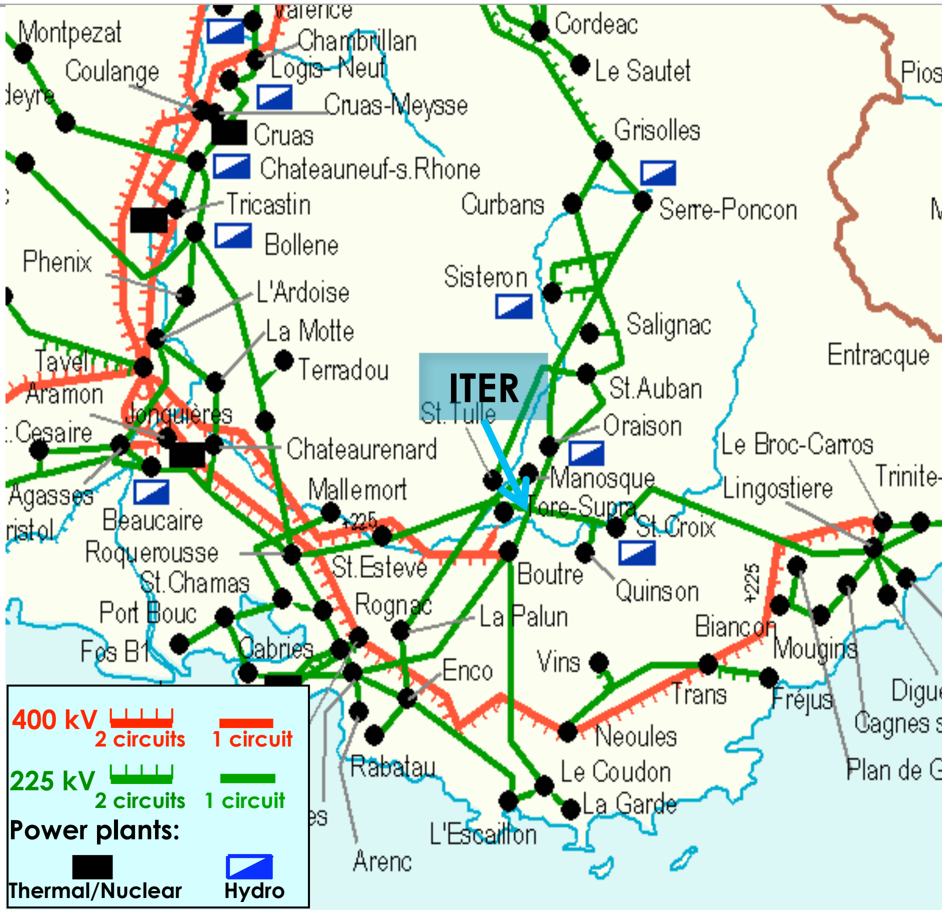
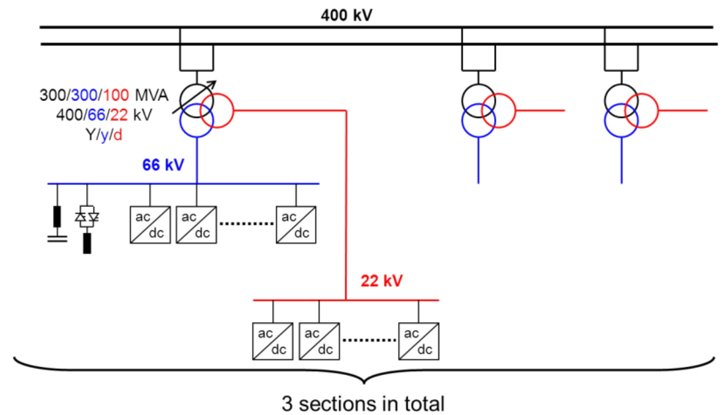
ITER Pulsed AC Distribution



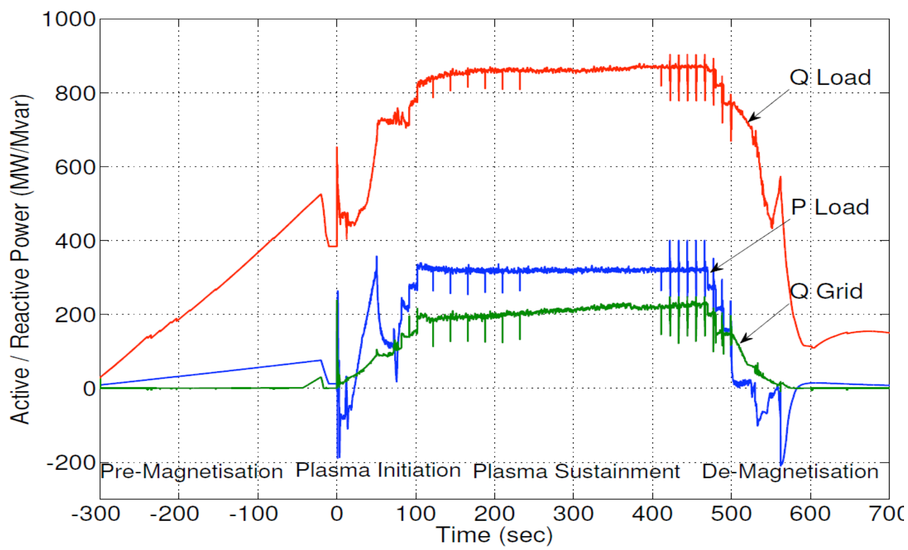


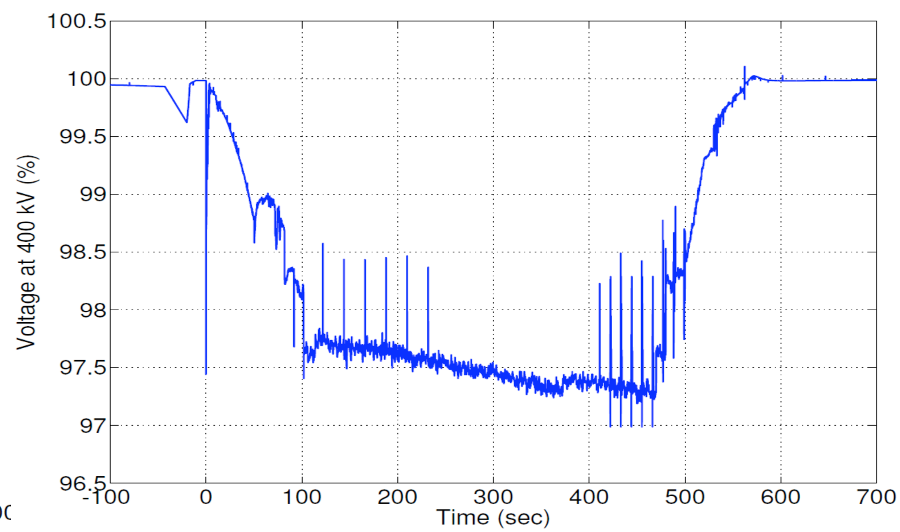
Max. P Max. Q	500 MW 200 Mvar
S.C Power	10 -12 GVA
ΔV	<3% (400kV)

- **Good capability to provide active pulsed power, but requires substantial reactive power compensation**
- **Relatively small S.C impedance for main step-down transformer**
- **Control coordinated between On Load Tap Changer (OLTC) and RPC& HF**

ITER Pulsed Load

- **Power required for PF scenarios, plasma current, position and shape control, including the vertical stabilization control**
- **Power to supply the correction coils**
- **Power to supply the H&CD systems**
- **Resistive losses**





- *Typical load profile representing 15MA inductive plasma, including the assumption of minor VDE and the modulation of H&CD power*
- *Constraints from 400kV Grid being met (200Mvar absorbed from Grid, max. 3% voltage variation at 400kV)*

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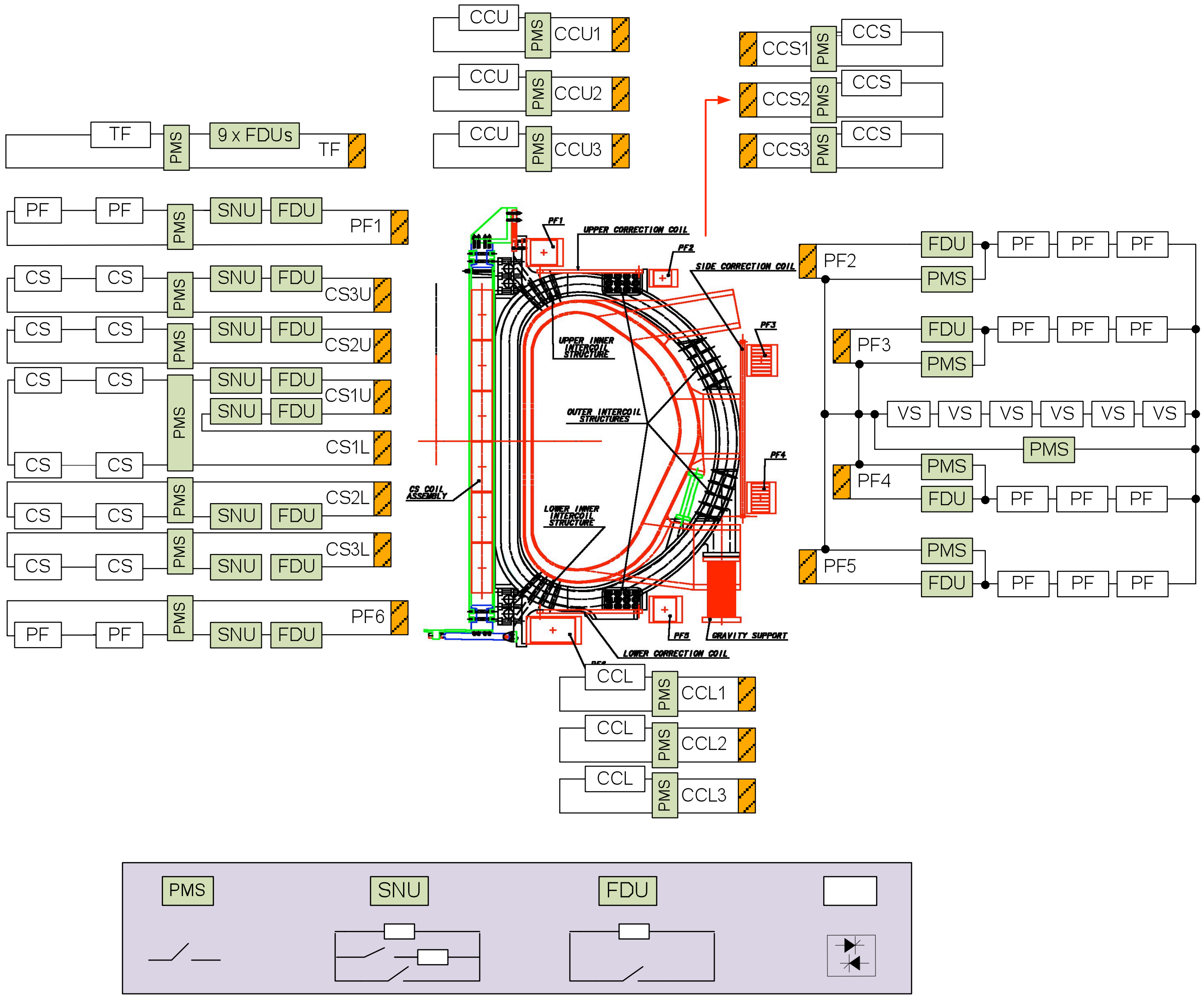
Configuration of Coil Power Supply System (CPSS)



- 1 circuit for 18 series TF coils
- 1 circuit for CS 1 upper & CS 1 lower in series
- 4 circuits for CS 2 U, CS 2 L, CS 3 U & CS 3 L
- 2 circuits for PF 1 & PF 6
- 1 circuit for PF 2, PF 3, PF 4 and PF 5, for plasma VS control
- 9 smaller circuits for error field CCs

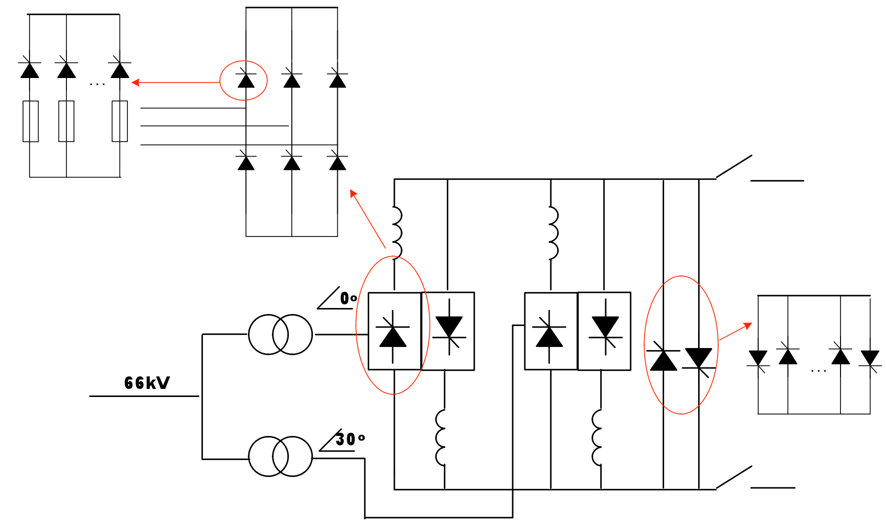
AC/DC Converter (1)

- **Main Design Features**
  - Thyristor based technology
  - Modular approach adopted (cost, technical risk, reactive power consumption)

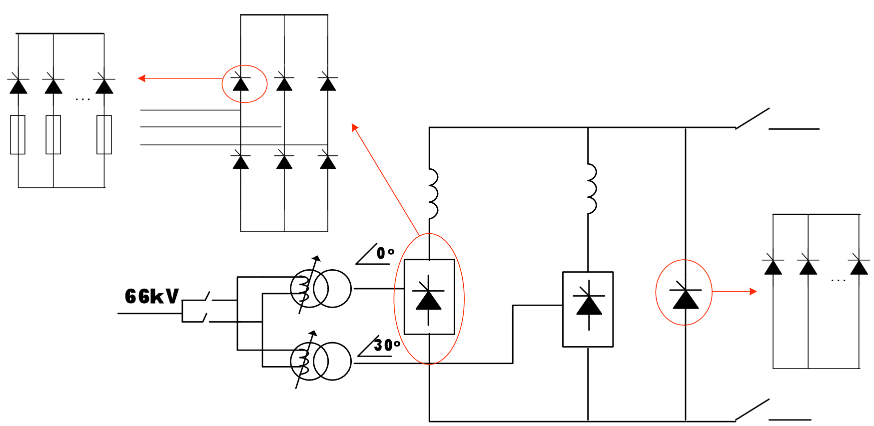
Circuit	U (kV) No-load	I (kA)
CS	±1.35	±45
PF	±1.35	±55
VS	±1.35	±22.5
TF	±0.9	68
CCS	±0.45	±10
CC U/L	±0.09	±10

AC/DC Converter (2)

- **Topology of ITER Power Converter Basic Units**



PF/CS/CC unit

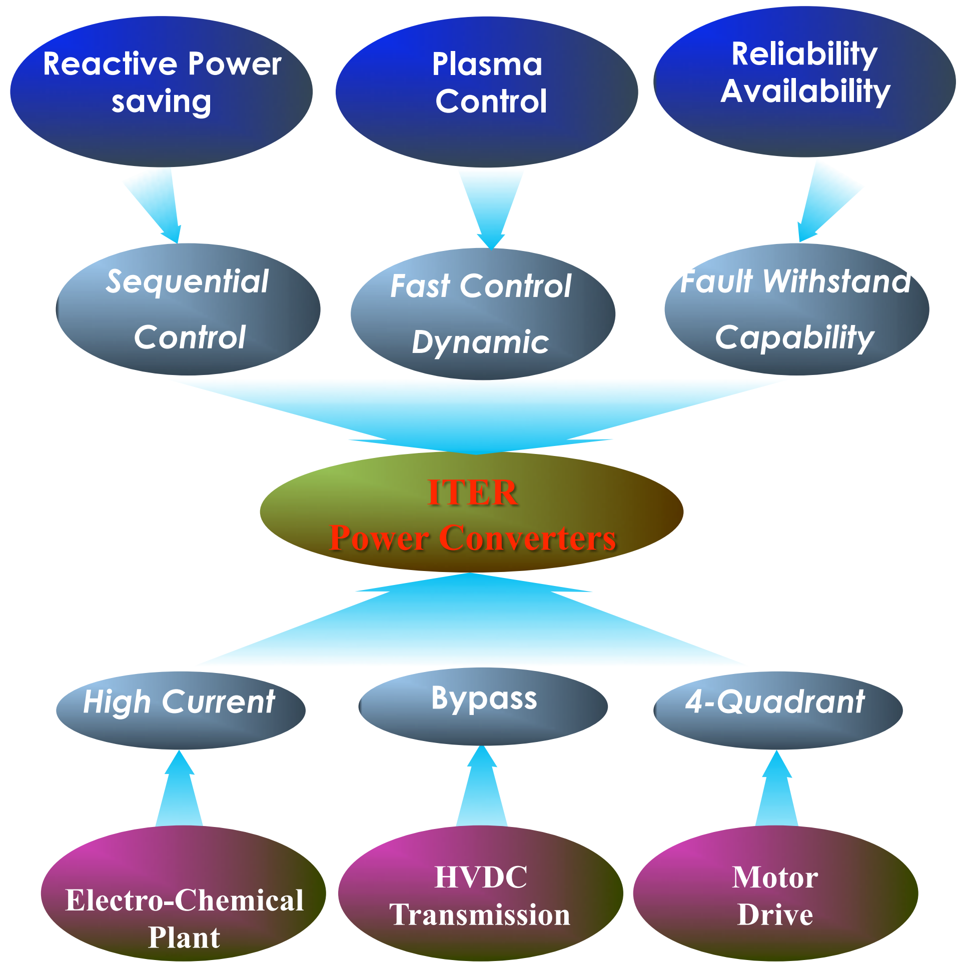


TF unit

- 4-quadrant ,12 pulse operation and back to back bridges configuration
- Large size thyristors directly connected in parallel, with individual arm fuse
- Circulating current operation used for the current polarity change
- External thyristor crowbar to handle the fault condition and circulate the load current, together with continuous duty PMS (protective make switch)
- 12-pulse, 2-quadrant converter for TF converter, with tapped transformer for the Q reduction during the steady state operation
- 4-quadrant, 6-pulse converter for VS unit to provide fast response

AC/DC Converter (3)

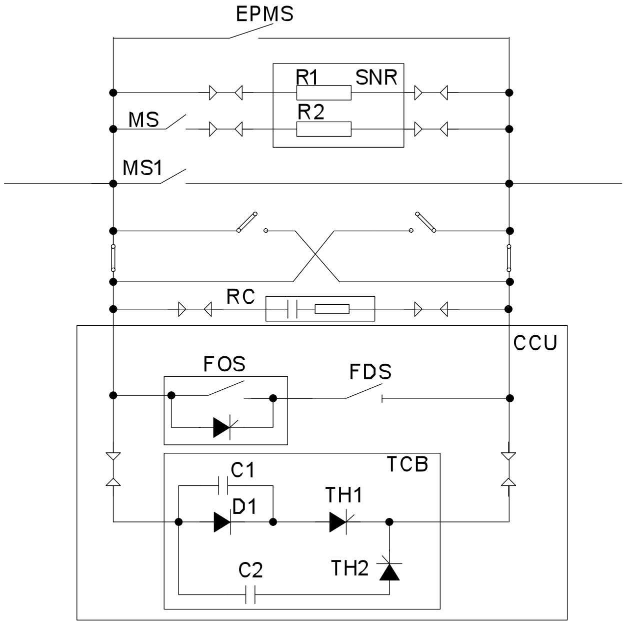
- **Design Challenges**
  - Multi-parallel thyristors
  - Bypass operation
  - 4-Quadrant operation
  - Larger amount of the reactive power generated
  - High dynamic characteristics
  - Reliability and availability



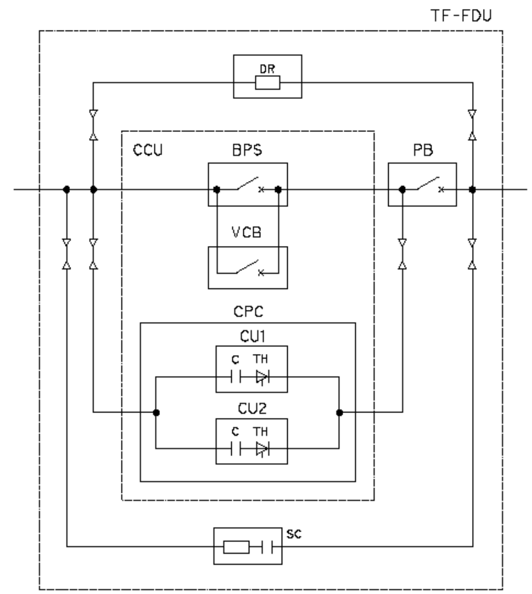
Switching Network Unit - SNU

- **Design Features**
  - Divert the coil current by CCU (Current Commutation Unit) into resistor banks
  - Two steps of the voltage
  - EPMS for backup protection

- **Design Challenges**
  - Interruption of lager DC current at high voltage
  - Repetitive operation
    - ➢ Two-stage mechanical switch design
    - ➢ Opening of FOS assisted by TCB (Thyristor Circuit Breaker) at very low voltage
    - ➢ Opening of FDS under no load condition
    - ➢ Current interruption at zero-crossing of TH1assisted by discharge of C2



Fast Discharge Unit - FDU



- **Design Features**
  - Current interrupted by CCU
  - BPS carries the continuous current, counterpulse circuit provides the artificial zero-crossing to open VCB
  - Pyrobreaker for backup
  - Switches and discharge resistors connected by coaxial cable
- **Design Challenges**
  - High current and high recovery voltage
    - ➢ Selection of the vacuum circuit breaker
  - Constrains from the magnet discharge
    - ➢ Selection of high thermal coefficient resistor (Max. voltage / Total I^2t)
    - ➢ Coaxial cable introduced to limit the transient voltage
  - Safety function
    - ➢ SIC-2 for the TF FDU, to support radioactive confinement
    - ➢ Sufficient redundancy
    - ➢ Fire segregation for the layout design

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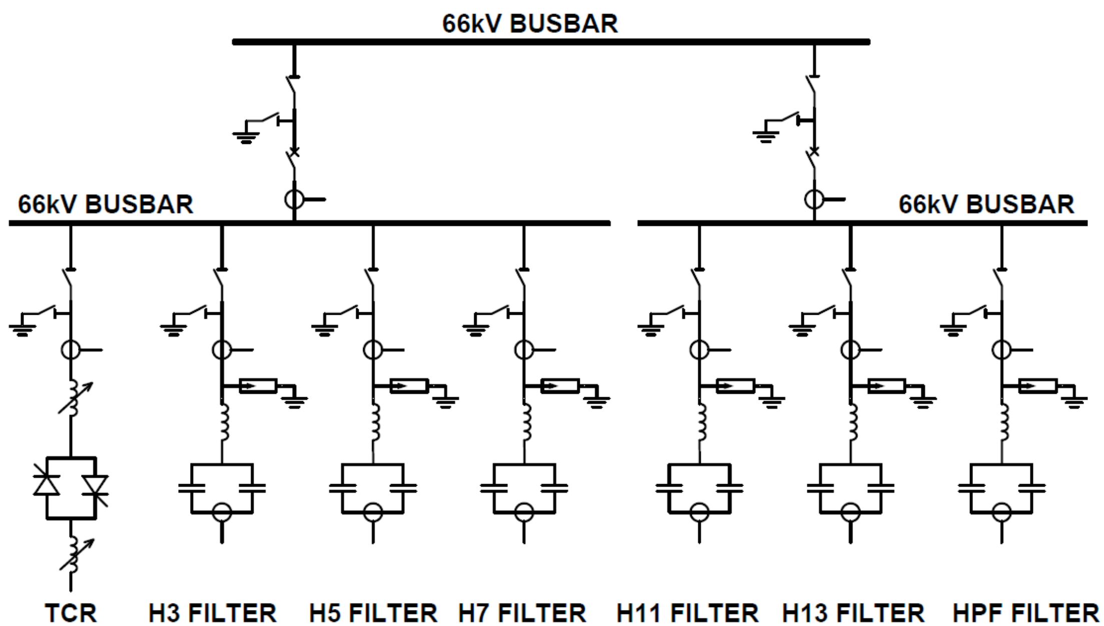
Design Requirements and Features

- To limit the voltage variation within 3% (400kV)
- To support the voltage of 66kV line (62-72kV) during the plasma pulse
- To limit the individual harmonic and total harmonic distortion (THD) to a level defined in IEC
- To provide dynamic compensation in timescale of 20ms to match the fast varied reactive power



Design Challenges and Solutions

- **High Voltage Valve**
  - N+2 or N+3 approach
  - LTT preferred with the integrated BOD
  - Optimized structure design to minimise the unequal distribution of the stray capacitance

- **Low Frequency Oscillation**
  - Continuous harmonic spectrum
  - Sufficient damping capacity required for the filters

- **Fast Response**
  - Open loop Q control
  - Voltage feedback added to increase the control accuracy

- **High Integration**
  - Integration with the load (Predictive control with the status of the load)
  - Integration with On Load Tap Change of main step-down transformer

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Conclusions

- **Significant technical challenges for the integrated ITER CPSDS**
  - Huge size and installed power
  - Unique requirements
  - Multi-procurements (Common design requirements and applicable standards);
  - Complex interfaces (Magnets, Cooling water, Centre Control, PCS, Inter-power supply…)
  - Layout integration

- **Conceptual design completed by ITER Organization during 2010 in collaboration with DAs**

- **Further detailed engineering design work performed by DAs in coming years**

- **Conceptual design demonstrates**
  - Technical feasibility
  - Manufacturability
  - Compliance with system requirements
  - But, significant challenges and integration to be addressed by DAs and their suppliers for the development and manufacturing of all CPSDS components

Thanks for your attention!