Final design of the Quench Protection Circuits for the JT-60SA superconducting magnets

presented by E. Gaio

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Outline

- The JT-60SA satellite Tokamak and TF and PF circuits
- The QPC requirements and final design
- The Hybrid CB – feasibility studies
- The main components:
    - The static CB
    - The Bypass Switch
    - The pyrobreaker
    - The dump resistor and the voltage clamp circuit
- Conclusions and future work

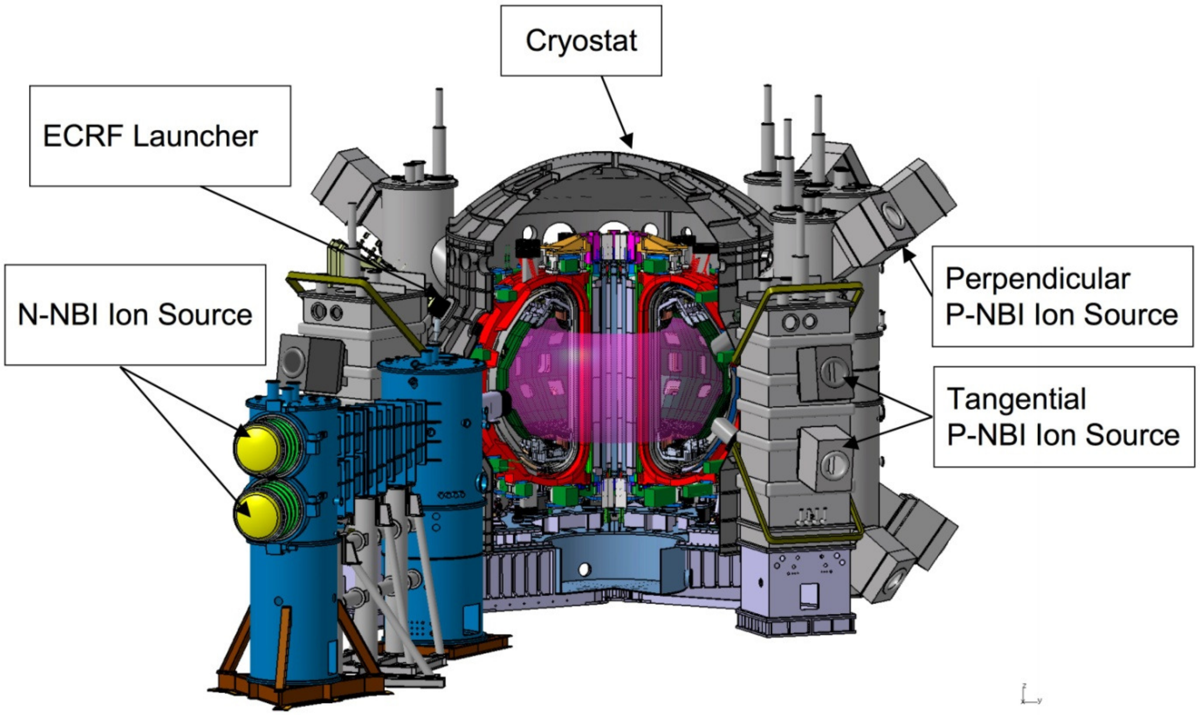
The JT-60SA satellite Tokamak

JT-60SA is a fully superconducting tokamak

The mission is to contribute to the early realization of fusion energy by supporting the exploitation of ITER and research towards DEMO

Basic machine parameters

Plasma I_p	5.5 MA
Toroidal Field B_0	2.25 T
Plasma R major radius	2.97 m
Plasma a minor radius	1.18 m
Plasma A aspect ratio	2.5
Elongation k_x	1.93
Triangularity δ_x	0.53
Safety factor q_{95}	~3
Plasma Volume	1.33 m^3
Flat top duration	100 s
Heating & CD	41 MW
N-NBI	10 MW
P-NBI	24 MW
ECRF	7 MW
Divertor wall load	15 MW/m^2



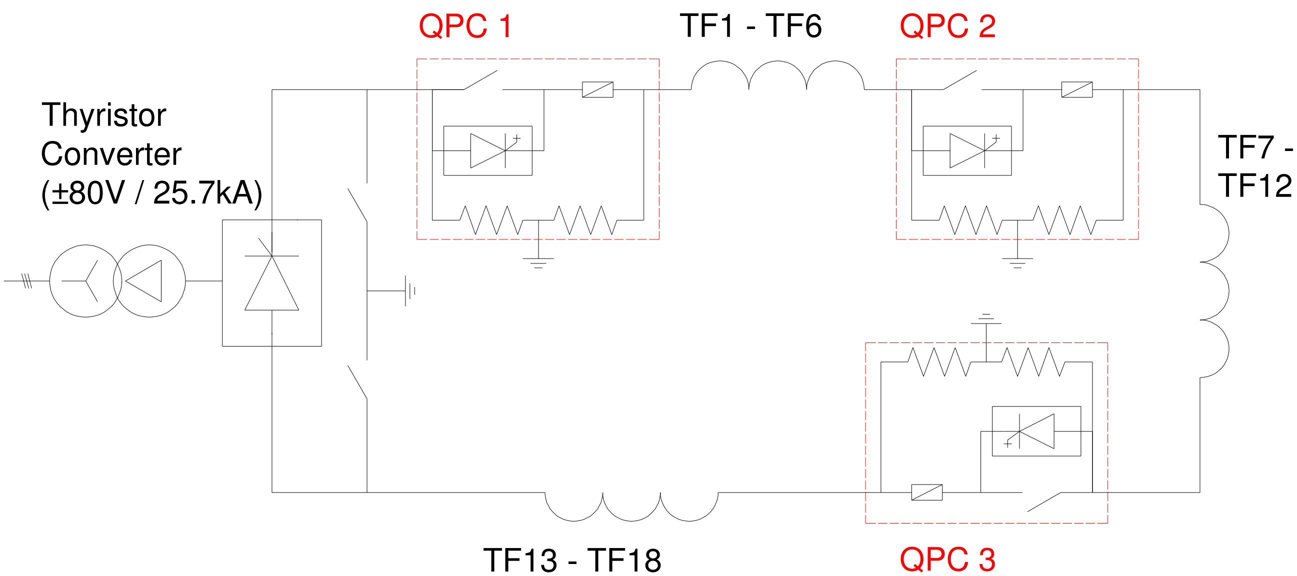
The JT-60SA TF and PF circuits

One Toroidal Field circuit

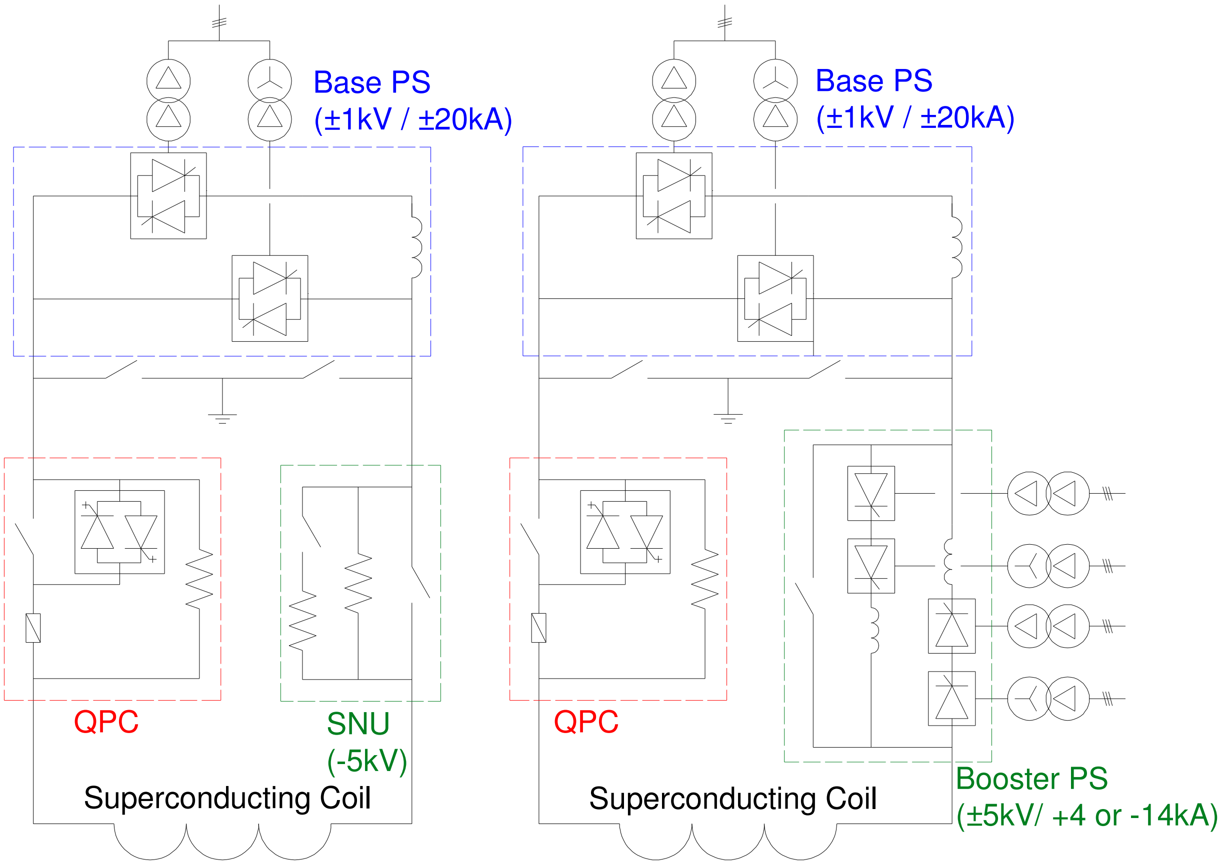
18 coils divided in 3 units

3 Quench Protection Circuit

single unidirectional converter



The JT-60SA TF and PF circuits



4 Central Solenoid Coils

6 Equilibrium Field Coils

10 PF circuits in total

Bidirectional thyristor converter

Quench Protection Circuit

and

Switching Network (left) or

Booster Converters (right)

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The QPC requirements

QPC requirements	TF circuit	PF circuit
Units	3	10
Nominal / maximum voltage per unit (kV)	< 2.8 / 2.8	< ±4.2 / ±5
Nominal current (kA)	25.7	±20
Maximum current to be interrupted by the hybrid CB/pyrobreaker (kA)	25.7 / 25.7	±21 / ±22.5
Current polarity	unidirectional	bidirectional
Dump resistance (Ohm)	< 0.11	< 0.21
Duty cycle	steady state	250 s/30 min
Maximum delay time from the command (s)	1	1
Maximum delay for the pyrobreaker operation (s)	0.5	0.5
Maximum allowed I^2t in the coil after quench detection (GA^2s)	4.6	2

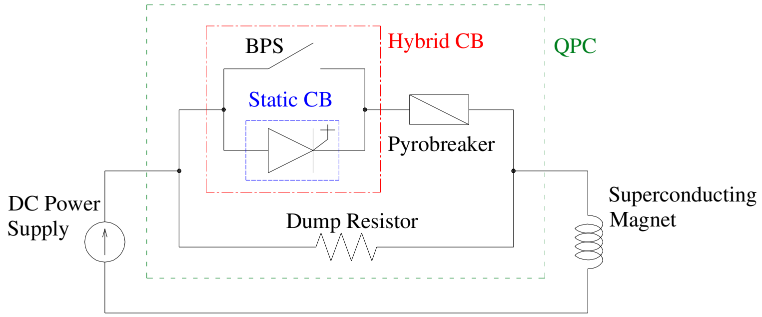
The contract award

Contract awarded to:

ANSALDO SISTEMI INDUSTRIALI (ASI)

Detailed Design Phase (DDP) started in December 2010

Design approach



- basic scheme of the conceptual design confirmed
- modularity improved:
  - *same ByPass Switch (BPS) and Pyrobreaker for both TFC and PFC QPC rated for the maximum current and voltage (25.7 kA and 4.2 kV)*
  - *same IGCT for both TFC and PFC QPC*

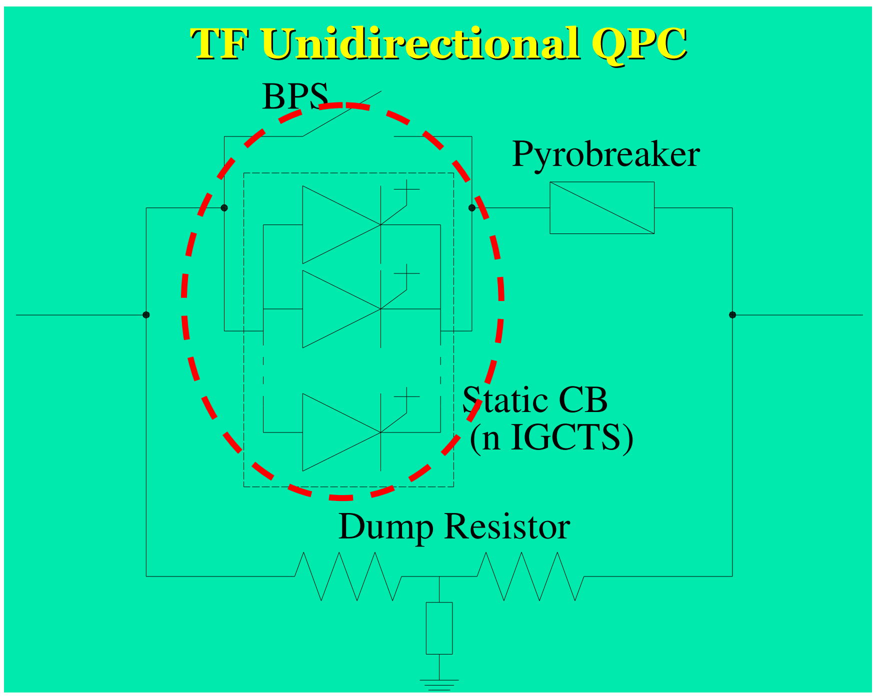
E. Gaio, L.Novello, R. Piovan, K. Shimada, T. Terakado, K. Kurihara, and M.Matsukawa, "Conceptual Design of the Quench Protection Circuits for the JT-60SA Superconducting Magnets", Fusion Engineering and Design, vol.84, Issue 2-6, pp. 804-809, June 2009

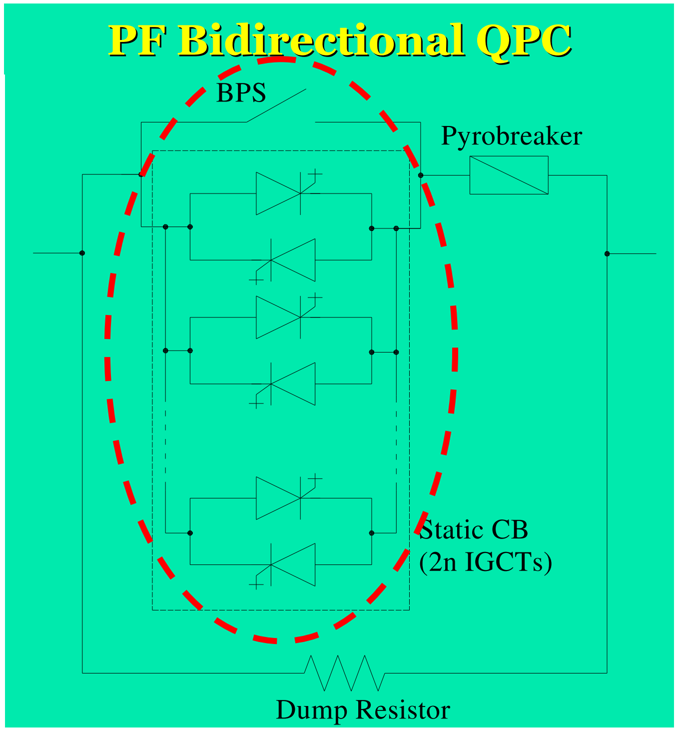
The QPC final design - the selected scheme

The QPC scheme is based on a **HYBRID CB** combination of:

- a **mechanical ByPass Switch** (BPS) for current conduction during normal operation
- a **IGCT Static CB** for current interruption

The **pyrobreaker** in series to the hybrid CB assures the backup protection.





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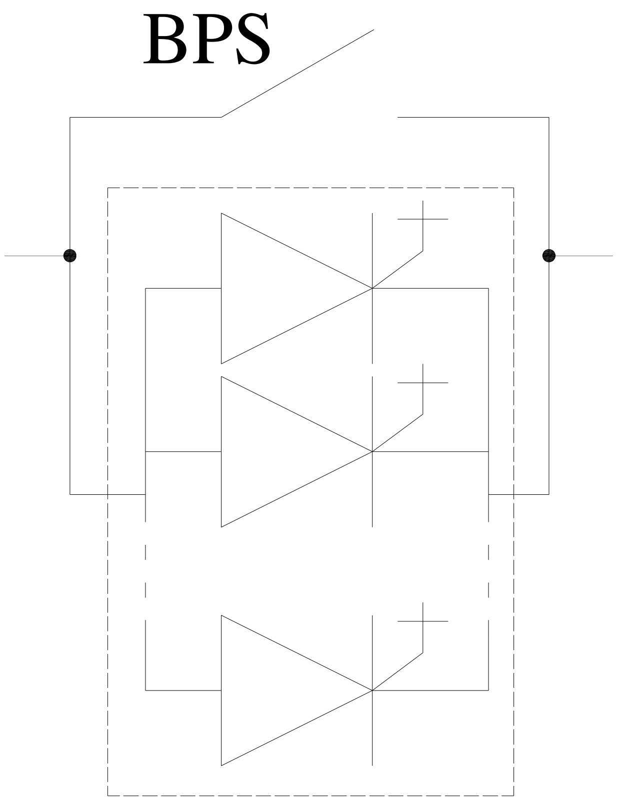
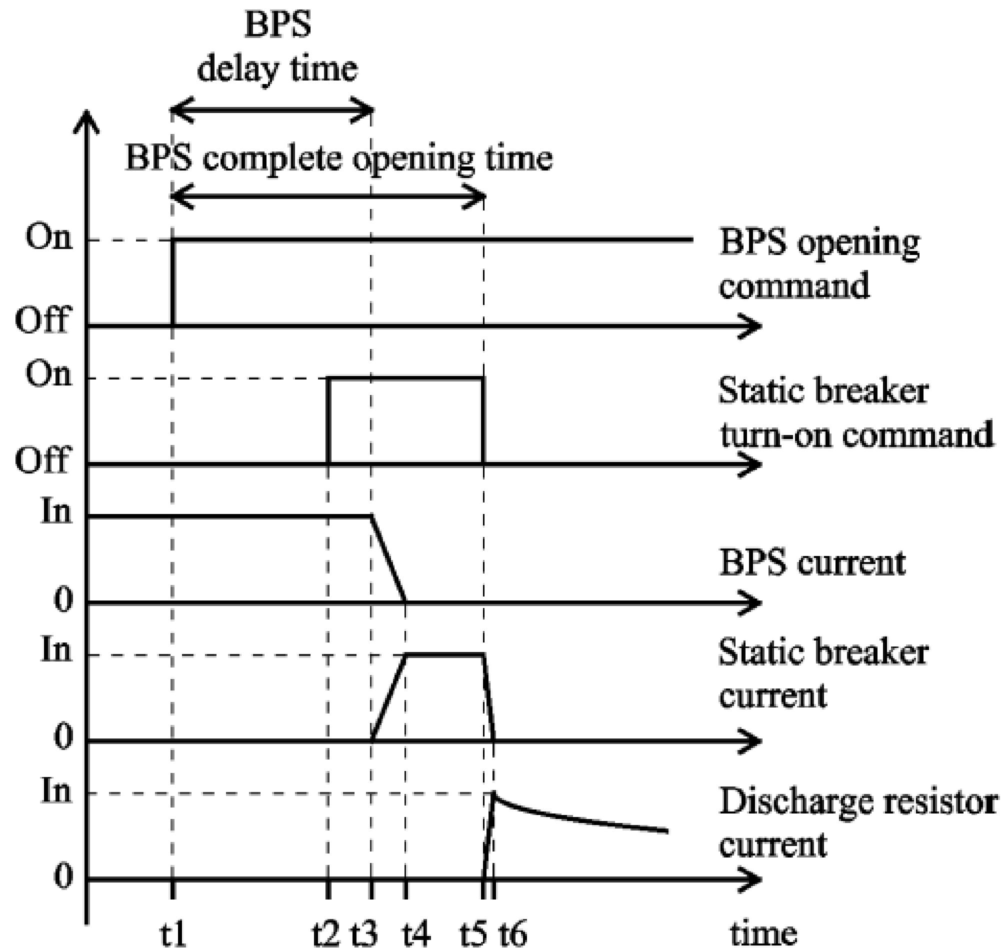
The QPC final design - hybrid CB op.sequence



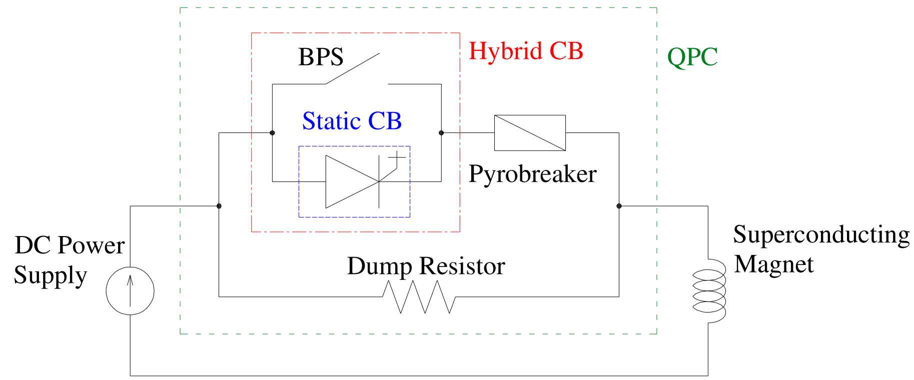


Hybrid Circuit Breaker **Operating sequence**

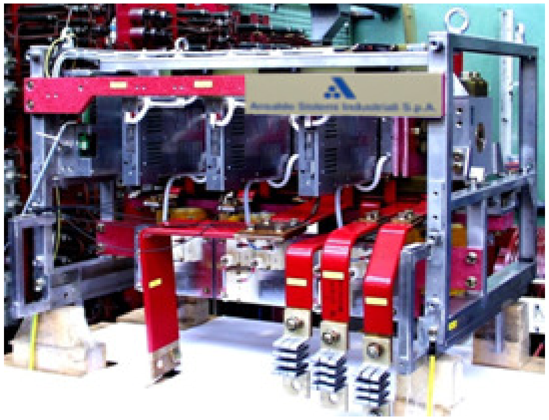
Strenghts of the proposed design

***Innovative solution**: brings togheter the advantages of mechanical and static technologies*

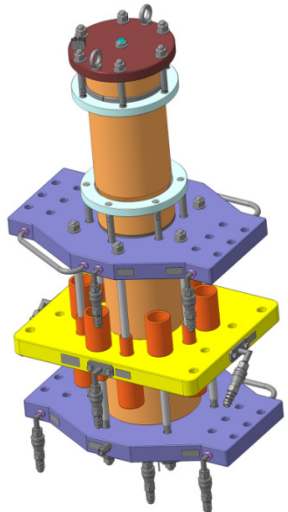
But based on components deeply studied and tested in the past to assure the required high reliability



BPS: based on the BPS prototype of FDU of ITER (manufacturer: Siemens)



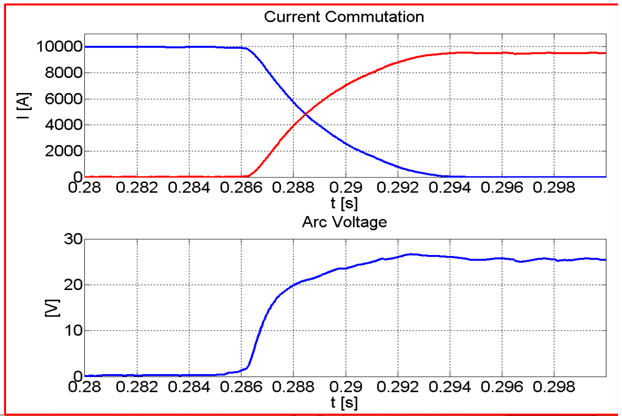
SCB: based on the Static Circuit Breaker design successfully in operation in the RFX-mod toroidal circuit (manufacturer: Ansaldo Sistemi Industriali)



Pyrobreaker: based on the design developed for ITER (manufacturer: Efremov Scientific Research Institute - St. Petersburg)

Feasibility issues

- reliable turn-on of IGCTs in parallel with low direct voltage applied between anode and cathode
- arc voltage characterization under different conditions
- current commutation from the BPS to the SCB at different current levels



Two experimental test campaigns were carried out to explore the feasibility of the practical implementation of the identified scheme

- ***The first allowed proving that few volts are enough to turn-on the IGCTs.***
- ***The second allowed studying the current commutation from the BPS to the static CB proving the feasibility and reliability of this design solution at a significant power level***

Development and tests of a 10 kA prototype

L. Novello, E. Gaio, and R. Piovan
Feasibility Study of Hybrid IGCTs-Mechanical CB for Superconducting Magnet Protection
IEEE Transactions on Applied Superconductivity, Vol. 19, No. 2, April 2009

Novello, F. Baldo, A. Ferro, A. Maistrello and E. Gaio
Development and Testing of a 10 kA Hybrid Mechanical-Static Dc Circuit Breaker
Submitted to IEEE Transactions on Applied Superconductivity

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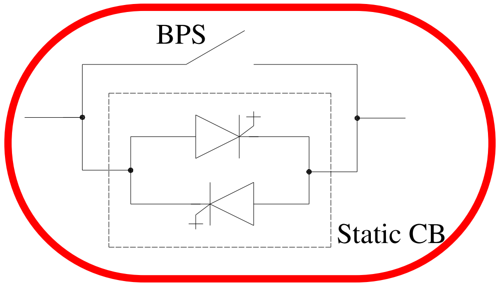
Hybrid CB: Static Circuit Breaker

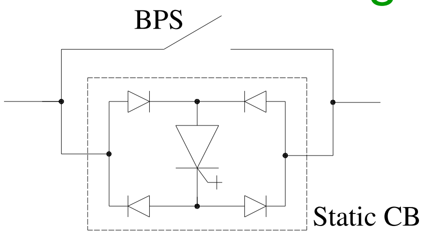
Bidirectional Static Circuit Breaker - Possible topology:

- two antiparallel static breakers



Selected topology

- unidirectional static breaker with a series rectifier diode bridge

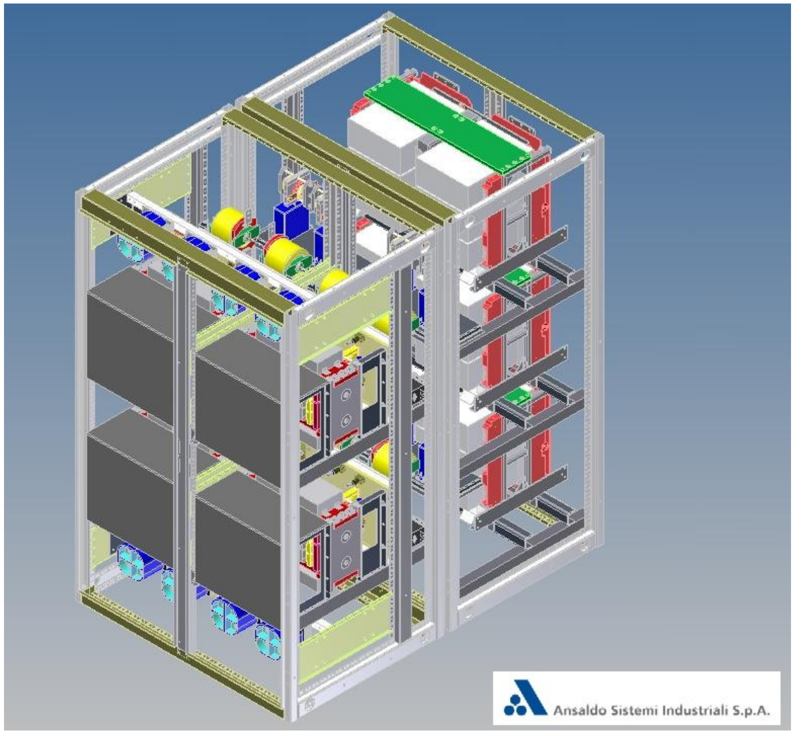


Motivations:

- *the total voltage drop is lower thus making faster the current commutation*
- *the layout is simpler*

One redundant IGCT branch

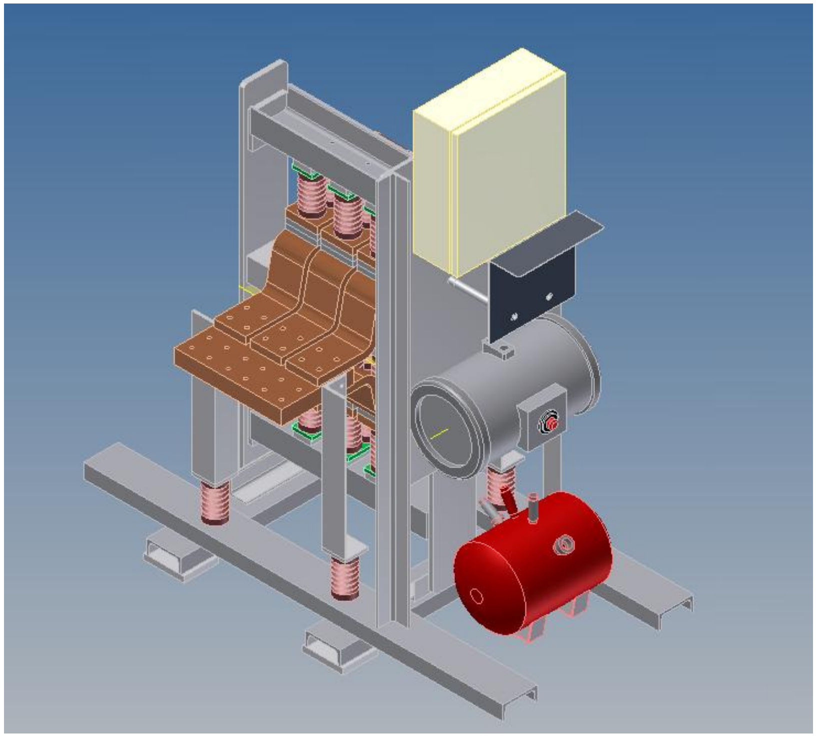
this means that the static CB is able to interrupt the maximum current with one branch less, without requiring intervention of the backup protection.

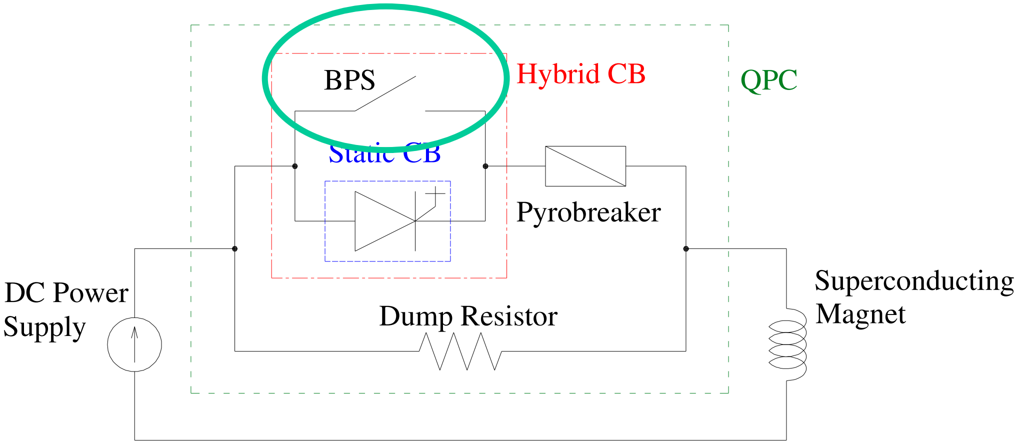


Hybrid CB: Bypass Switch

The BPS design derives from that developed by Siemens for the ITER switching unit (70 kA, 20 kV), but it is provided with a reduced number of contacts, six instead of twelve, to conduct the lower steady state dc current of 25.7 kA.

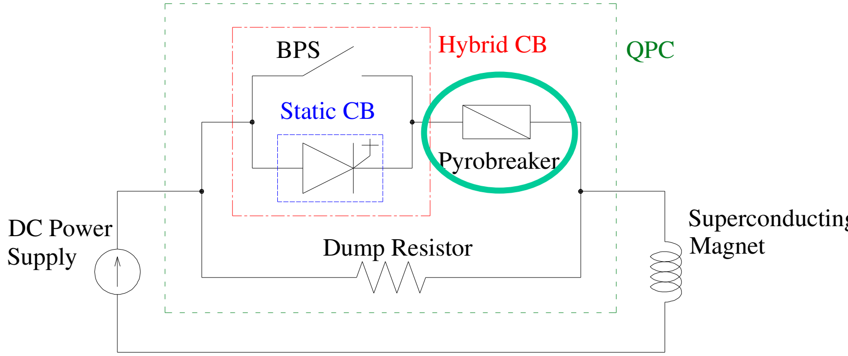
The maximum BPS operation time, from the command to the complete opening of the contacts is 350ms .





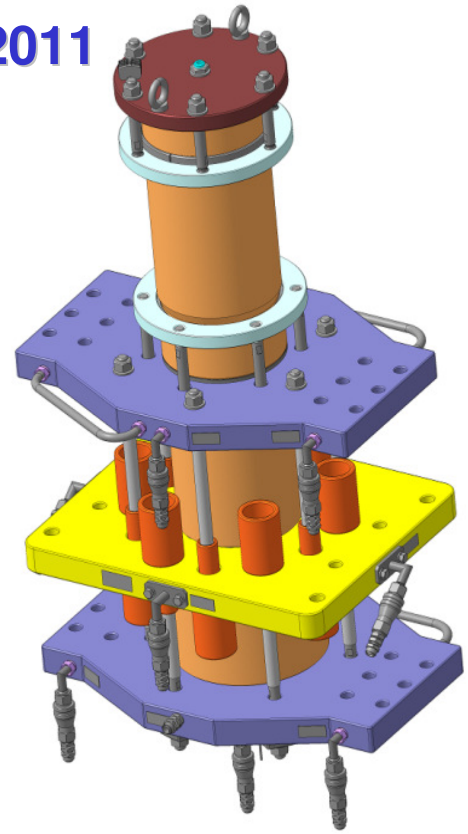
Pyrobreaker

- Manufacturer:
  Efremov Scientific Research Institute
- Design derived from that for the FDU of ITER



First prototype delivery delivered in May and tested in June 2011

Second prototype delivery in autumn 2011



First tests on the pyrobreaker:

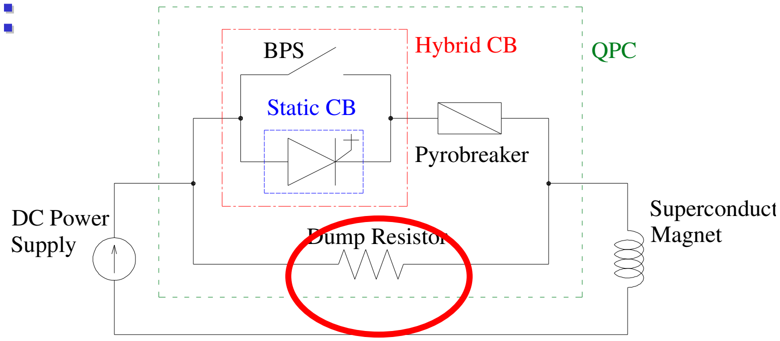
- **Four interruption tests up to 40 kA;**
- **Insulation tests;**
- **Temperature rise test (two hours conduction time at 30 kA). The temperatures measured with thermocouples in several points were all below 70 °C.**

Results very successful

Dump resistor

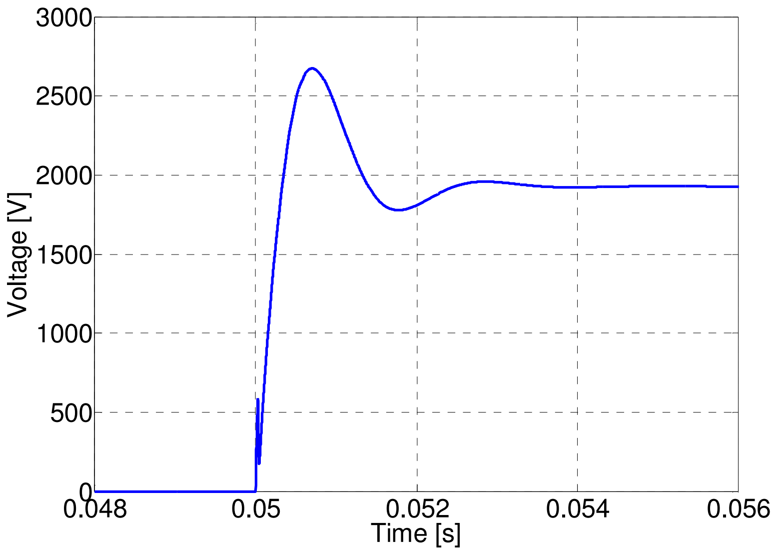
Value determined to satisfy two main constraints:

- the maximum voltage across the coils
- the maximum I^2t on the coil after quench detection



Main resistor data		
	TF	PF
Value	0.0075 Ω	0.19 Ω
Energy	350 MJ	70 < E_{PFcoil} <200 MJ

Voltage across the TF dump resistor, i.e the TF SC coils, at the commutation.



Minimized thanks to:

- the reduction of the total QPC intervention time with respect to the specifications
- the minimization of the stray inductances between the static CB and the resistor
- the exploitation of the resistance variation of the dump resistor with the temperature
- the design of suitable clamp capacitors

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Conclusions and future works

- *The contract for the procurement of the JT-60SA Quench Protection Circuits has been awarded to the company Ansaldo Sistemi Industriali*
- *The final design of the QPCs has just been completed*
- *It is based on an innovative Hybrid CB composed of a mechanical BPS and a IGCT static CB in parallel. A pyrobreaker in series provides the back-up protection.*
- *The next step is the manufacture of a full-scale prototype*
  to perform special type tests aimed at verifying the final design choices, the newest aspects like the bidirectional operation of the static CB, the coordination of the internal protections, the effectiveness of the voltage clamp circuits and the layout optimization level in reducing the stray impedances.

Thanks for the attention!