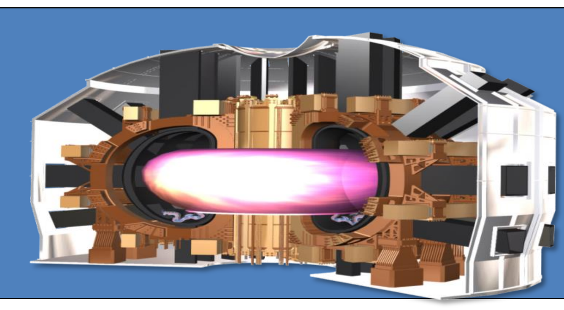

Divertor Tokamak Test facility

Design of a quench protection system by implementing an optimization procedure

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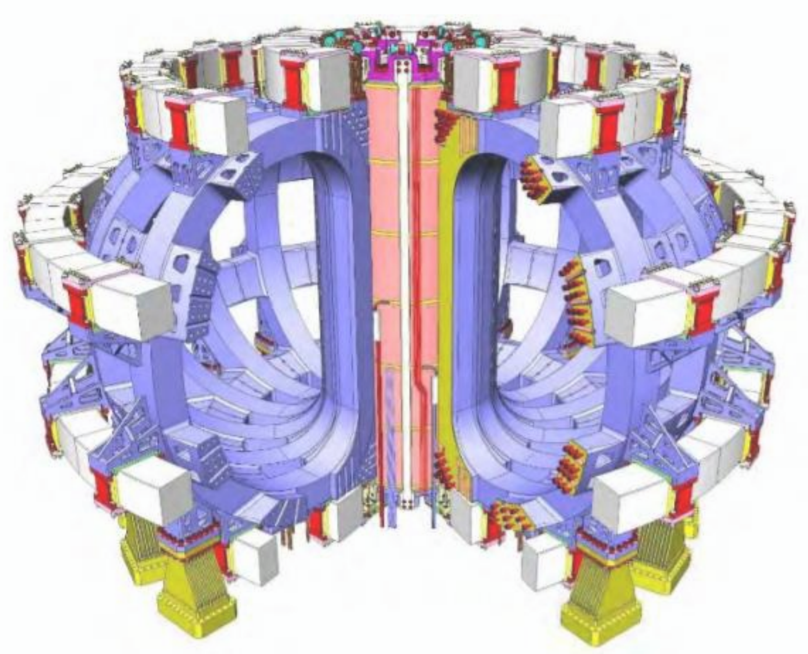
Abstract — ENEA is currently involved in the design of a fully superconducting magnet system of the Divertor Tokamak Test (DTT) facility to explore robust divertor alternatives and to study the plasma-material interaction scaled to long pulse operation. The DTT magnetic system will be realized using superconductor materials thus implying the need for specific protection strategies. The design of quench protection circuits should take into account reliability requirements and also possible protection circuit failures. In this work, all possible failure scenarios are analyzed in order to identify the most critical conditions.

DTT PROJECT OVERVIEW



18 TF coils:
Nb_3Sn CICC: 44.8 KA – 11.9 T
providing 6.0 T over plasma major radius (2.14 m)

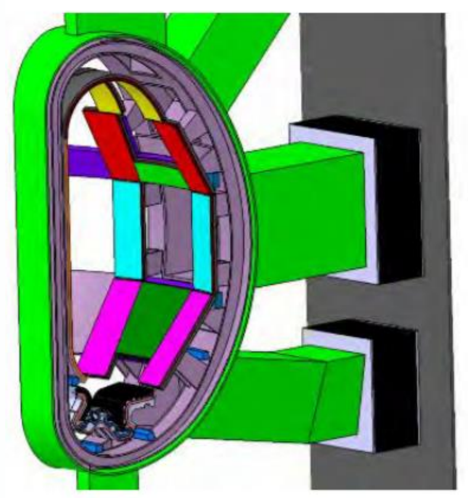
6 CS modules
Nb_3Sn CICC: 29 KA – 13.4 T
providing 16.4 Weber magnetic flux for plasma initiation at breakdown

6 PF coils
Nb_3Sn (PF1 & PF6) CICC: 28.3 KA – 9.1 T
NbTi (PF2 to PF5) CICC: 28.6 KA – 5.4 T
Identical in pairs to guarantee full top/down symmetry

Divertor Tokamak Test (DTT) general objectives:

- to test whether the alternative divertor solutions (e.g., advanced divertor configurations or liquid metals) can be technically integrated and are able to withstand the strong thermal loads in the DEMO device if the fraction of radiated power turns out to be lower than expected;
- to improve the experimental knowledge in the heat exhaust scientific area for parameter ranges that cannot be addressed by present devices.

In particular, it will be possible to assess whether:
- the alternative divertor magnetic configurations are viable in terms of the exhaust problems as well as of the plasma bulk performances;
- the alternative divertor magnetic configurations are viable in terms of poloidal coils constraint (i.e., currents, forces, etc.);
- the various possible divertor concepts are compatible with the technological constraints of DEMO;
- the divertors based on the use of liquid metals are compatible with the characteristics of the edge of a thermonuclear plasma;
- liquid metals are applicable to DEMO.



QUENCH PROTECTION SYSTEM DESIGN

From the viewpoint of magnetic couplings, for the quench protection, the whole superconducting coils' system, may be thought for two main magnetic subsystems:

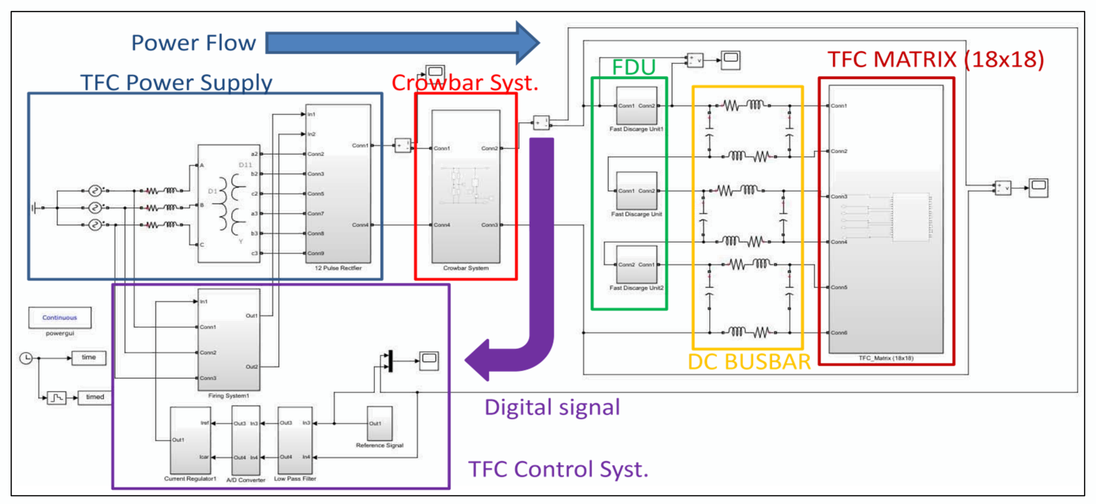
1) the **Central Solenoid coils (CS)**, **Poloidal Field coils (PF)** and **Plasma**;
2) **Toroidal Field coils (TF)**.

Both the magnetic subsystems include **Fast Discharge Units (FDU)** for the safely and the fast extraction of the stored magnetic energy into the superconducting coils, in case of a quench detection.

The protection is implemented by:
- A **dump/discharge** resistor connected in series (i.e. to each TF coil sector, such resistor is actually divided in 2 identical units to limit the voltage to ground at insertion).
- A **DC hybrid circuit breaker**, split in a mechanical **By-Pass Switch (BPS)** and a **Static Circuit Breaker**.
- A back-up protection made by a **pyro-breaker**.
- An **earthing resistor**.

When a **quench** is detected, the current carried out by the circuit breaker **is commutated into the discharge resistor**, and the superconducting coil energy is dissipated with a fixed circuit **time constant**.

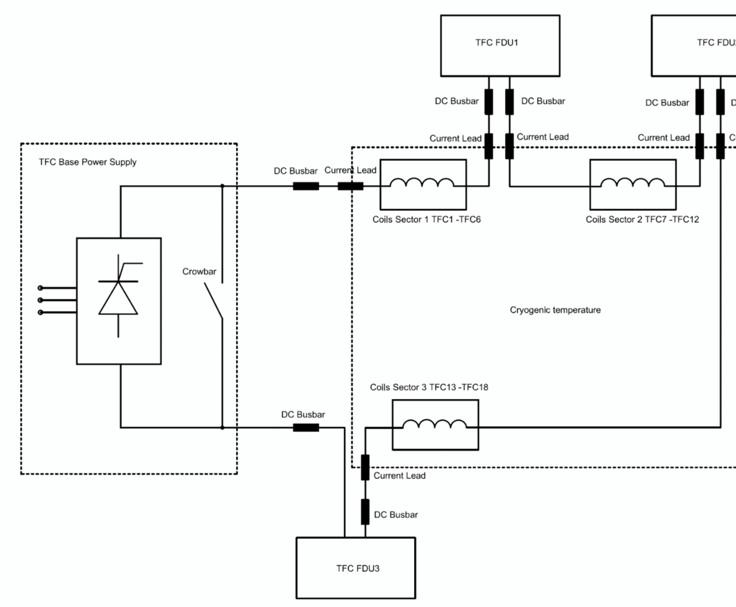
The **reliability** of the FDU plays a crucial role, in order to protect superconducting coils and their power supplies. Therefore the design of FDUs has to take into account the **maximum stress in terms of over-voltages and over-currents** may occur in the superconducting coil circuit in normal conditions and as a result of a fault.
In order to answer to reliability requirements a suitable **electrical model of TF** coil system was implemented by MATLAB/SIMULINK software, and also a following **fault analysis** was carried out for the estimation of **over-voltage peaks in transient** per typology of fault.



OPTIMIZATION PROCEDURE

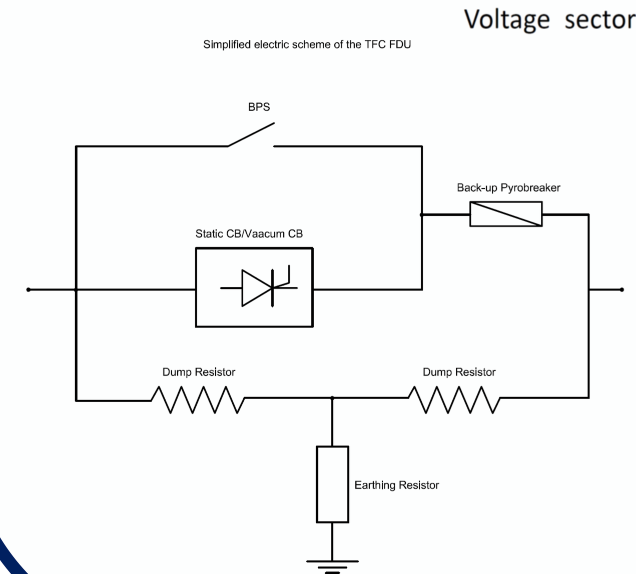
Toroidal Field coils were divided in three sectors, each consisting of six coils and hence three FDUs were included to protect the TF coils' circuit, for each sector. **The maximum stress in term of over-voltages** may occur in the superconducting coil circuit in normal conditions and as a result of a fault (assuming the simplified electric scheme of a FDU) were estimated considering **different operating conditions**:
- Intervention of all FDUs;
- Intervention of all FDUs and a ground fault at one FDU terminal (Tgf1, Tgf2, Tgf3, Tgf4, Tgf5 and Tgf6 represent terminal ground fault dummy variables);
- Intervention of all FDUs except one, opening with a delay time of 5ms and gradually increasing with a step of 5ms (DT1, DT2, DT3 and DTCB are delay time for FDU1, FDU2, FDU3, and Crowbar System).

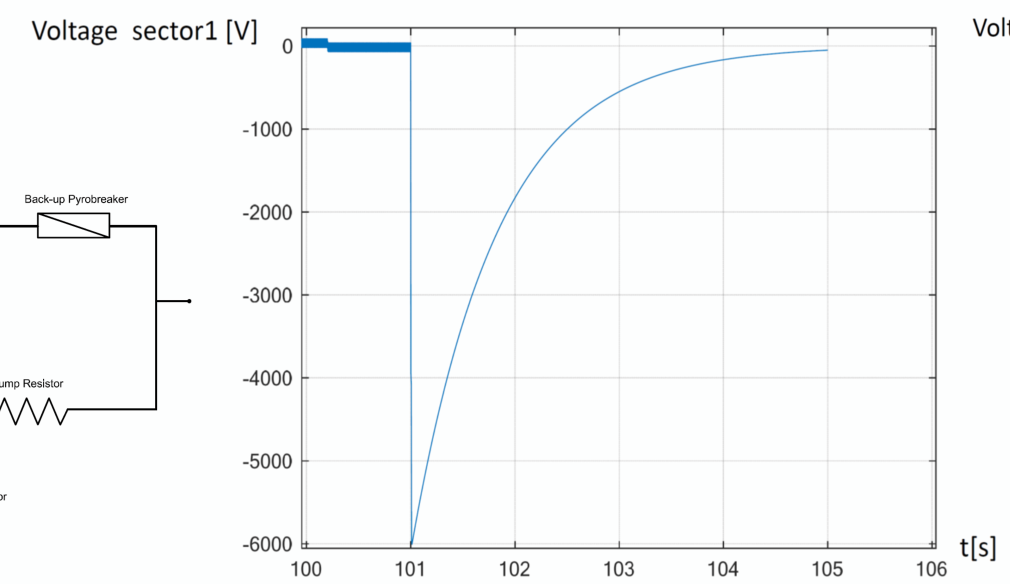
The set of all combinations produced 147 possible failure scenarios. All failure scenarios were analyzed in order to identify the most critical conditions. **The maximum over-voltage (about 10,25 kV)** occurred for double fault, delayed activation of a FDU and ground fault at one of its terminals. The maximum value appeared on sector 3 when the FDU1 was failed.

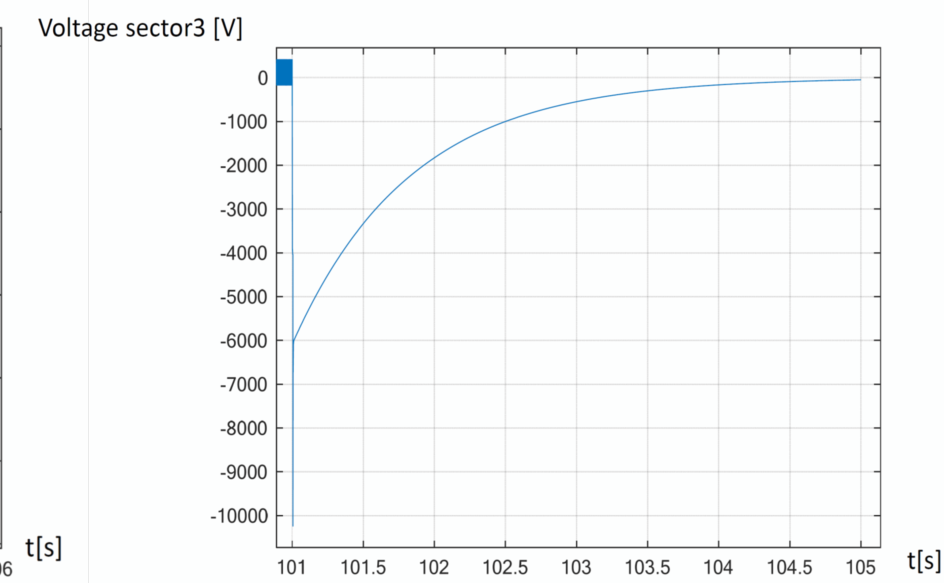


DT1	DT2	DT3	DTCB	Tgf1	Tgf2	Tgf3	Tgf4	Tgf5	Tgf6	Volt_sec1	Volt_sec2	Volt_sec3
0	0	0	0	0	0	0	0	0	0	6659,08	6396,11	6120,65
0,005	0	0	0	0	0	0	0	0	0	7401,10	6242,01	6880,25
0	0,005	0	0	0	0	0	0	0	0	7146,96	7140,88	6025,37
0	0	0,005	0	0	0	0	0	0	0	6511,48	7140,87	7147,41
0	0	0	0,005	0	0	0	0	0	0	6565,78	6372,12	6385,50
0,01	0	0	0	0	0	0	0	0	0	7371,64	6242,01	6852,89
0	0,01	0	0	0	0	0	0	0	0	7118,52	7112,47	6001,25
0	0	0,01	0	0	0	0	0	0	0	6511,48	7112,46	7119,00
0	0	0	0,01	0	0	0	0	0	0	6565,78	6372,12	6385,53
0,015	0	0	0	0	0	0	0	0	0	7342,14	6242,01	6825,46
0	0,015	0	0	0	0	0	0	0	0	7090,03	7084,00	5977,24
0	0	0,015	0	0	0	0	0	0	0	6511,48	7084,00	7090,51

……….Follows







CONCLUSIONS & FUTURE PERSPECTIVES

- ✓ **The developed model** of TFC circuit took into account **stray capacitances and stray inductances of DC busbars and of all FDUs,** also it took into account the magnetic mutual coupling among TF coils through a 18x18 TF matrix.
- ✓ **The maximum stress in term of over-voltages** were estimated considering 147 possible failure scenarios. Most critical failure condition occurred for double fault, delayed activation of a FDU and ground fault at one of its terminals.
- ✓ **Alternative topologies of FDU** will be taken into account to appraise their potential viability.

Acknowledgment
This work is carried out in the frame of the DTT activity. The authors are very grateful to all the colleagues involved in the DTT project for their precious contribution