Failure Mode And Recovery Strategies For The Operation Of The Tore Supra Tokamak

Ph. Moreau, F. Saint-Laurent, S. Brémond, J. Bucalossi, D. Douai, P. Hertout, M. Lennholm, P. Pastor, F. Leroux, N. Ravenel, and the Tore Supra team

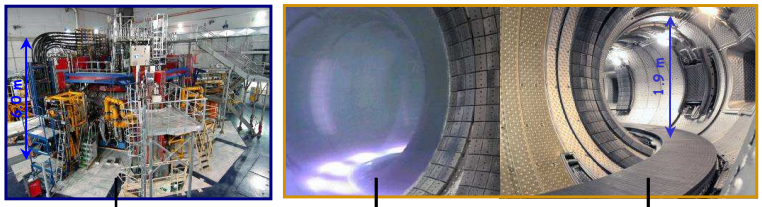
Association EURATOM-CEA CEA / DSM / IRFM
CEA-Cadarache, 13108 ST PAUL-LEZ-DURANCE (France)

Abstract

Plasma experiments in tokamaks are more and more demanding in terms of performance and discharge duration. In parallel the machine protection must be ensured. **Handling any deviation from the reference plasma scenario and any failure of the tokamak subsystems without terminating the discharge is becoming a crucial point.** On the Tore Supra tokamak, off-normal event detection procedures and mitigation strategies have been embedded in the real time Plasma Control System (PCS) and are now in frequent or routine operation.

What is an off-normal event on a tokamak?

- Tokamak operation requires the orchestration of many systems (> 50)
- Tore Supra tokamak is the largest superconducting tokamak in routine operation (started in 1988). It is devoted to long-duration high-performance discharge research.



Many and complex subsystems
Cryogenic plant, water cooling loops, multimegawatt RF systems, diagnostics, etc.

Plasma control and performance
Plasma is a non-linear media

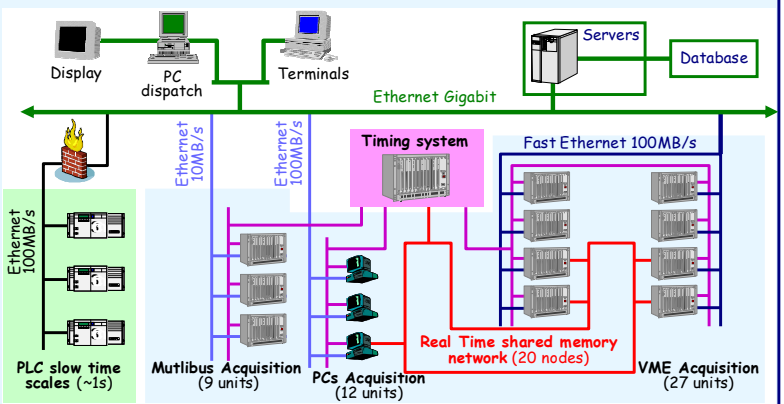
Protection of Investment
Chamber entirely covered by actively-cooled components

During a plasma discharge default manifests itself in various ways and has various consequences:

- **Actuator may degrade** or switch off for self protection temporarily and/or partially.
- **Diagnostics** comprise a large set of channels or sensors amongst which only a small number can be unavailable.
- **PCS or related networks** may crash, or real time (RT) evaluation and feedback processes may go wrong.
- Being a non linear media, the **plasma** can experience unexpected evolution or instability growth leading to a degraded performance plasma regime or to the abrupt termination of the plasma discharge in a disruption.

Tore Supra Plasma Control System (PCS)

The Tore Supra real time PCS is completely integrated into the data acquisition system



- **A unique timing unit** to synchronize all the subsystems (1 MHz clock)
- A timing network used to perform the plasma **event distribution**
- **Continuous acquisition** and monitoring at low frequency 24h a day for specific systems
- **Fast acquisition** (kHz – GHz) made through 3 technologies (Multibus, VME and PCs)
- **Real time information sharing** performed by a dedicated shared memory network
- **5 VME units dedicated to the control of actuators + 1 PC unit for the RT supervision**

Hardware failure Handling

- RT **detection** of hardware failure is performed at:
  - → **both sub-plant system and inter-plant link levels**
  - → **any step of the data flow** (from the diagnostics to the actuators via the acquisition units)
- Most of the time a **hardware failure results in a plasma soft stop** (no hardware redundancy)

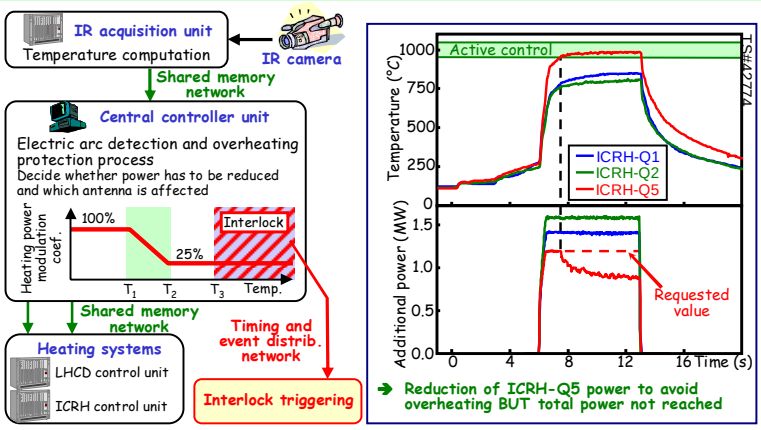
Some **exceptions** exist and are embedded in the hardware failure handling processes:
  - → **complementary diagnostics** (interferometry ←→ plasma Bremstrahlung emission),
  - → **equivalent actuators** e.g. heating systems use several antennae

- **Prevention actions** are necessary to reduce probability of failure. Any controller units ensures that the actuator limits are not reached.

Present Plasma off-normal event handling

The plasma off normal events can be classified in 2 categories:

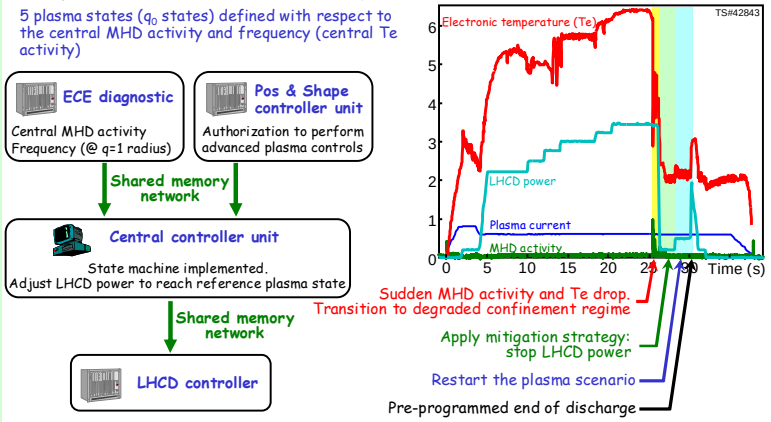
→ **machine protection: ~11 automatic processes implemented and routinely used**
Against: disruption, in-vessel damages and water leak, fast electrons, etc.
➤ **Example of protection against overheating using IR diagnostic**



→ Reduction of ICRH-Q5 power to avoid overheating BUT total power not reached

→ **degradation of the plasma discharge performance**

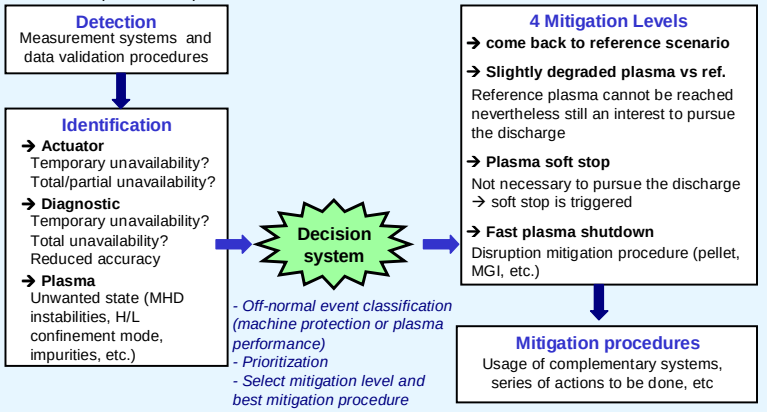
In some case a degradation of the plasma performance is observed without any machine protection issues. Such degradation is usually related to magnetohydrodynamic (MHD) activity in the plasma. Recently an **automatic detection and basic mitigation procedure have been tested.**



General framework under development

Improvement of failure detection and mitigation strategies is under development through:

- → the enhancement of **data validation procedures** (data certification)
- → the **identification and the classification of events**
- → the selection of the best mitigation strategy via an **expert system**
- → the **improvement of the mitigation strategies**. (e.g. considering a multi-antenna heating system, the reduction of injected power due to the overheating of one antenna could be compensated by the others)



Considering the international characteristic of fusion research and the construction of ITER, **generic tools and generic mitigation processes must be developed** to be used on any present day and futures machines