As-built design of the control systems of the ITER full-size beam source SPIDER in the Neutral Beam Tests Facility

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SPIDER Experiment

The ITER Neutral Beam Test Facility hosts

- ❖ **SPIDER** – ITER full-size negative ion source – in operation
- ❖ **MITICA** – ITER full-size HNB prototype – under advanced construction

- ■SPIDER aims at optimizing the negative ion source for the ITER Neutral Beam Injector
- ■768 signals from PXI ADC devices (100 Hz-2 MHz)
- ■8634 signals from EPICS Process Variables (0.1-10Hz)
- ■24 camera devices (0.1-10Hz)
- ■**Pulse duration up to 3000s – Beam pulses longer than 1000s are routinely performed**

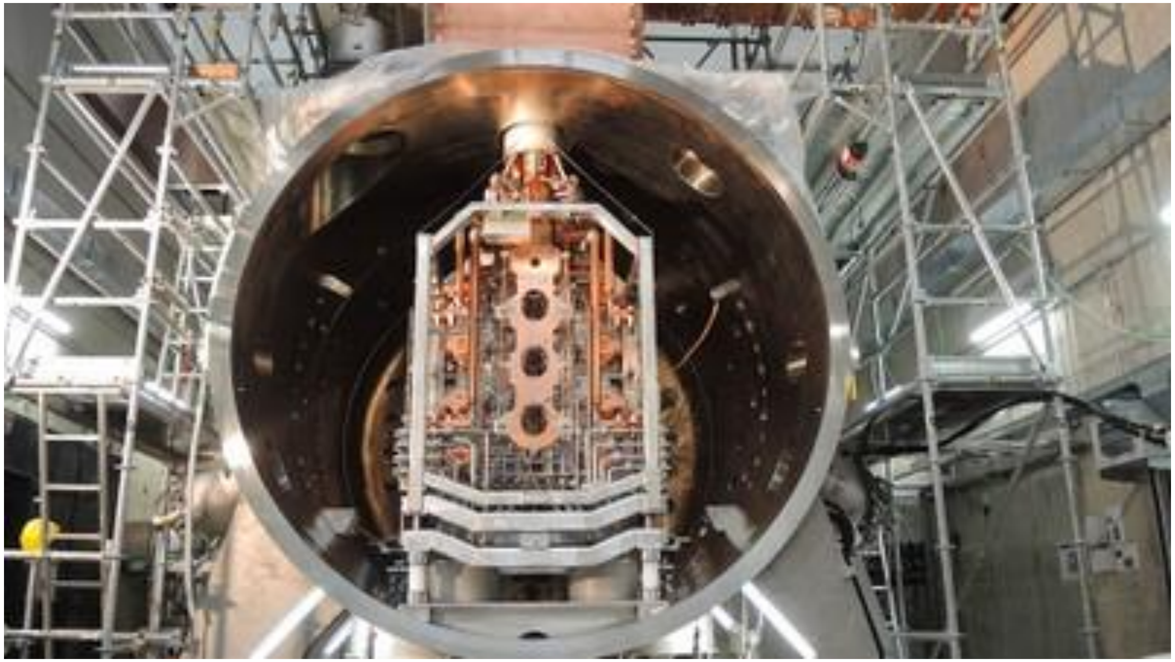

Fig.1. View of the SPIDER ion source

→"CODAS for long lasting experiments. The SPIDER experience" presentation on Wed 7th July h16:20

Outlines

- SPIDER Architecture
- SPIDER Central Interlock System
- SPIDER Central Safety System
- SPIDER System Integration
- Lesson learnt

SPIDER Architecture

- Classical three-tier including
  - ✓ conventional control (**CODAS**)
  - ✓ investment protection (so called **interlocks**)
  - ✓ personnel safety (non-nuclear).

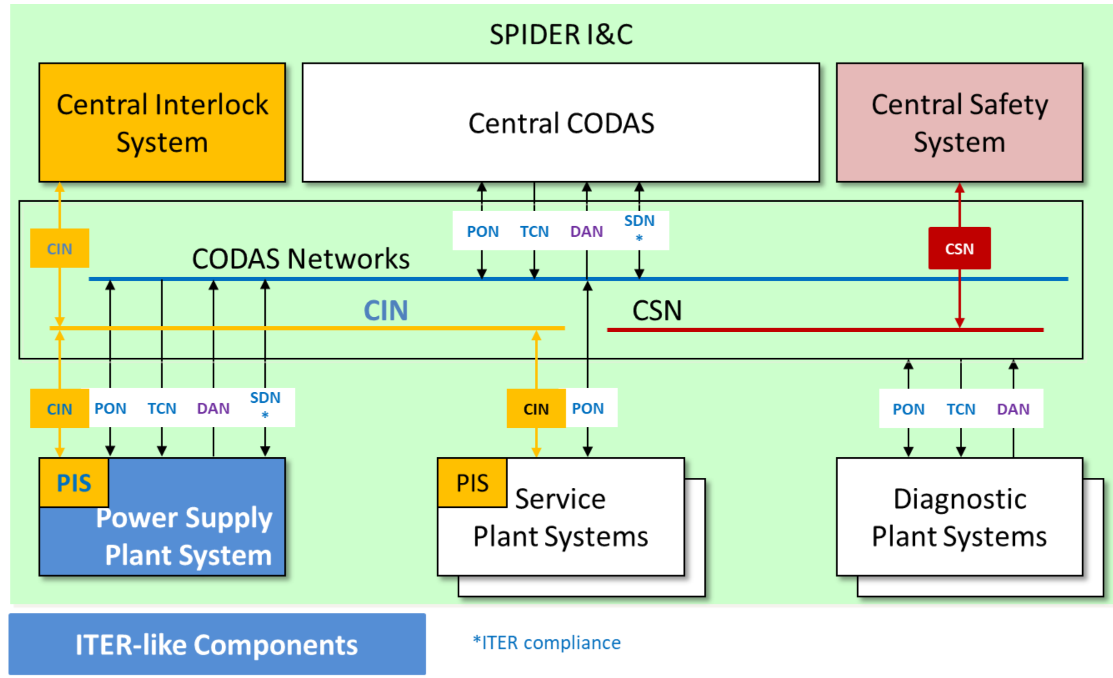

Fig.2. Three-tier architecture

The tiers are logically independent of each other and their implementation uses different hardware/software technologies.

The three systems have been developed and tested separately and finally have undergone the integrated commissioning to achieve coordinated operation.

SPIDER Control System: Numbers

- 15 cubicles
- 10 physical Linux server
- 6 physical Windows PC
- 7 Virtual Linux server
- 9 PXIe Chassis
- 9 cPCI Chassis
- 28 ADC PXIe
- 2 Event Driven ADC
- 10 Timing Module
- 4 spectro CCD
- 4 spectroscopy
- 2 IR Cameras
- 21 Visible Cameras
- 8 Red Pitaya boards
- 4 Raspberry boards

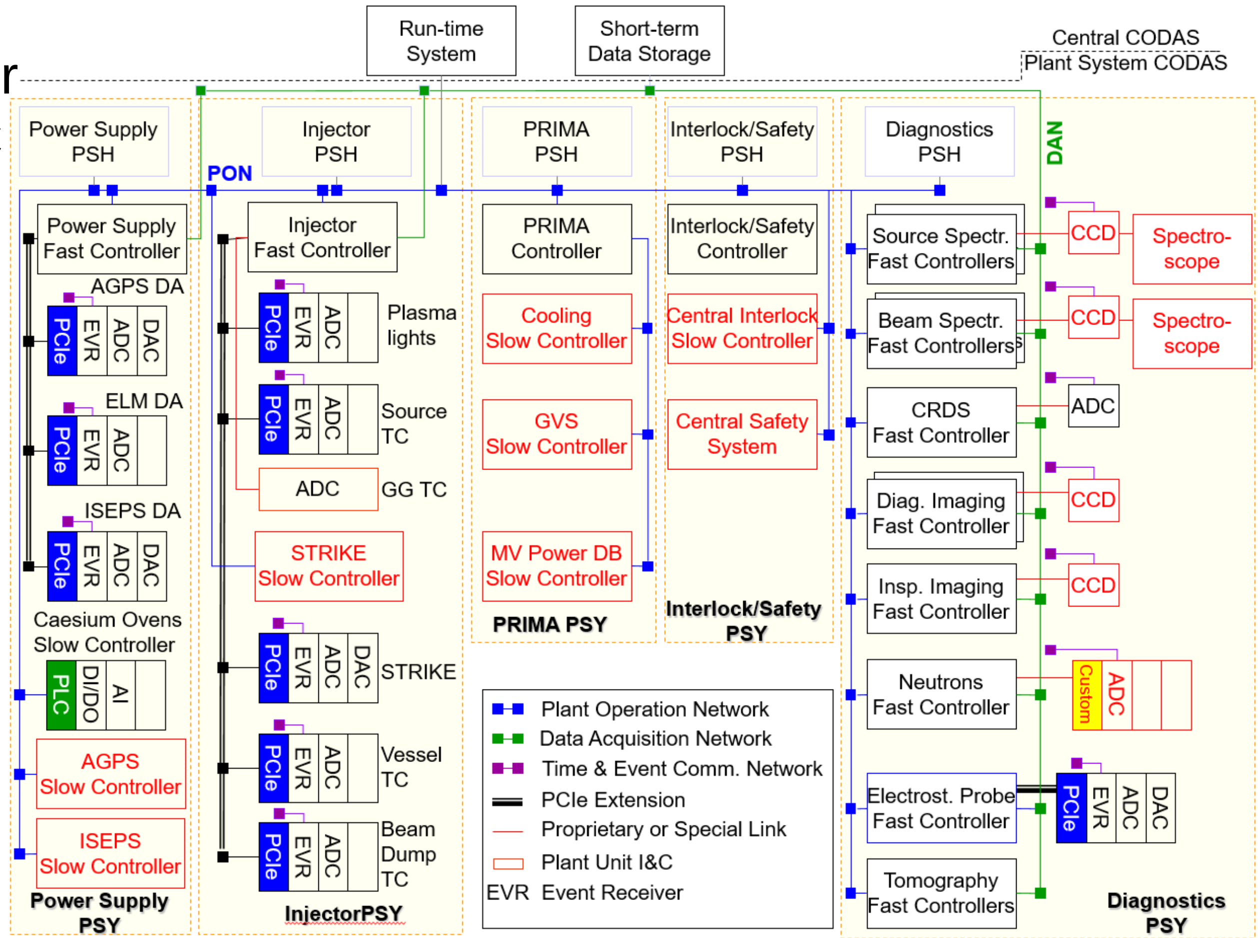

Fig.3. SPIDER CODAS block diagram

SPIDER Control System

- Software components
  - EPICS
    - 10 ITER CODAS IOCs
  - MDSplus
    - 1 MDSplus Dispatcher
    - 38 MDSplus Servers
  - MARTe
    - 1 MARTe thread

SPIDER Central Interlock System (CIS)

Provides **slow** (**20 ms** PLC reaction time) and **fast protection functions** (**10 µs** FPGA reaction time time), defining reaction time as the time slot from fault detection to generation of protection commands

Hardware

- ✓ 1 Siemens S7-1516 PLC (no redundancy)
- ✓ 9 Remote I/O nodes - ET 200SP
- ✓ 3 NI CompactRIO chassis

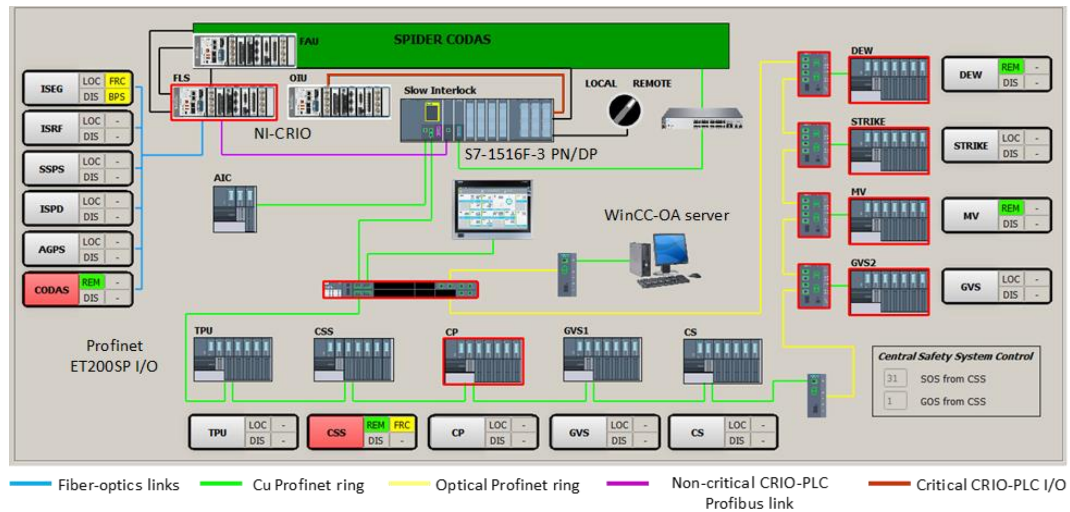

Fig.4. Layout of SPIDER Central Interlock System

Software

- ✓ WinCC-OA SCADA.
- ✓ Protection function reliability up to SIL1 (IEC 61508-1).
- ✓ Protection functions are programmed through incidence matrix (connections between causes and effects)

SPIDER Central Safety (CSS)

CSS is devoted to protection of safety and health of personnel.

Hardware – Fully industrial – ITER solution

- PLC S7-400FH PLC
- 11 Remote I/O nodes
- Fully-redundant architecture (PLC, remote I/O, servers, consoles, network).

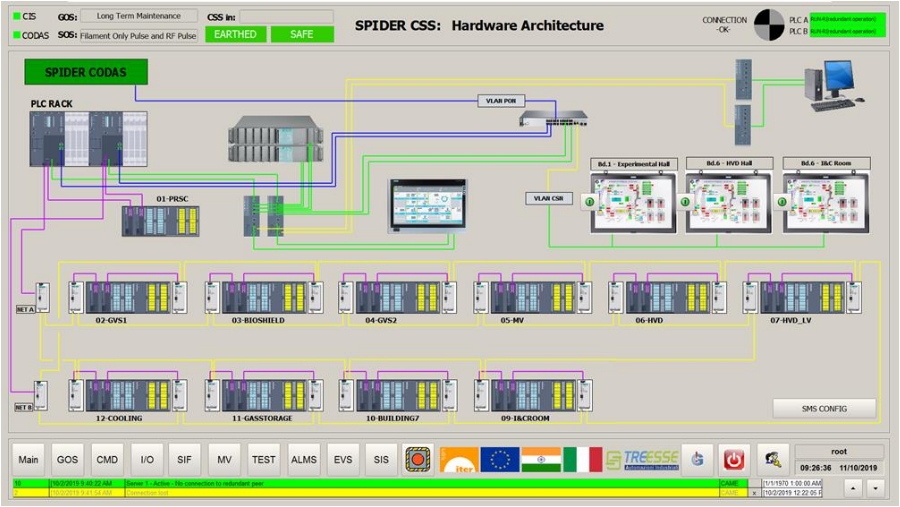

Fig.4. Layout of SPIDER Central Safety System

Software

- PROFIsafe communication (tests still ongoing to qualify S7-400FH to WinCC-OA PROFIsafe communication profile).
- System supervision is implemented through WinCC-OA SCADA.
- Hw and safety-relevant Sw certified up to SIL3 (IEC 61508-1)
  - (Safety F-blocks and Matrix tool)
- ~ 60 Instrumented Safety Functions (SIF) qualified from SIL0 up to SIL2
- SIFs implemented by Matrix tool. Makes tests faster and more reliable.

System Integration

- Integration of Control, Interlock and Safety is achieved via
  - Global Operating States (GOS)
    - Overall states associated with permission/prohibition of specific activities
  - Session Operating Scenarios (SOS)
    - Scenarios describing within a given GOS the actual activities to be carried out in a specific experimental session

Table 1. Operating states

GOS	SOS
Long-Term Maintenance	---
Short-term Maintenance	---
Test and Conditioning	Gas only-pulse
	Plasma pulse
	HV test with/without gas
	ISEPS-only pulse
Beam Operation	Beam in H/D onto instrumented calorimeter
	Beam in H/D onto beam dump

System Integration

- GOS/SOS have safety implications and are set in CSS.
  - GOS/SOS enables the active SIFs that are active.
- GOS/SOS are propagated to Central Interlock System
  - CIS selects the active protection matrix based on GOS/SOS.
- CODAS receives the current association GOS/SOS from CIS
  - CODAS select the plant system sequences to be used in control based on GOS/SOS

Real-time Breakdown Management

1,2 EG and AG BD detect signals acquired on Interlock Fast Acquisition Unit.
3,4 EG voltage and current slow acquisition.
5,6 AG voltage and current acquisition.
7,8 EG voltage and current fast acquisition triggered on BD detection.

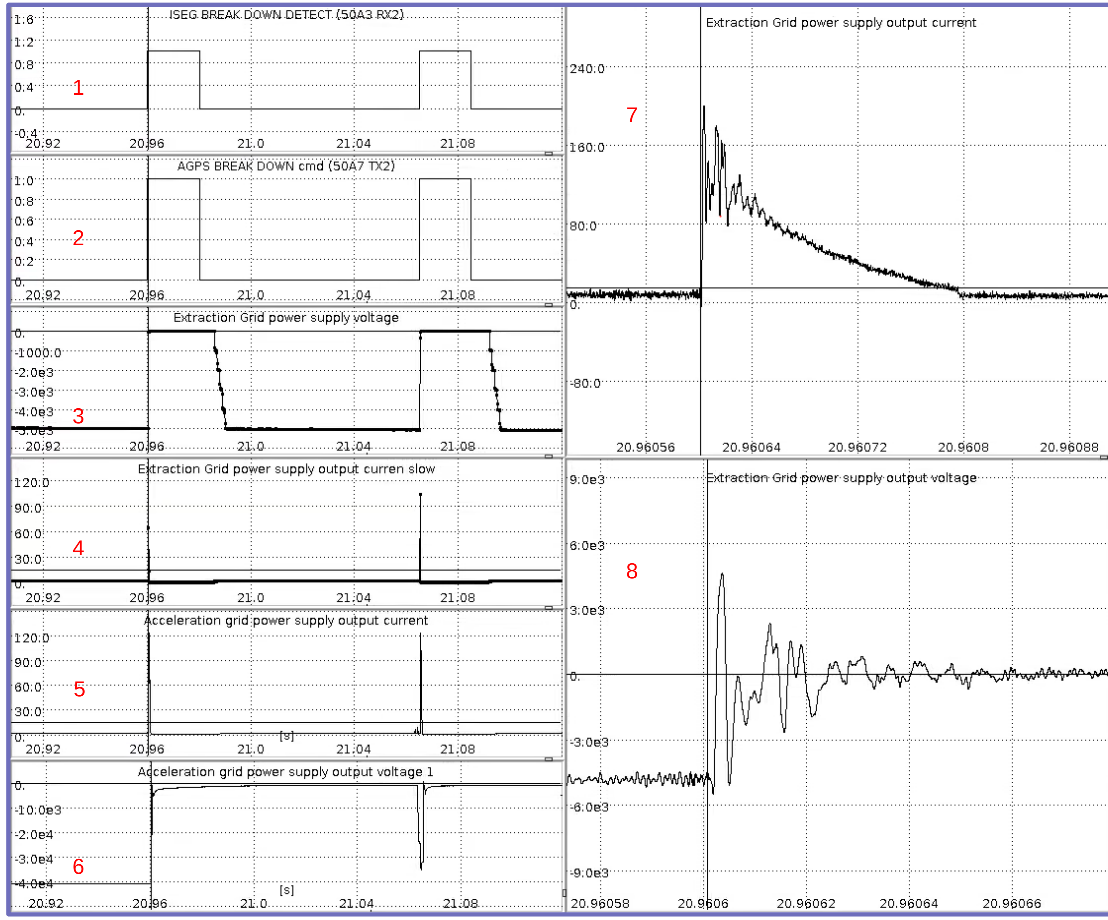

Fig.5. Real-time breakdown management

Lesson learnt

- Pulse duration has grown more rapidly than expected from 10 s to 3600 s (40/60 s of beam every 240/360 s) in less than 3 years
  - Event driven acquisition must be used where possible.
  - Enable acquisition only during the beam phase.
  - Attention should be paid to accessing data during the pulse when data reading and writing are simultaneous.
- Diagnostic requirements have sometimes been underestimated.
  - 6 visible cameras were initially foreseen, while now 21 cameras are installed
  - Region of Interest and frame rate reduction mitigate the impact on data storage and network throughput.

Lesson learnt

- Diagnostic systems not defined in the design phase have been later integrated in CODAS using non-standard, heterogeneous hardware.
  - The solution PXIe + ADC modules is too rigid and is often an overkill solution, especially in dynamic experiments
  - a stand-alone mini-acquisition system to be placed everywhere (In SPIDER Red-Pitaya acquisition board) is very useful to test and validate new and evolving diagnostic system
- Battery-powered oscilloscopes are often used to execute temporary measurements:
  - CODAS should integrate acquisition from commercial oscilloscope

SPIDER Central Control Room

Thank you