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Integration of control, investment protection and safety in the ITER Neutral Beam Test Facility

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Abstract - The ITER Neutral Beam Test Facility (NBTF) is an extensive R&D programme currently under advanced construction at Consorzio RFX, Padova (Italy), with the aim of developing and testing the technology required by the ITER neutral beam injectors. The NBTF uses a two-step approach that involves the implementation of two experimental devices: the first, SPIDER, for the study of the ion source and the second, SPIDER, for the development of the full-size HNB prototype. SPIDER is currently in operation, whereas SPIDER is being constructed and most electrical and mechanical components have been already installed.
The operation of each experiment will be managed through three instrumentation and control (I&C) systems, independent of each other, referred to as the Control and Data Acquisition System (CODAS) to manage conventional control, the Central Interlocks System (CIS) to protect the investment, and the Central Safety System (CSS) responsible for occupational safety and environmental protection. Following a common principle in system engineering, it is required that system reliability increases significantly from CODAS to CIS to CSS, whereas complexity decreases drastically.
The paper will first discuss on the operation of the SPIDER I&C systems, discussing the advantages and disadvantages of the SPIDER realization. It will then describe the status of the SPIDER I&C systems, with focus on the system evolution from SPIDER to SPIDER, triggered by both additional requirements and technology evolution.
Finally the paper will discuss the interaction of the SPIDER I&C systems in the overall operation of the experiment.

Introduction

SPIDER (Source for Production of Ions in Deuterium Extracted from Rf plasma) [1] is the R&D that aims to build and test the full-scale beam source of the ITER Heating Neutral Beam Injector (HNB) [2]. It has been operating since June 2018 at the Neutral Beam Test Facility that is located in Padova, Italy at the Consorzio RFX site [3-4].

Table 1. Scientific Requirements.

SPIDER figures	Unit	values
Beam energy	keV	-100
Max source filling pressure	Pa	0.3
Max deviat. from beam uniformity		±10%
Extr. ion current density	A/m^2	>355 H_2 >285 D_2
Beam on time	s	3600
Co-extracted electron fraction		<0.5 H_2 <1 D_2

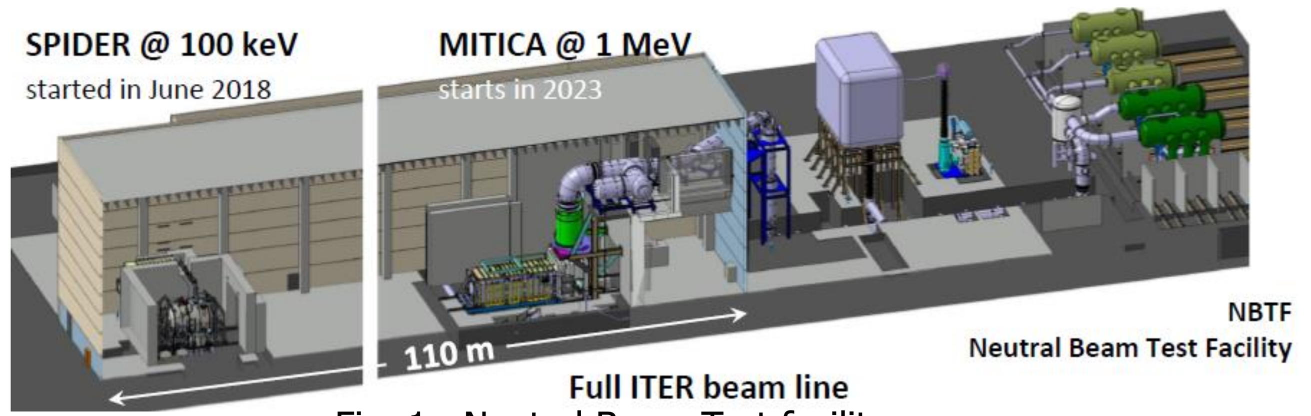

Fig. 1. Neutral Beam Test facility

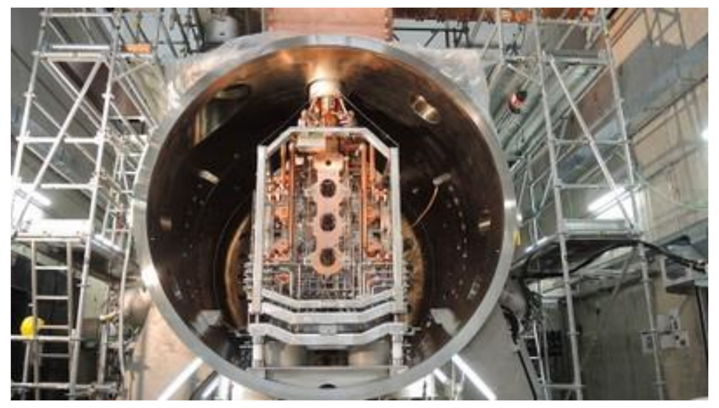

Fig. 2. SPIDER Ion Source – View of RF drivers

Fig. 3. View of SPIDER bio-shield

SPIDER Instrumentation and Control - Three-Tier Architecture

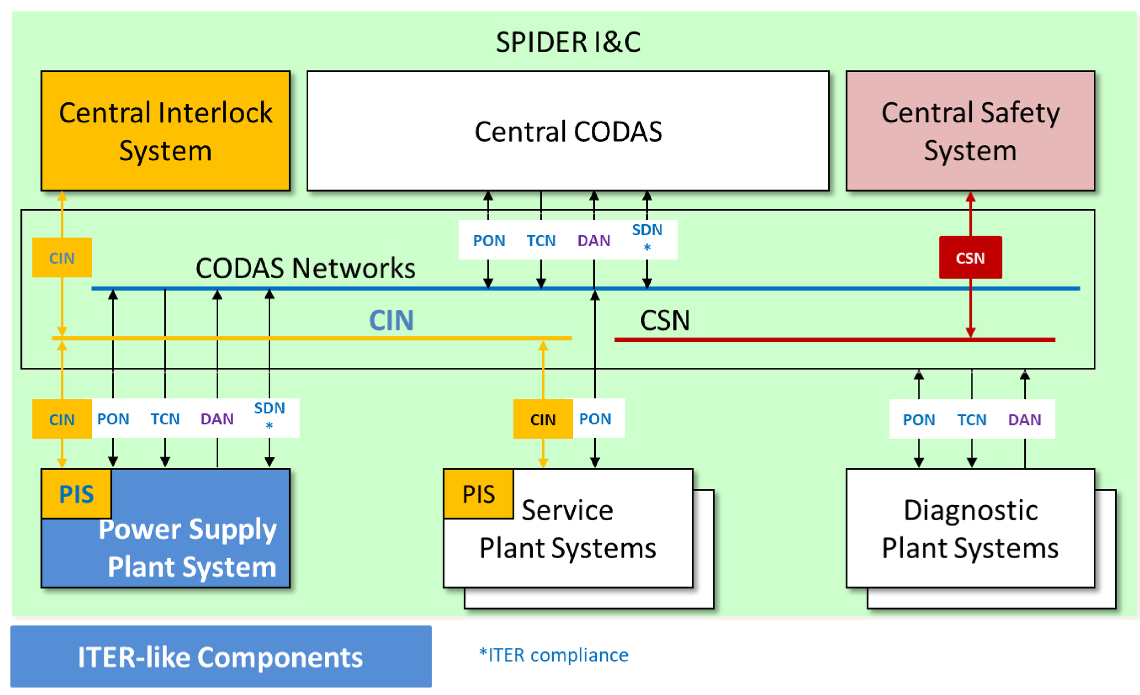

Fig. 4. SPIDER classical three-tier architecture including conventional control (CODAS), investment protection (so called interlocks), and personnel safety (non-nuclear).
The tier are logically independent of each other and their implementation uses different hardware/software technologies.

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

SPIDER Conventional Control (CODAS)

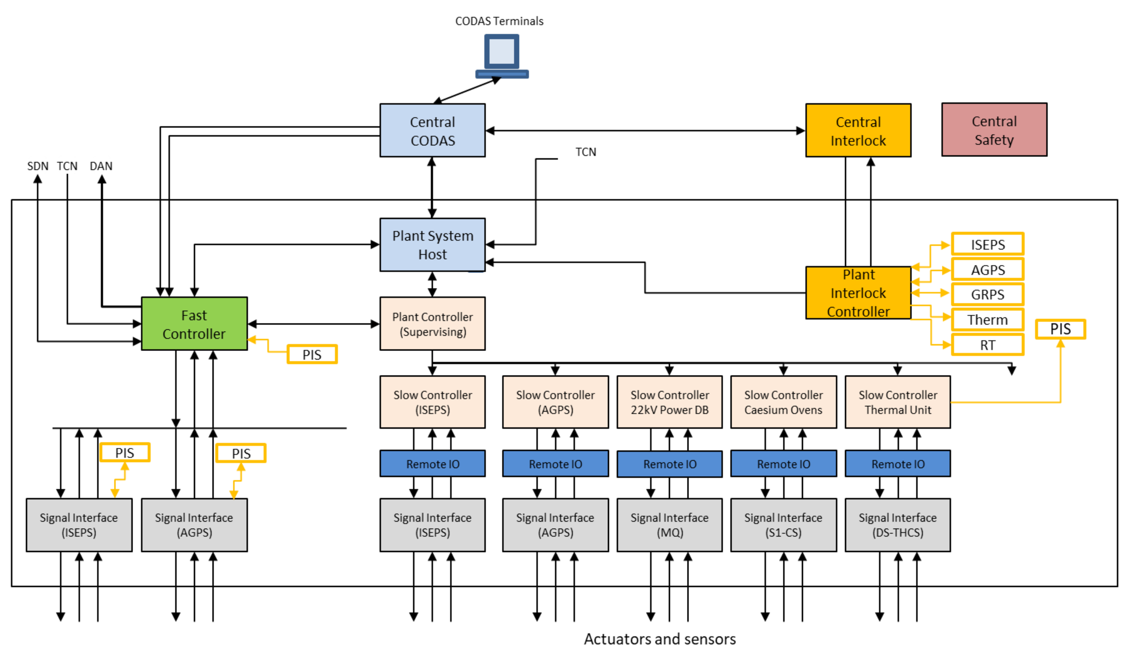

Fig. 5. Slow plant control is implemented by using EPICS in the distribution by ITER included in the CODAC Core System.
Fast control (submillisecond) uses state-of-the-art servers and the software framework MARTe for real time-control
Data acquisition is based on state-of-the-art servers and the software framework MDSplus for data management.

SPIDER Central Interlocks (CIS)

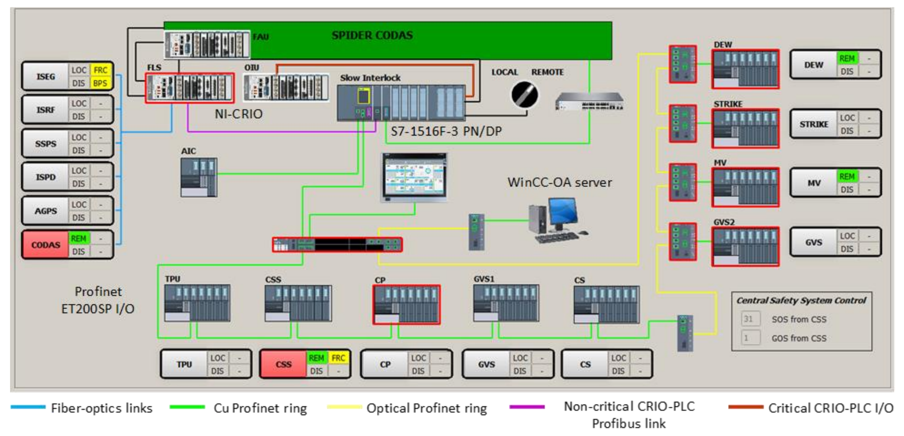

Fig. 6. SPIDER Central Interlocks System. It provides slow protection functions (20 ms PLC reaction time) and fast protection functions (10 µs FPGA reaction time time), defining reaction time as the time slot from fault detection to generation of protection commands.
Implementation of slow functions uses a non-redundant PLC connected to I/O through Profinet, whereas fast functions are implemented through NI compactRIO (FPGA only, no processor on board).
System supervision is implemented through WinCC-OA SCADA.
Protection function reliability up to SIL1 (IEC 61508-1).
Software is data driven: protection function can be programmed through incidence matrix (connections between causes and effects)

SPIDER Central Safety System (CSS)

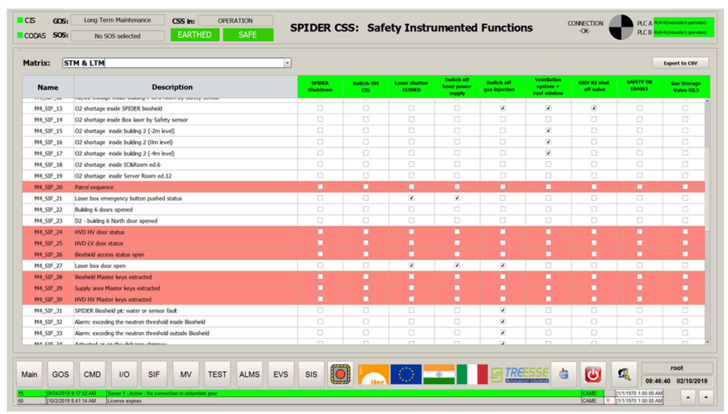

Fig. 7. Safety Instrumented Functions.

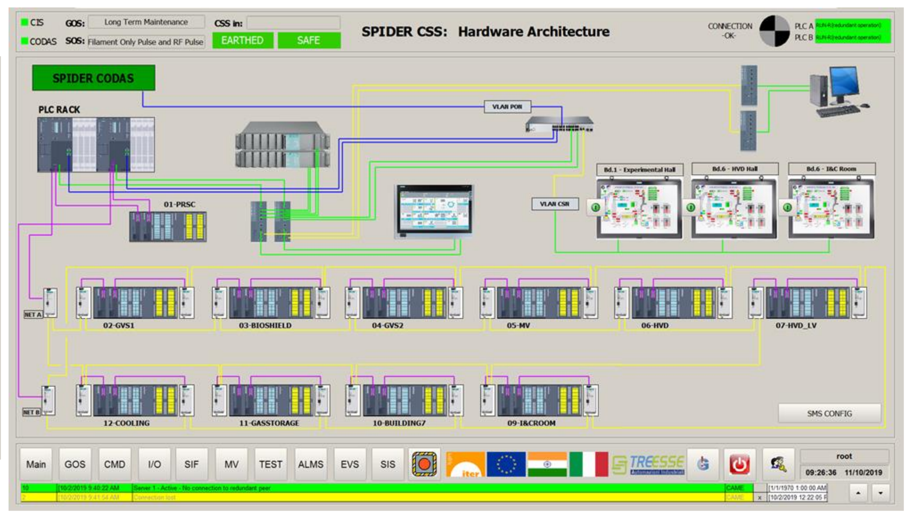

Fig. 8. SPIDER Central Safety System exploit a full-redundant architecture (S7-400FH PLC, WinCC-OA SCADA servers, network components).
Communication is implemented through PROFIsafe (tests are ongoing to qualify S7-400FH to WinCC-OA PROFIsafe communication profile).
System supervision is implemented through WinCC-OA SCADA.
Hardware and safety-relevant software are certified up to SIL3 (IEC 61508-1)
Safety Instrumented Functions are implemented through Matrix tool that also makes the test process faster and more reliable.

Global Operating States / SPIDER Operating Scenarios

Table 2. Global and SPIDER 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

Fig. 6. Integration of Control, Interlocks and Safety is achieved through Global Operating States (GOS) and Operating Scenarios (SOS). GOS are overall states associated with permission/prohibition of specific activities. SOS are scenarios describing within a given GOS the actual activities to be carried out in a specific experimental session.
GOS/SOS have safety implications and, as such, are set in CSS. The association GOS/SOS enables the active SIFs that are active.
GOS/SOS are propagated to CIS, through digital I/O signals, and select the active protection matrix.
CODAS receives the current association GOS/SOS from CIS and select the plant system sequences to be used in control.

Conclusions

SPIDER CODAS, Central Interlocks System and Central Safety System are fully integrated and their coordinated operations allow the management of the SPIDER experiment either in experimental sessions or in maintenance.
Integration is achieved through high-level concepts, such as Global Operating States and SPIDER Operating Scenarios.

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