ITALIAN NATIONAL AGENCY FOR
NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

Control system design for hybrid nuclear reactors

FUNFI-IT Workshop

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Outline

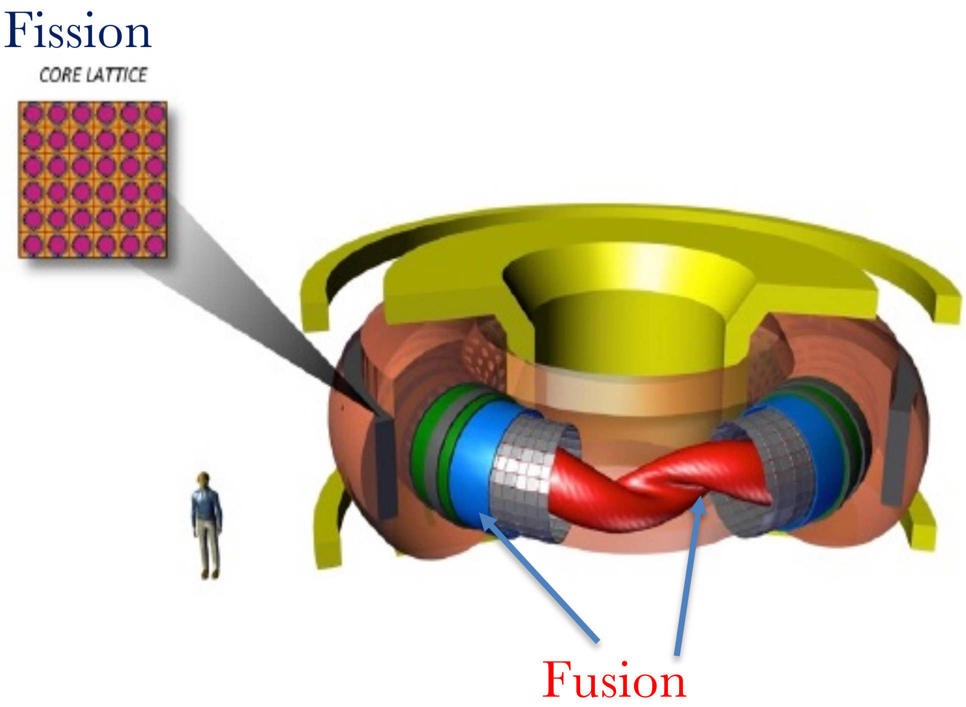
Why a control system?

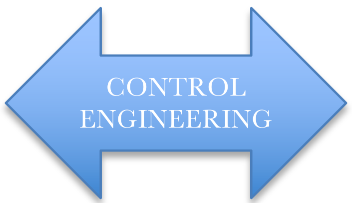
- What plant
- Control objectives
- How to design it
- A possible control system architecture
- Conclusions

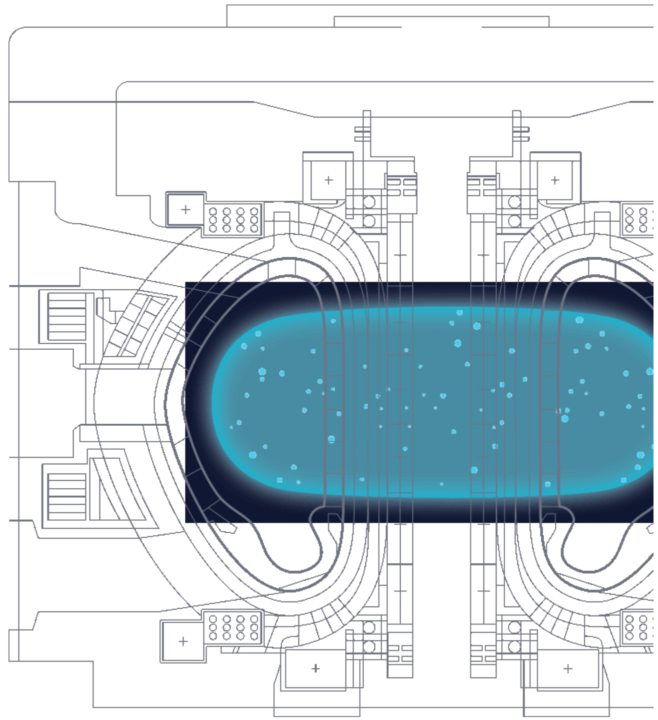
Fusion-fission hybrid systems

ITER FUSION PLANT

HYBRID PLANT







+ Fission Power plant complexity

Control objectives

Magnetic and Kinetic Control

- Plasma current and shape
- Divertor configuration (strike points)
- Heat load (ELMs, divertor power)
- Current (J) and Te profiles
- Fusion power
- Tritium control
- Neutron production

Machine Protection and Safety

- First wall/divertor heat load protection
- H-L back-transition avoidance
- MHD control
- Disruption avoidance/mitigation
- Runaway electron avoidance/mitigation
- Instabilities
- Impurity events
- Radionuclide leakage
- Neutronics
- Personnel protection

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Diagnostics and actuators

Diagnostics

- Magnetics
- Reflectometry
- ECE
- Neutron/Gamma diagnostics
- IR polarimetry/interferometry
- Spectroscopy
- Tomography
- …..

Actuators

- Central Solenoid (CS) coils
- Poloidal Field (PF) coils
- Gas Injection
- Pellet injection
- Auxiliary Heating (ICRH, ECRH, NBI,…)
- ….

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EX: EU DEMO diagnostic and control concept

	Control quantity	Operational limits	Diagnostics	Actuators + interactions
equilibr. control	Plasma current	safety factor limit (q_{95})	magnetic diagnostics	CS coils auxiliary heating
	Plasma position and shape, incl. vertical stability	wall loads (FW and div.) max. Δz / VDE disruption	magnetic diagnostics Reflectometry, ECE neutron/gamma diagnostics IR polarimetry/interferometry	PF + CS coils auxiliary heating gas injection
kinetic control	Plasma (edge) density	density limit	Reflectometry IR polarimetry/interferometry Plasma radiation	pellet injection (fuel) gas injection pumping system
	Plasma radiation, impurity mixture, Z_{eff}	radiation limit LH threshold	Spectroscopy+radiation meas. U_{loop}	impurity gas injection auxiliary heating
	Fusion power	wall loads (FW and div.) LH threshold	Neutron diagnostics FW/blanket and div. power (for calibration only)	pellet injection (fuel) impurity gas injection auxiliary heating
	Divertor detachment and heat flux control	divertor wall loads LH threshold	Spectroscopy+radiation meas. Thermography Divertor thermo-currents Reflectometry, ECE	gas injection (impurities + fuel) pellet injection (fuel) PF coils pumping system
instabilities/events	(MHD) plasma instabilities	various (→ disruptions)	Reflectometry, ECE IR polarimetry/interferometry magnetic diagnostics neutron/gamma diagnostics	auxiliary heating ECCD PF coils
	Plasma pressure	beta limit	magnetic diagnostics density and temperature meas.	auxiliary heating fuel and impurity injection
	Unforeseen events (impurity ingress, component failure)	various (→ disruptions)	all	all

From: Wolfgang Treutterer, ITER Control System, IAEA DEMO Programme Workshop 2018, Daejeon

How to design a plant control system

Control Architecture

- Plant Modelling
- Control strategy (Operating modes)
- Control functions (Conventional, Protection, Safety)
- Control logics
- Control architecture details

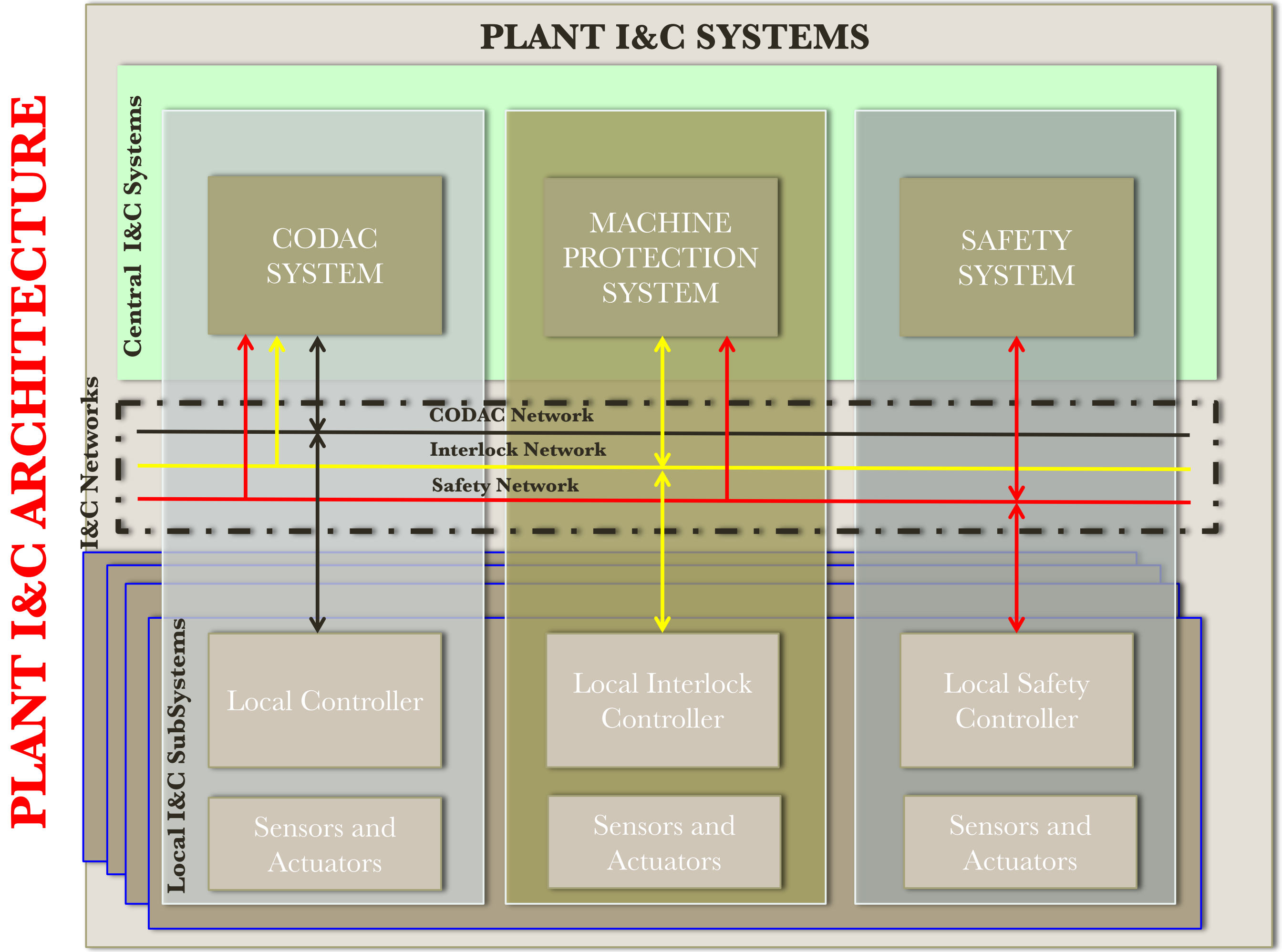
Controller design

- Local control indentification
- Monitoring needs
- Diagnostics characteristics
- Actuator characteristics
- Control loop timing
- Control reliability (PFH)

Control system implementation

- Control framework
- Real-time issues
- Control technology (HW/SW)

Plant I&C Architecture



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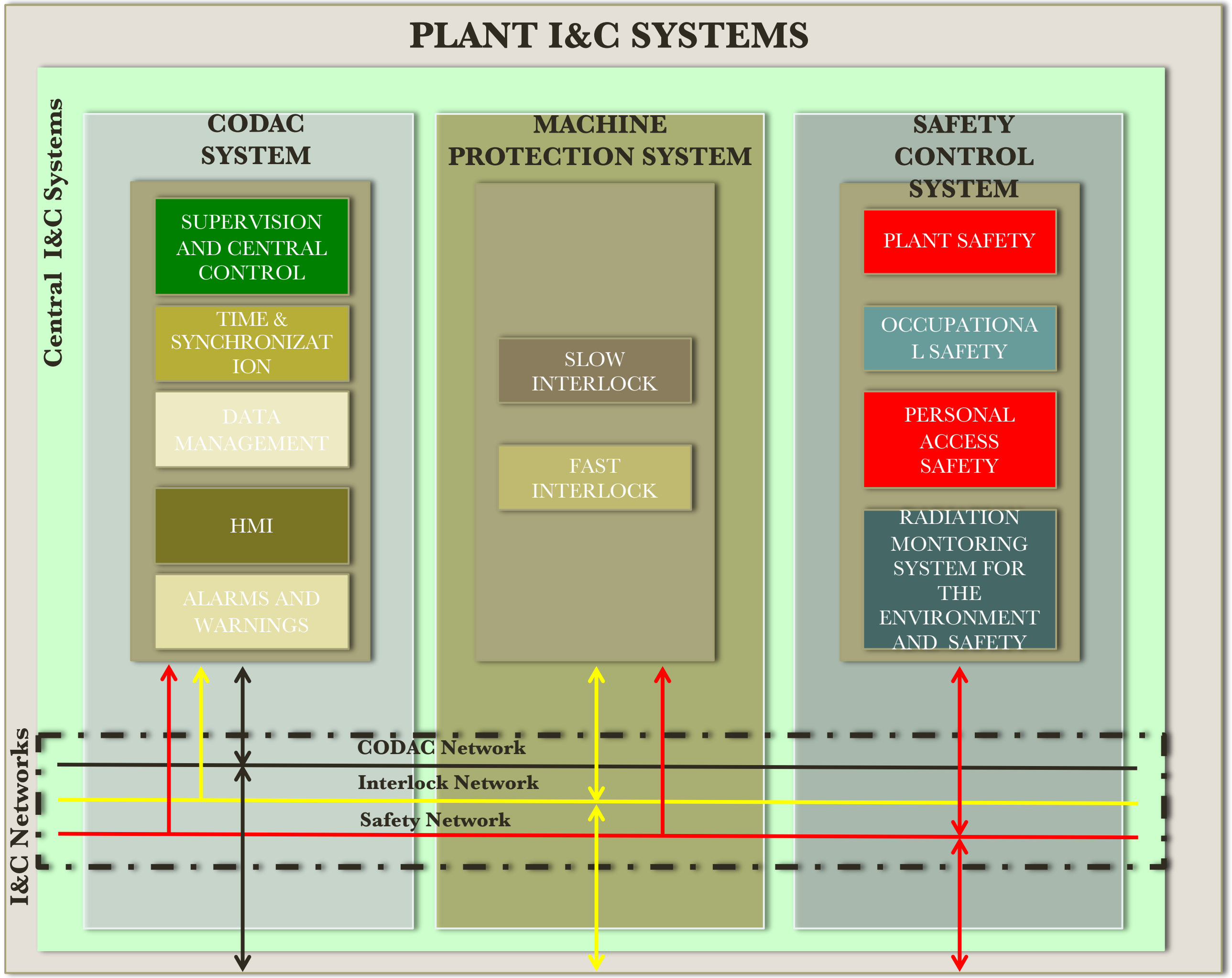
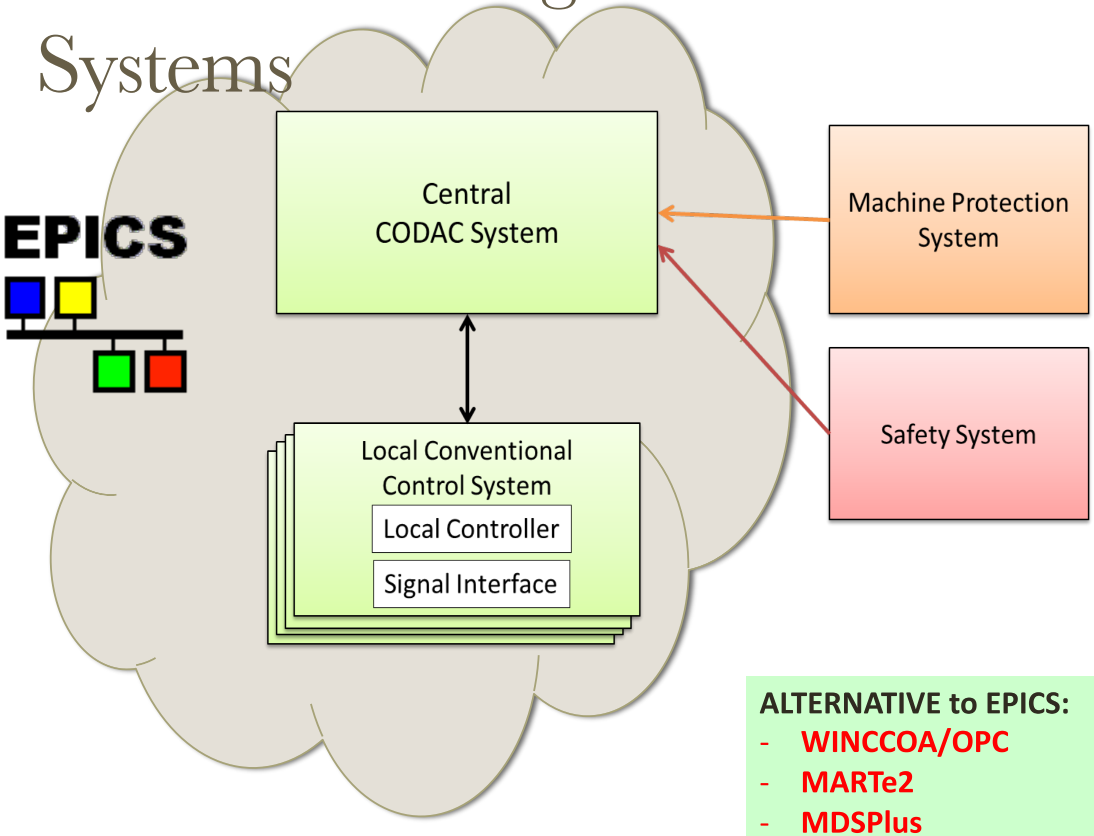
Plant I&C Architecture

PLANT I&C ARCHITECTURE



Plant I&C Architecture

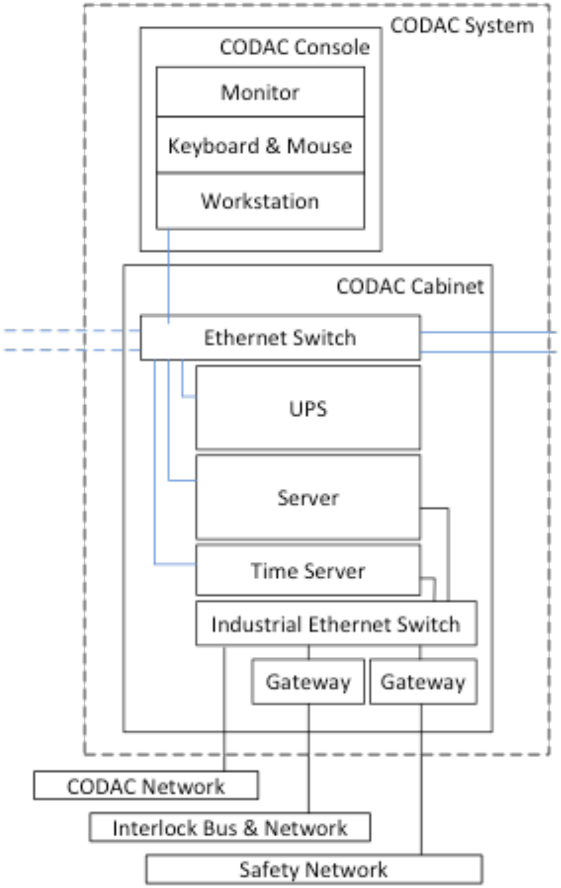
Relations among Control Systems



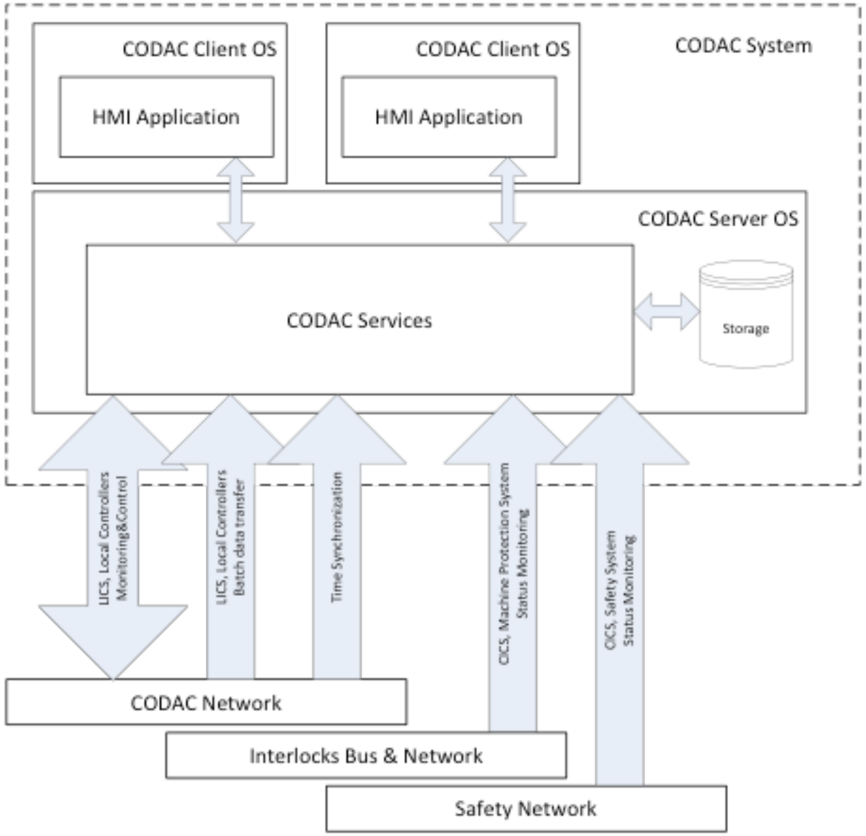
ALTERNATIVE to EPICS:
- **WINCCOA/OPC**
- **MARTe2**
- **MDSPlus**

CODAC - Main components identification

Physical Architecture

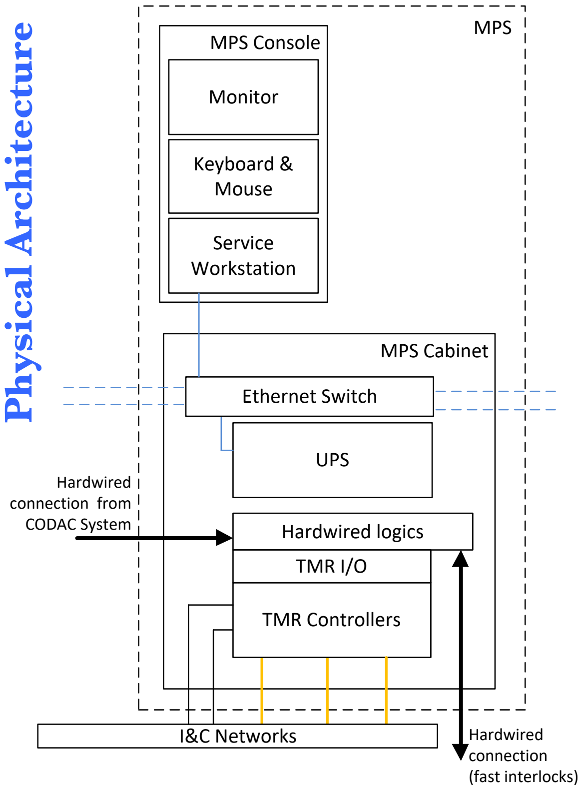


Software Architecture



MPS - Main components identification

Physical Architecture

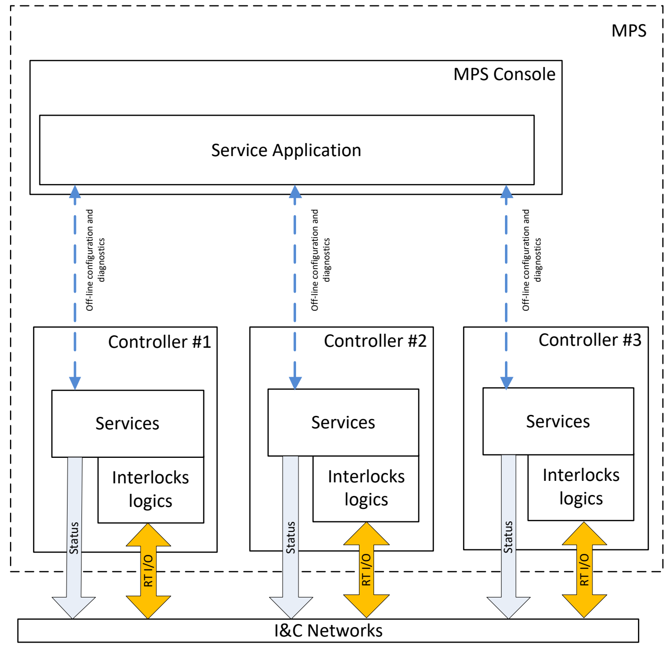


Three Modular Redundant (TMR) controller for slow interlocks

Hardwired logics for fast interlocks

Service workstation for configuration and management

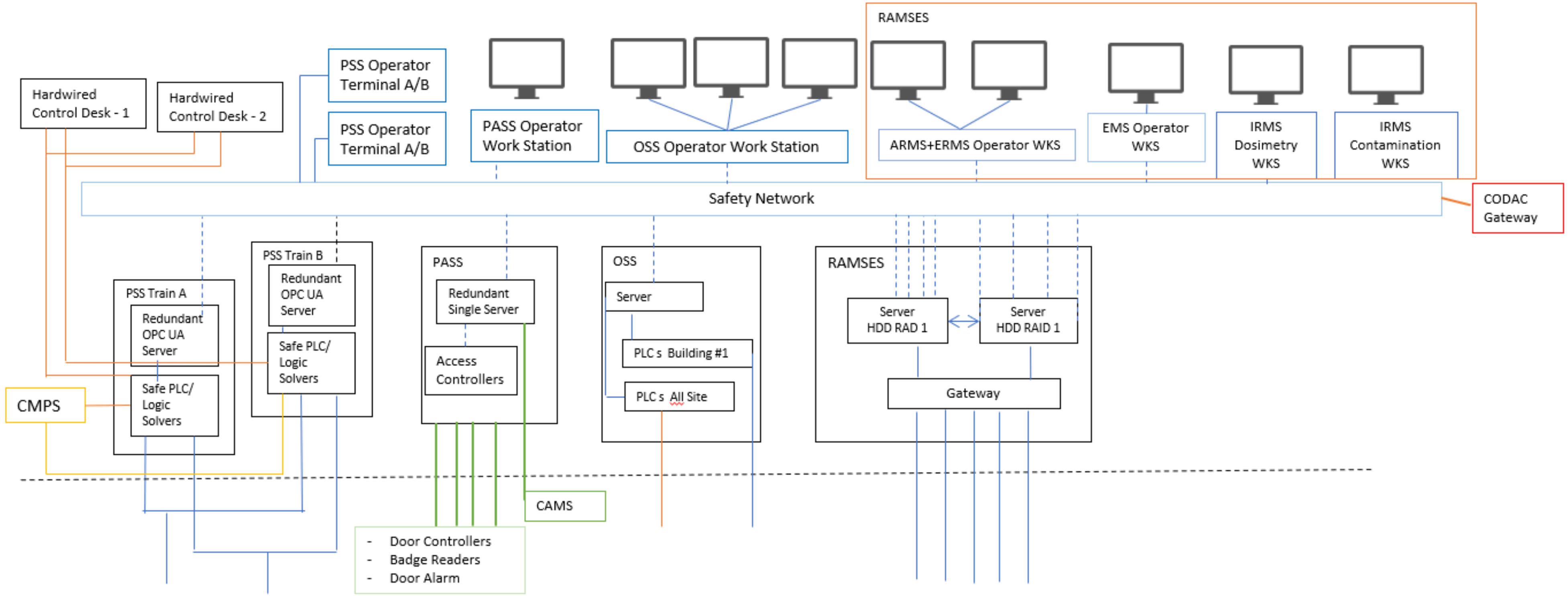
Software Architecture



Three identical control logics running in parallel

Voting system: logics 2oo3

SCS - Main components identification

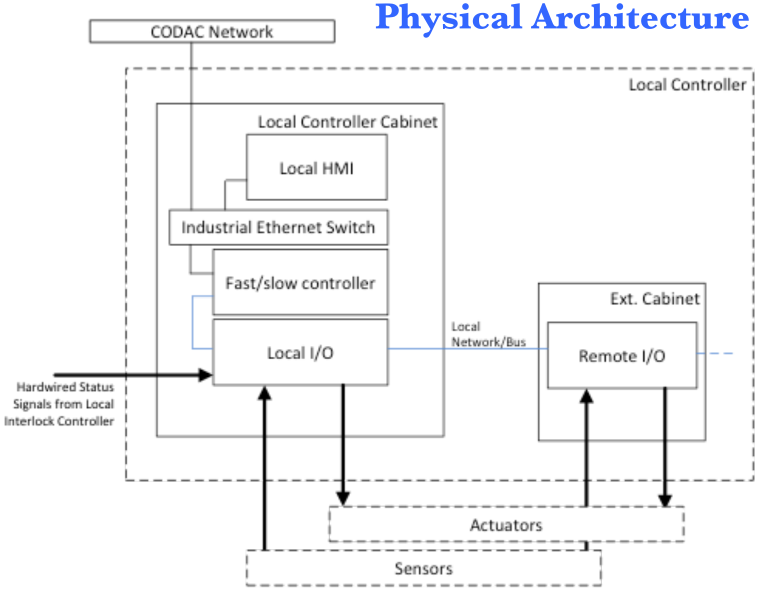


Local Control

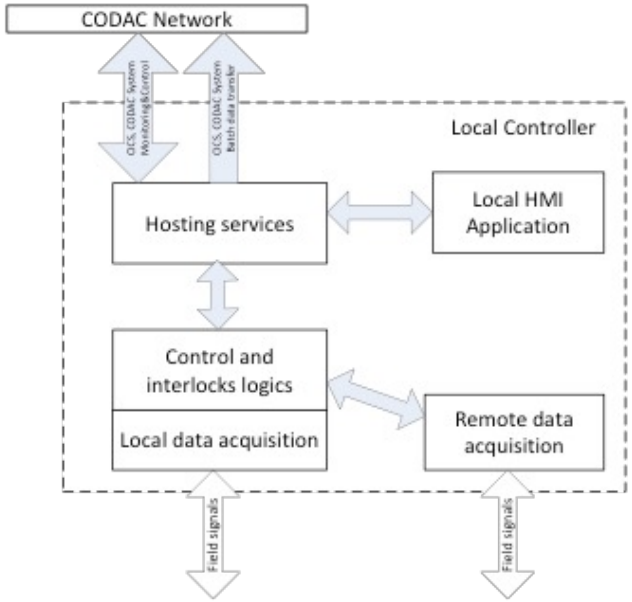
The typical Local Controller system consists of one Local Controller Cabinet and a set Extension Cabinets.

The Local Controller software have to provide the following operation:
Field data acquisition and generation;
Field data processing, control loops and soft interlocks execution;
Data exchange with the CODAC Server;
Local HMI.

Physical Architecture

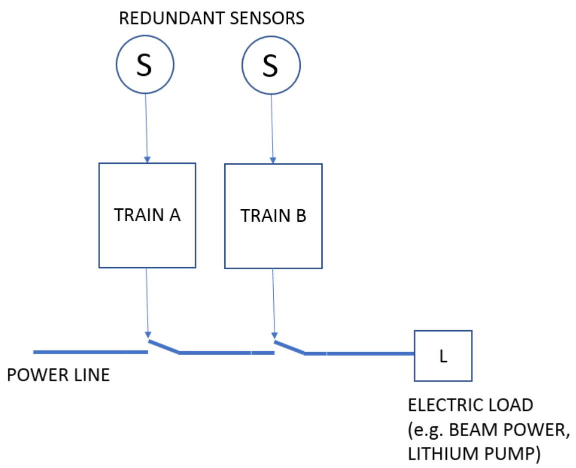


Software Architecture

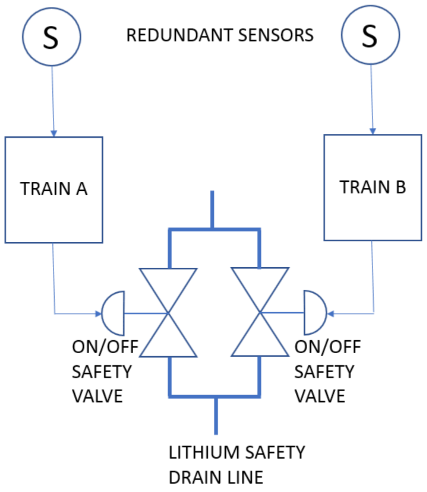


Local Safety Control

Example of SCS redundant command to stop a safety electric load



Example of SCS redundant command to open safety valves.



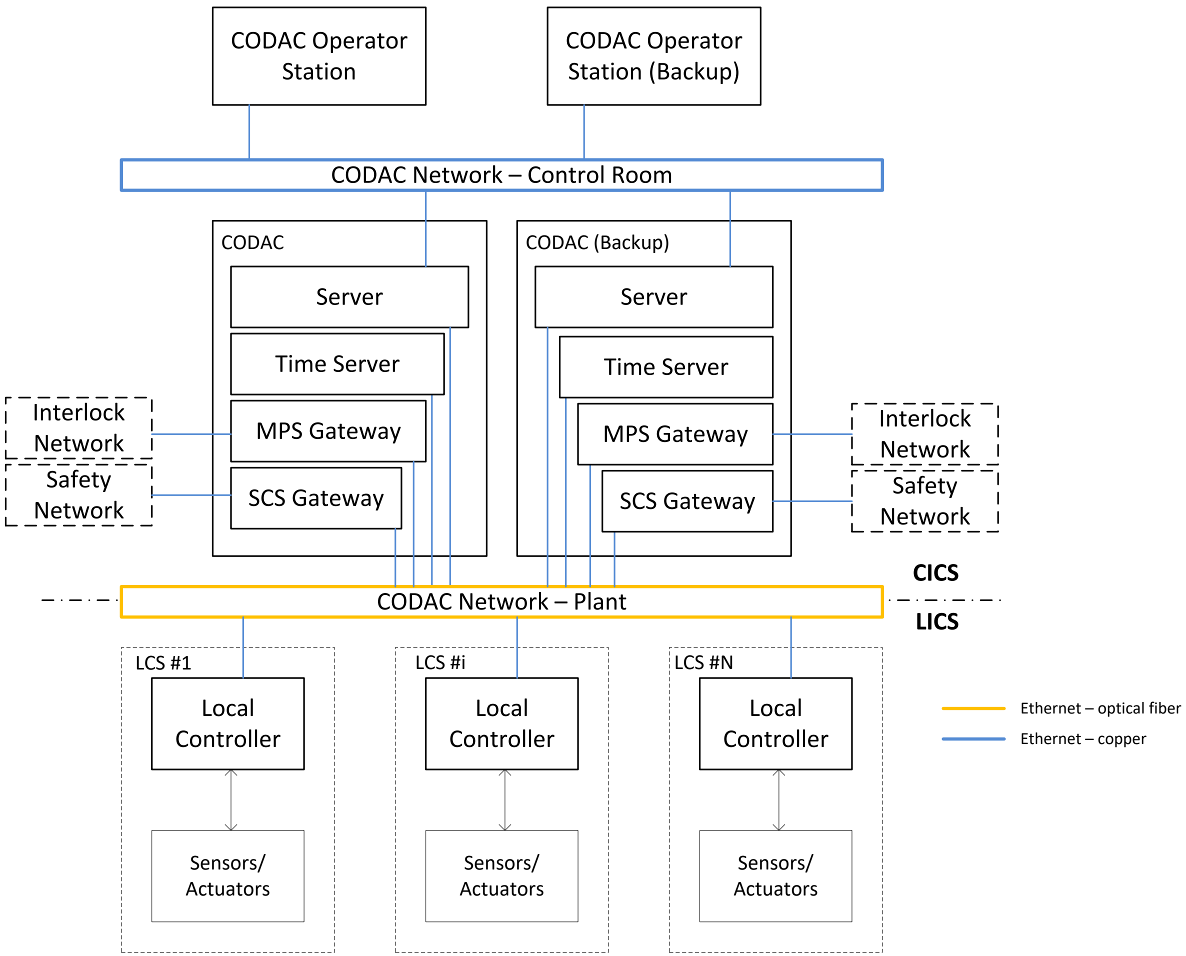
PFH (Probability of dangerous Failure per Hour) is used as a target parameter to measure the hardware safety integrity of the SCS.

SIL limits and PFH values

SIL	Limits and PFH values
1	$< 10^{-5}$
2	$< 10^{-6}$
3	$< 10^{-7}$

Networks and buses

CODAC Network Architecture



Conclusions

The design of a control system in complex plants:

- is **not a service** that is added at the end of the project (like the electrical system in an apartment)
- must accompany the project **from the beginning** to:
  - follow its evolution step by step
  - understand the underlying physics
  - anticipate problems
  - identify safety classes
  - highlight the design limits (excessively heavy constraints in terms of performance, safety,...)
- is the technological modality with which the **actual integration** of all the systems is carried out (most delicate phase)
- is essential to **demonstrate safety** to the relevant Authority during the **licensing** phase
- It is the part that must follow **technological developments** more quickly and be able to implement them
- It is the only way that **humans can interact with machines**
- can be revolutionized by the incessant development of **artificial intelligence (AI)**

Conclusions

It's **not just technology**
but the **brain** that drives the physics of the experiment!

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