ITER Controls approaching one million integrated EPICS Process Variables

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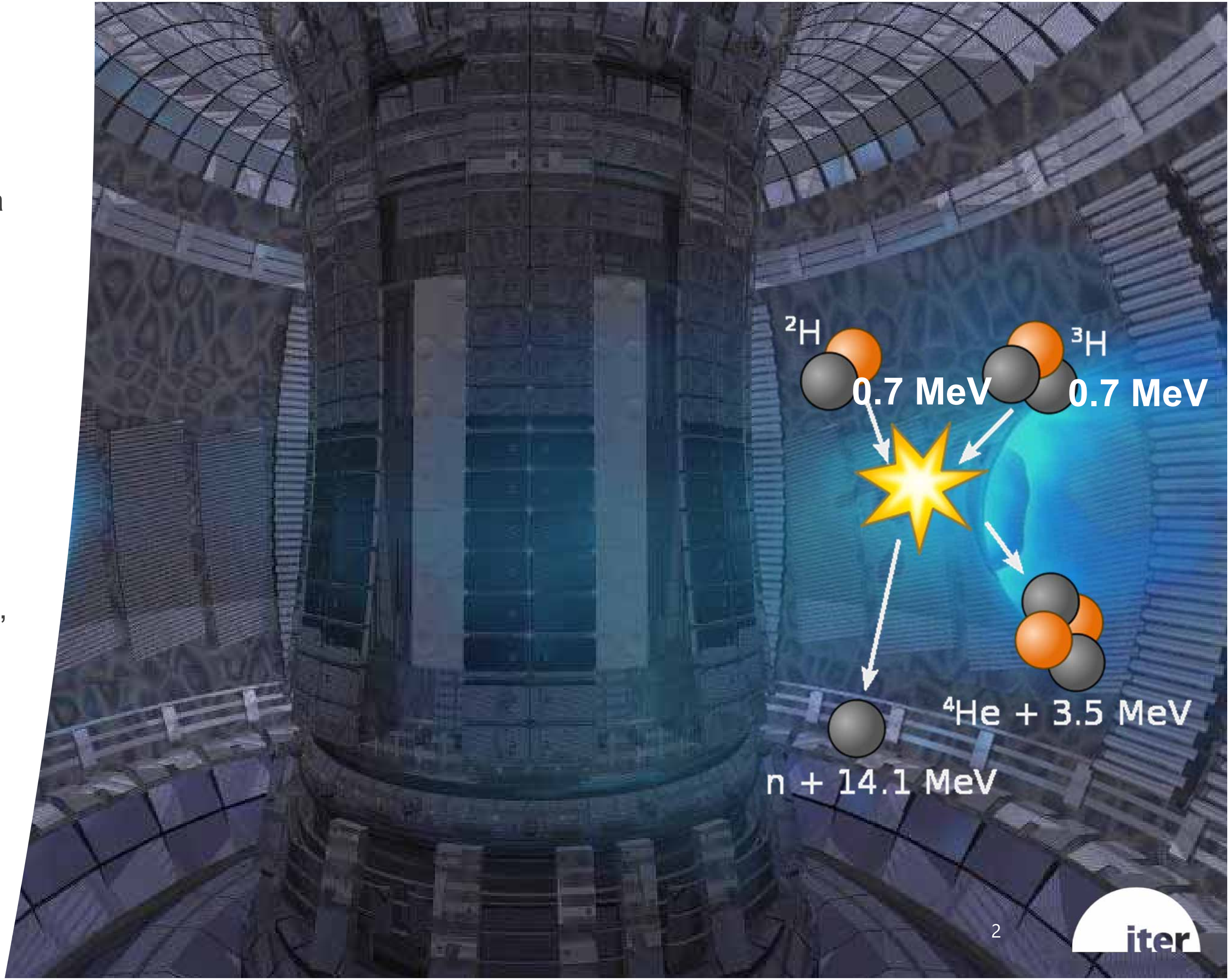
china eu india japan korea russia usa

ITER BASICS

- Demonstrate technical feasibility of commercial production of fusion as a future energy source
- Use magnetic confinement to create and maintain a super-hot hydrogen plasma in a doughnut-shaped vacuum chamber (Tokamak)
- Collaboration between China, Europe, India, Japan, Korea, Russia and the US
- Based on 90% in-kind procurement (members deliver hardware/systems, not money)
- Main challenge for the central ITER Organization is to integrate all those contributions



ITER CONTROLS BASICS

Mitigation actions to address challenge of integrating 170 local control system established more than ten years ago

- Definition of standards (Plant Control Design Handbook)
- Distribution of software tool kit based on EPICS (CODAC Core System)
- Distribution of hardware integration kit
- Training and hands-on workshops
- Active outreach

Continues evolution and updates to address obsolescence and return of experience

These actions have been effective

Without them there would have been total chaos now


ITER TECHNICAL REPORT

iter

china eu india japan korea russia usa

REPORT NO.

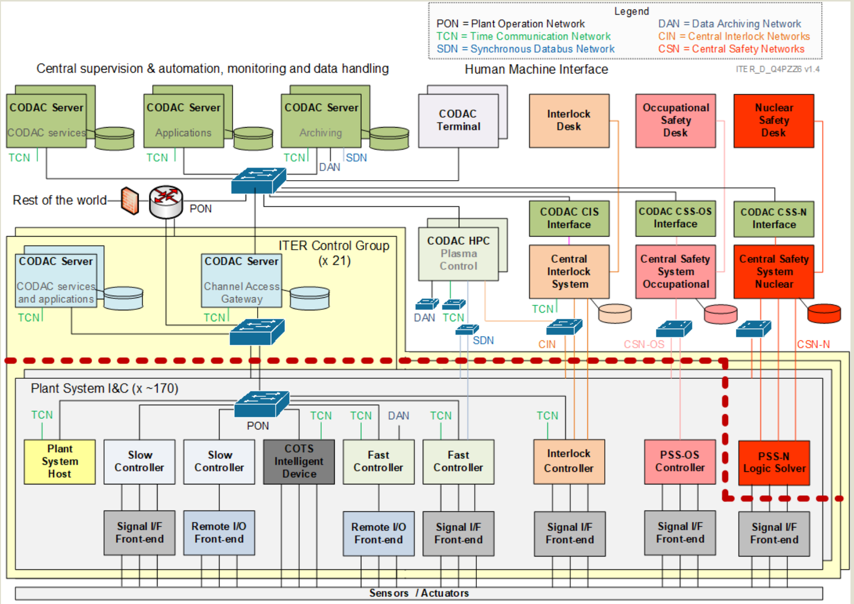
ITR-23-009

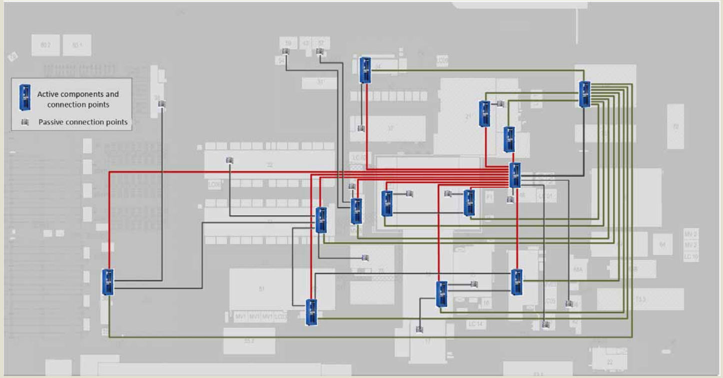
TITLE

Plant Control Design Handbook

ARCHITECTURE AND INFRASTRUCTURE

- Hierarchical with 21 subsystems and 170 local control system (in-kind)
- Vertical segregation of (1) conventional control and operation, (2) protection and (3) safety
- Dedicated networks for (1) control and monitoring, (2) time synchronization, (3) distributed real-time control, (4) high throughput data acquisition, (5) protection and (6) safety
- Redundant dual star network cable infrastructure
- Virtualized central servers for supervision, automation, configuration, plasma control and data handling
- Data streamed to HDF5 back-end storage accessible on the intranet





INTEGRATION AND COMMISSIONING STATUS

First local control system delivered in 2018. Over the last 4 to 5 years systems have been integrated incrementally, followed by commissioning and operation.

In-kind local control systems integrated

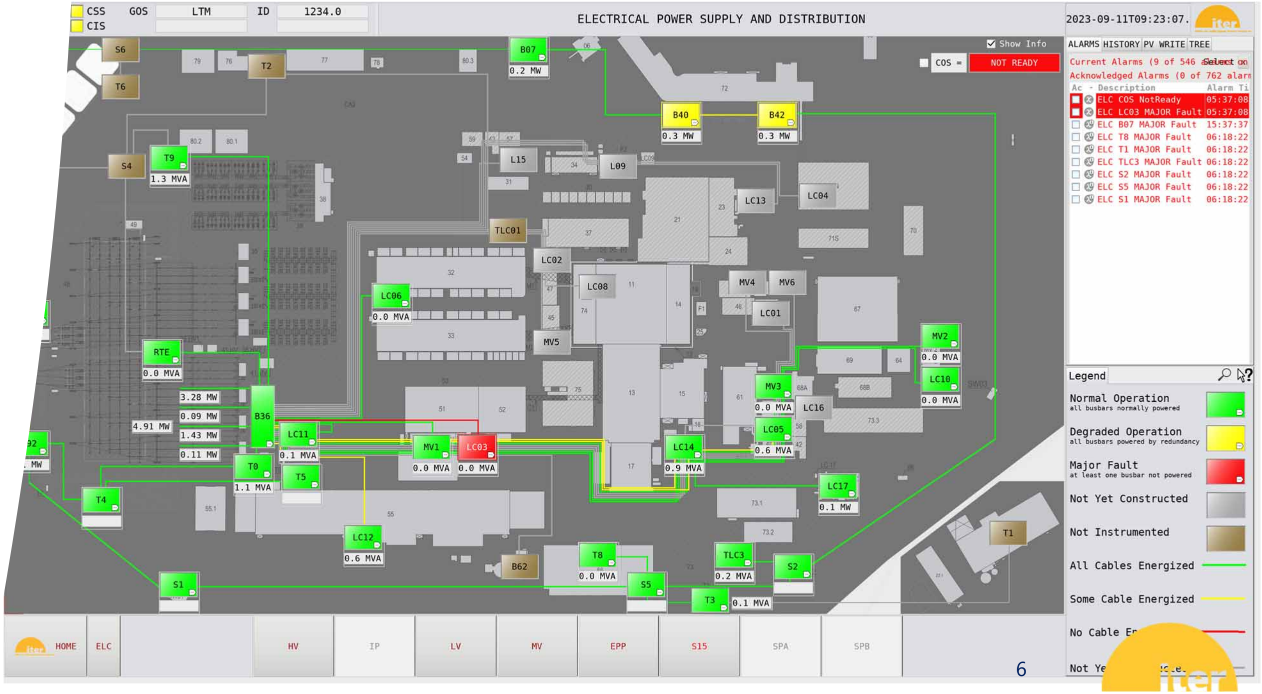
- Steady state electrical network
- Buildings and site services
- Cooling water
- Cryoplant
- Pulsed power electrical network
- Reactive power compensation and harmonic filtering

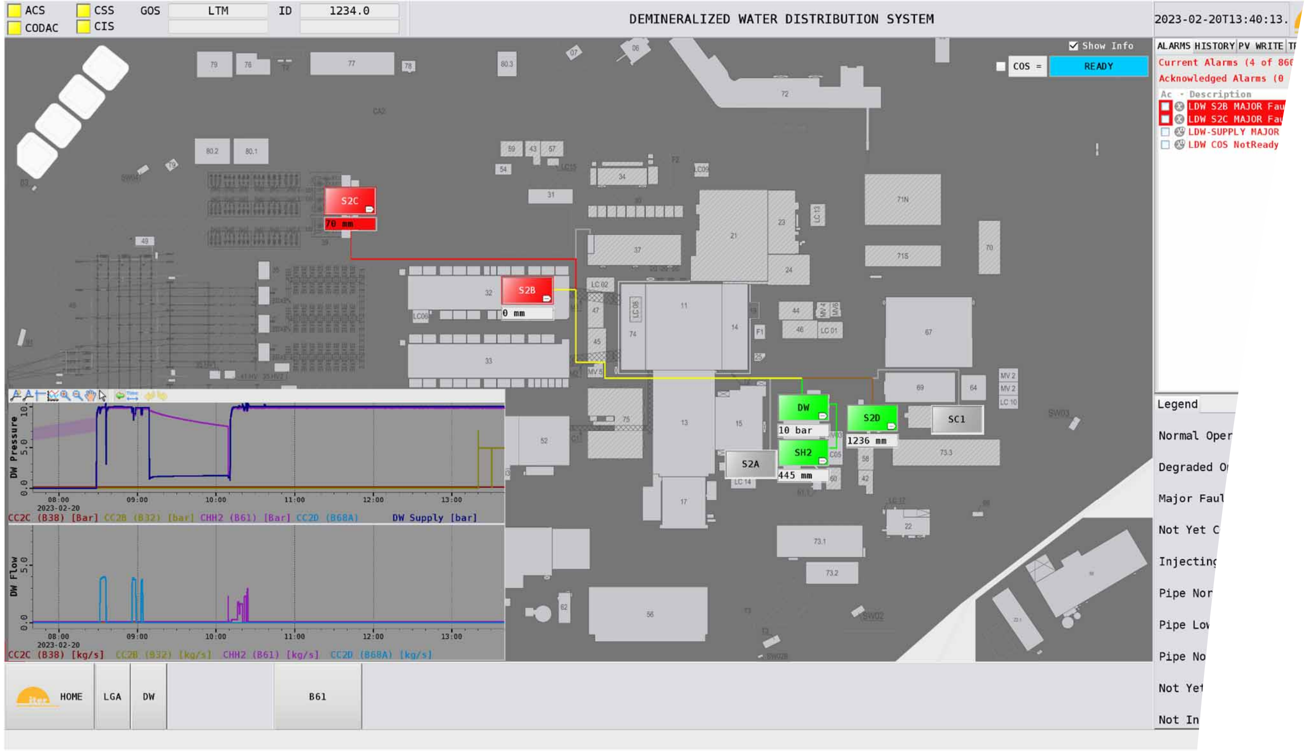
Central functions

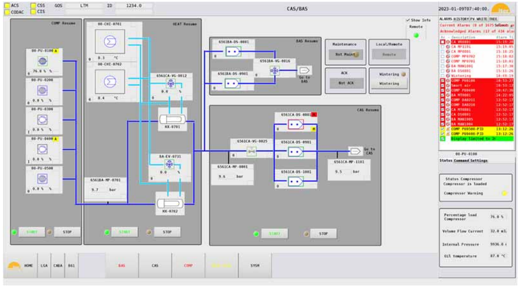
- Supervision
- Data archiving and data access
- Orchestration and sequencing
- Configuration

ELECTRICAL NETWORK

- Started integration and commissioning in 2018
- Four 400 kV/22 kV transformers feed medium and low voltage load centers distributed over the site
- Today more than 50 % of total system in 24/7 operation
- Top level CS Studio Human Machine Interface (HMI) gives geographical overview and instant power consumption
- Electrical components and high voltage cables animated using color coding





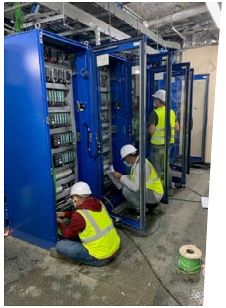


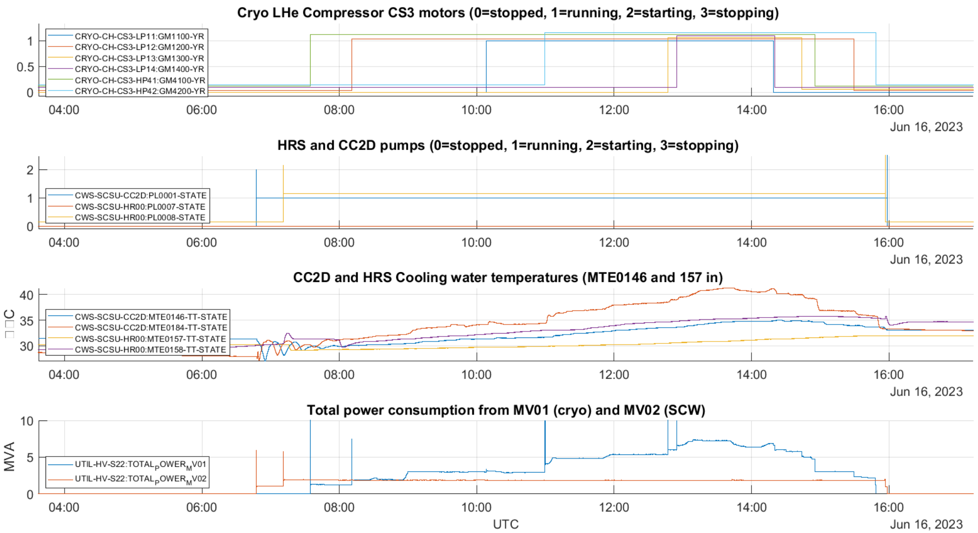
BUILDINGS AND SITE SERVICES

- Started integration and commissioning in 2019
- Provides environmental conditions, fire protection and distribution of liquid and gas services
- Today 50 % of auxiliary buildings and 20 % of distribution of services in 24/7 operation
- Example of top level HMI giving geographical overview over demineralized water production and distribution
- Clients status and flows in pipes are animated using color coding and a six hours trend shows pressures and flows at various points

COOLING WATER

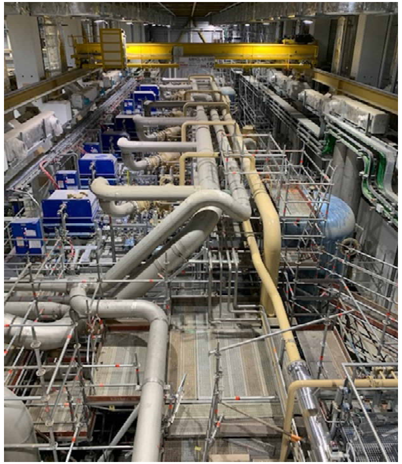
- Started integration and commissioning in 2021
- Provides heat rejection through cooling towers, component cooling, chilled water and blowdown
- Today heat rejection, chilled water and 2 component cooling loops are in commissioning or operation
- Top level HMI giving geographical overview over cooling water and distribution
- Equipment status and flows in pipes are animated using color coding

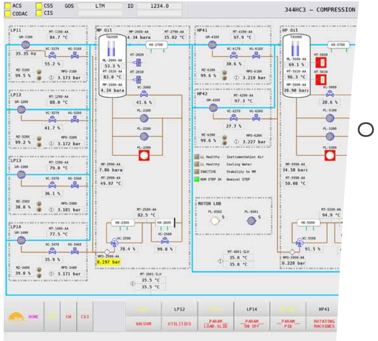




CRYOPLANT

- Started integration and commissioning in 2022
- Produces and supplies liquid helium to the superconducting magnets etc.
- Today in commissioning with a main milestone reached in June 2023 running six water cooled liquid helium compressors in parallel
- Data extracted from backend archive show status of compressors and pumps, cooling water temperatures and power consumption
- Good example of plant system dependencies and software integration across multiple systems





ACCESS CONTROL

Integration and commissioning is performed by different groups of people in different geographical location

The infrastructure supports read access to any data from any terminal independent of geographical location

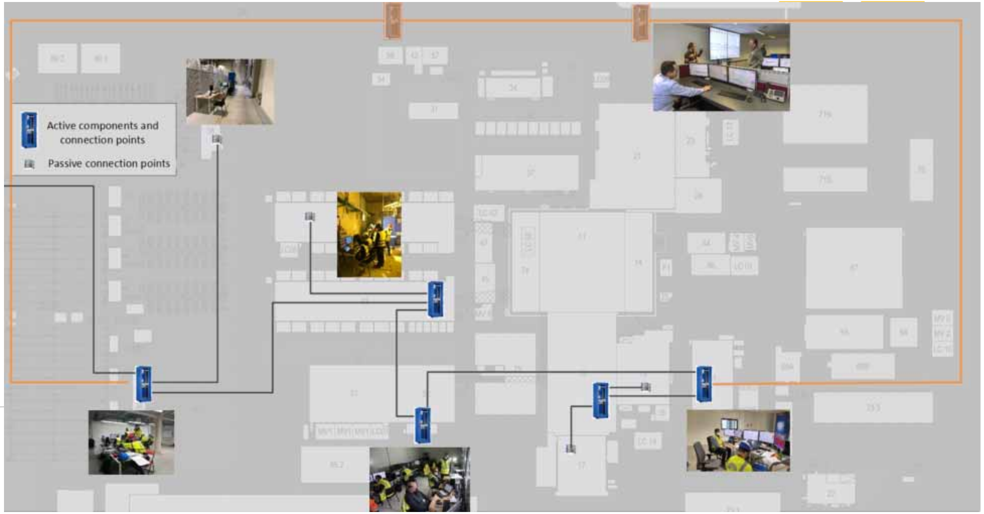
It is important that any control action (write) can only be executed by authorized people

Access control is enforced by using personal accounts and EPICS gateway access lists

Three conditions are required to allow control access

1. User belongs to authorized group
2. Control action is executed from authorized terminal
3. ITER machine is in a state allowing the action

All control actions are logged including the user executing the action

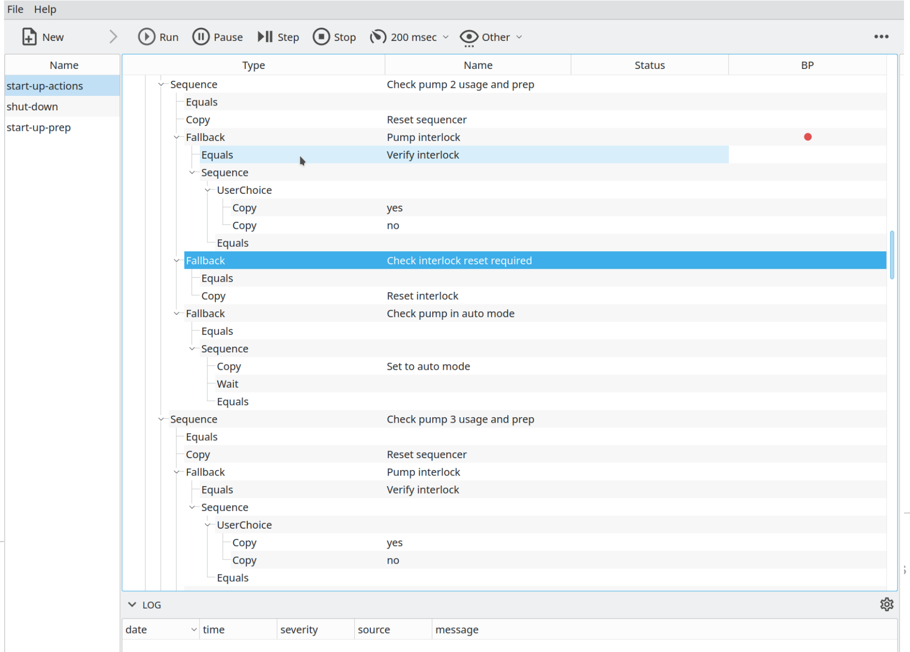


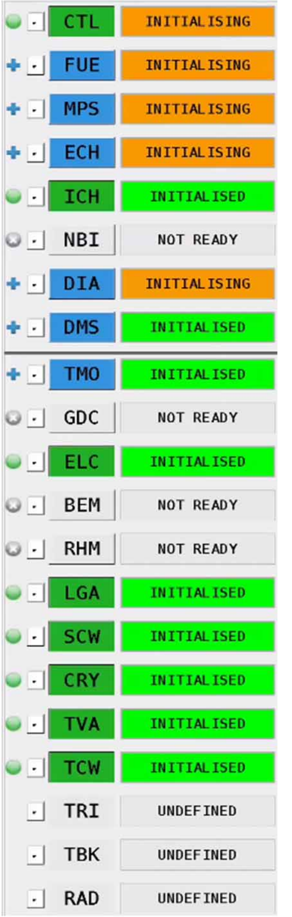
SUPERVISION AND AUTOMATION

Each subsystem represented by a common operation state

Gives status of ITER machine at a glance and used as pre-requisites for permitting/rejecting operational tasks

Sequencer allows execution of operational tasks (e.g. start cooling water) checking pre-requisites and sending sequences of commands to different systems





METRICS

Useful to measure size and progress of the control system

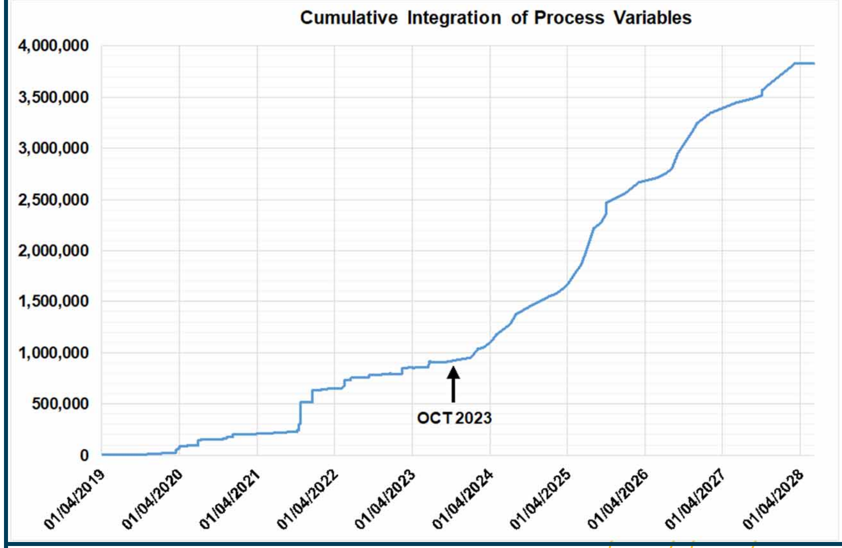
Number of integrated process variables easy to obtain from the software repository

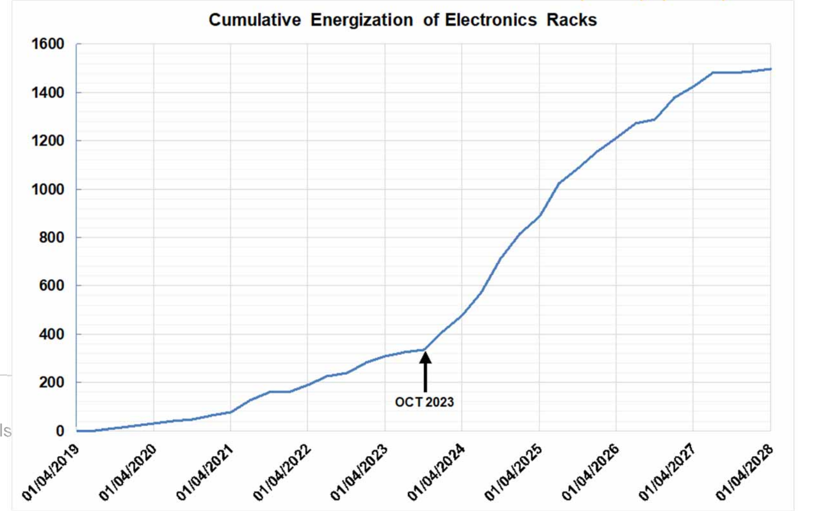
Can be predicted for future systems based on design data and system complexity

Similar, number of energized electronics racks can be counted and future predicted based on engineering data

Commissioning schedule gives timeline as racks must be energized and process variables integrated before commissioning can start

Curves to the right have similar shape and indicate close to 25% of integration towards first plasma has been achieved today





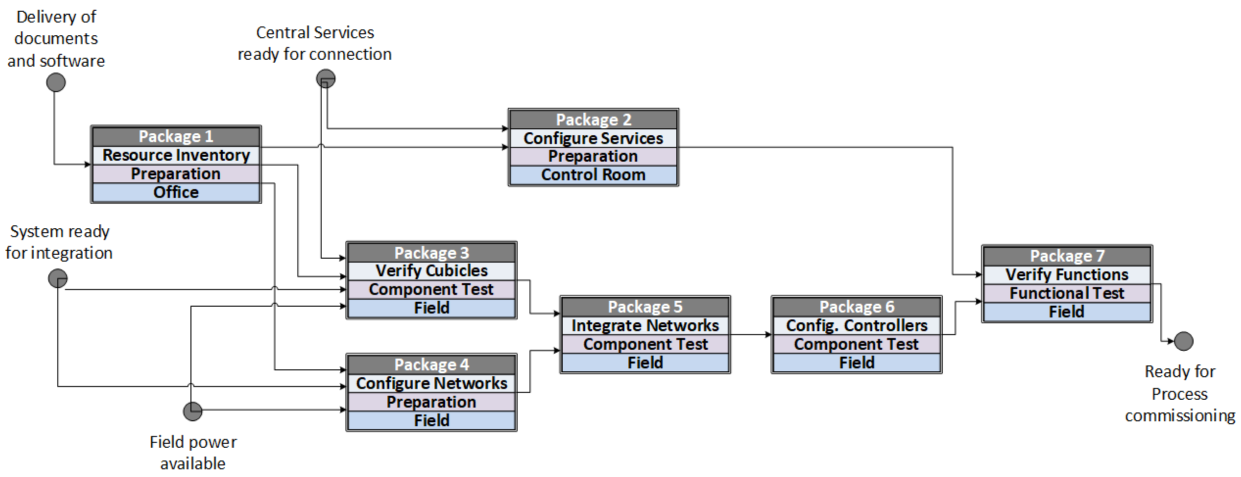
INTEGRATION PROCESS

1. Perform inventory of deliverables, including inspection of software code, packaging and deployment on a test platform
2. Configure central services (human machine interface, data archiving and alarm handling)
3. Energize and verify electronics racks
4. Configure the networks between the central infrastructure, the local system and the field
5. Verify the networks
6. Configure the controllers and verify field signals
7. Perform local functions verification

System declared ready for process commissioning

Pre-requisites

1. Installation of hardware and cabling completed
2. Delivery of documentation and software source code

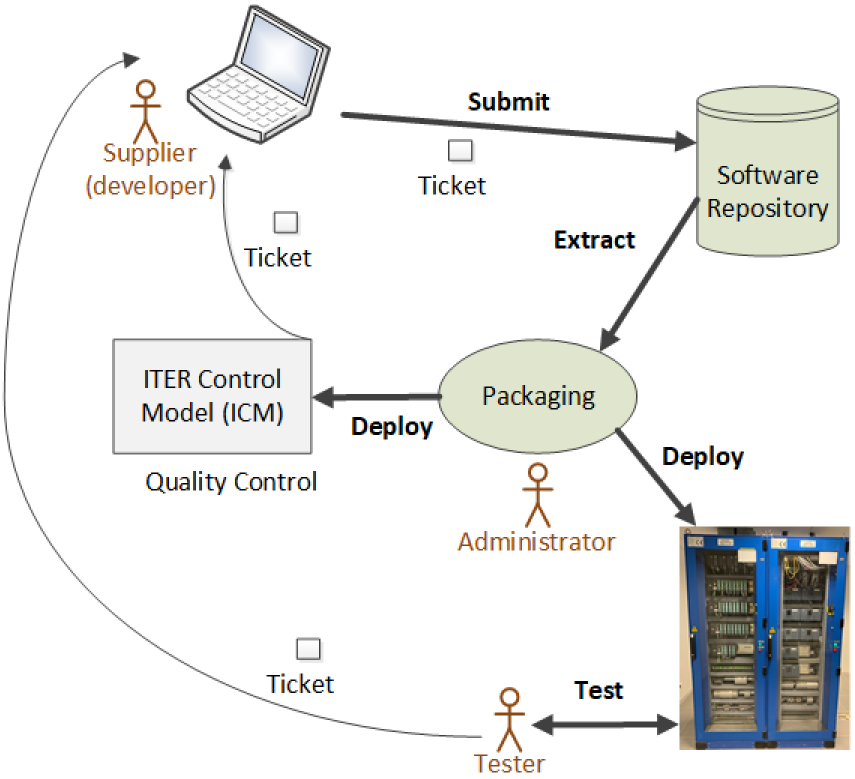


SOFTWARE CONFIGURATION CONTROL

Robust configuration control of software sources is essential in production environment

1. The supplier delivers a tagged software version in the repository and issues a ticket
2. The administrator extracts the software, performs packaging and deploys on a testbed for quality checks
3. If not successful, the administrator informs the supplier using ticketing system
4. If successful, the administrator deploys on the production target.
5. The tester performs tests on target and record issues/change requests in the ticketing system
6. The supplier addresses the issues/change requests and deliver a new tagged software version

During commissioning agility is achieved by applying multiple roles to a single person and by exceptionally allowing hot fixes rectified afterwards using the same workflow



LESSONS LEARNED

- Early definition of standards, distribution of software and hardware tool kit, training and outreach have been effective
- Delivered electronics racks not compliant with French legislation. Hardware modifications required with associated cost and delay before energization
- Resistance by the suppliers to deliver software source code in repository. Late delivery results in delay in integration
- Delivered software poorly tested and inferior quality. Considerable internal resources must be allocated to rectify this
- Delivered software code not structured as required. Pre-processing using scripting required before deployment
- Some cases where technical team has been formed with all stakeholders and a common goal. By demonstrating added value, trust can be earned. When this approach fails it is usually for non-technical reasons imposed by politics and/or financial and contractual reasons
- Some cases where the delivered system has been declared not fit for purpose and the supplier has been unwilling or unable to fix it. Formal non-compliance process has been applied to transfer the scope, with funding. Tedious and slow process.
- In some cases an early agreement has been reached to transfer the scope, with funding, during the design phase. These cases have always been successful

NEXT STEPS

- Integration of coil power supplies, electron cyclotron heating power supplies and gyrotrons starting in 2024
- The high-level software will be further developed and deployed
- The final infrastructure, with networks and main control room, will be put in operation
- Integration in the Tokamak Complex will start in 2025 covering vacuum vessel, cryostat, magnets, first wall, vacuum, fueling, Tokamak cooling water, cryolines, additional heating and diagnostics to measure the plasma parameters
- Detailed obsolescence management plans will be developed to cope with the long lifetime of the project
- Expanding the system will lead to new discoveries to be continuously integrated back into the deployed systems

CONCLUSIONS

- ITER control system is in production with close to one million integrated EPICS process variables
- Almost 25 % of the integration scope towards first plasma has been achieved
- Integration of many in-kind local control systems has been and remains challenging
- The most successful mitigations have been (1) establishment of joint technical team with a common goal or (2) scope transfer
- The project organization makes both these mitigation actions difficult to achieve
- Nevertheless, we continue to work towards the functional integration of the ITER machine to enable integrated and automated operation