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Analysis of the Control System of ICE, the Insulation and Cooling Test Facility for the Development of the ITER Neutral Beam Injector

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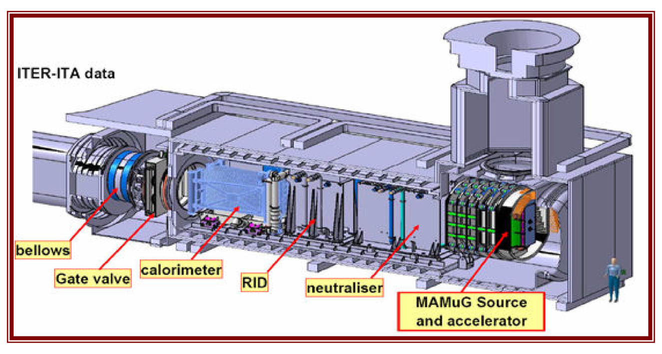
Abstract

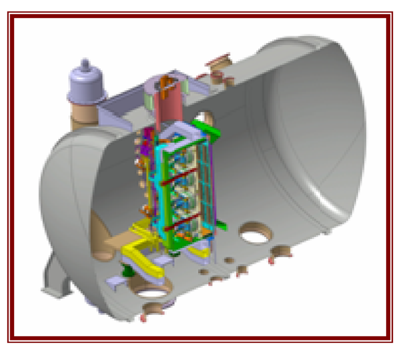
Consorzio RFX will host two experimental devices to address the main issues of the ITER heating neutral beam injectors: SPIDER (Source for the Production of Ions of Deuterium Extracted from Rf plasma), an ion source at low acceleration voltage (100 kV), and MITICA (Megavolt ITer Injector and Concept Advancement), a neutral beam injector at 1 MV. ICE (Insulation and Cooling Experiment) is a test facility developed at Consorzio RFX to tackle significant SPIDER and MITICA technological aspects that require a preliminary study. The ICE control system is mainly based on commercial off-the-shelf products. It is composed of four local units: automation and monitoring, supervision, data handling, and communication. The automation and monitoring unit is based on Siemens PLC technology. The supervision unit relies on the commercial PVSS-II SCADA system that is widely used at CERN. The data handling unit, the only part of the ICE control system not based on industrial products, extends the functionalities of MDSplus, a framework for the management of scientific data. The communication unit comprehends the network infrastructure and the timing system. The paper presents the ICE control system, its local units and the main performance and operational requirements.

I. Introduction

PRIMA



MITICA

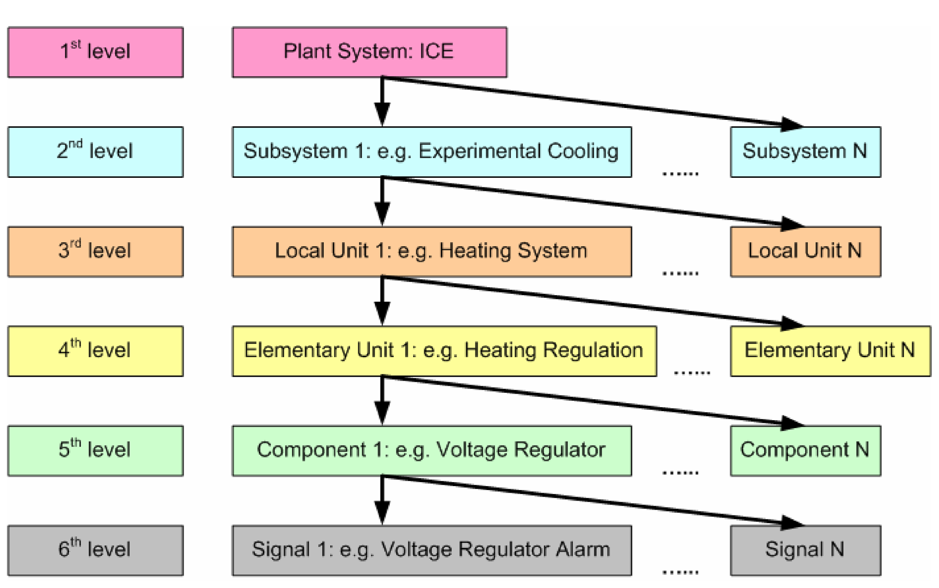


SPIDER

- PRIMA (Padova Research on Injectors Megavolt Accelerated) is a new facility under development at Consorzio RFX in the framework of an ITER collaboration aimed at realizing and providing the ITER Heating Neutral Beam Injectors [1].
- PRIMA will encompass MITICA (Megavolt ITer Injector and Concept Advance) and SPIDER (Source for the Production of Ions of Deuterium Extracted from Rf plasma).
- SPIDER will provide a full-scale ion source prototype for MITICA and will operate at the reduced acceleration voltage of 100 kV with just one acceleration stage.
- MITICA will comprehend a full-scale Heating Neutral Beam Injector prototype. Its beam will be accelerated at 1 MV (five acceleration stages of 200 kV each [Multi Aperture Multi Grid – MAMuG – concept]).
- ICE (Insulation and Cooling Experiment [2]) is a new test bed designed at Consorzio RFX in order to preliminarily investigate critical SPIDER and MITICA technological aspects:
  - high-voltage insulation breaks;
  - high-heat-flux water cooling;
  - a prototype SCADA (Supervisory Control and Data Acquisition) system;
  - a prototype continuous data logging system.

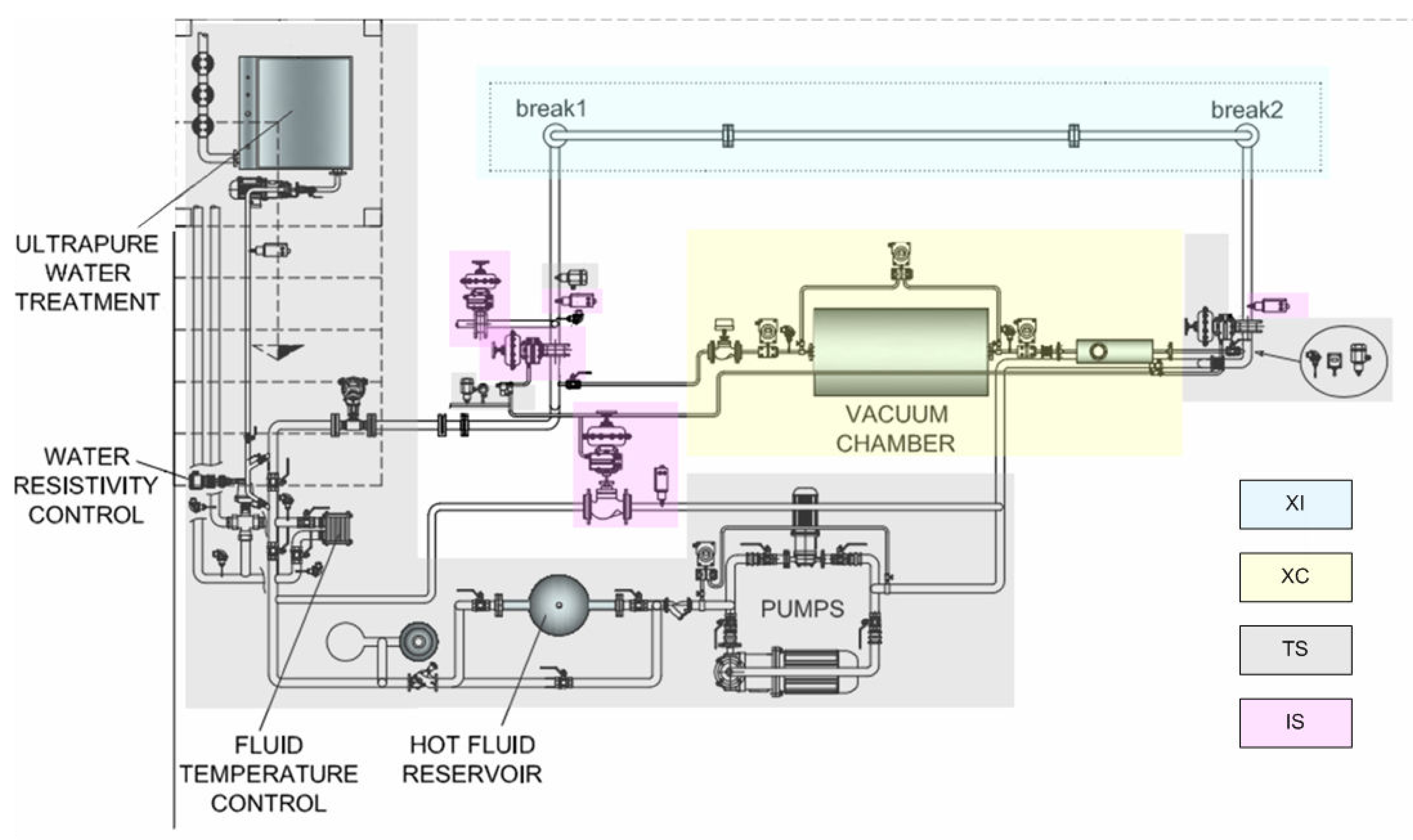
II. Breakdown Structures

- ICE breakdown structure:
  - six levels;
  - relevant for assigning names to components and signals.



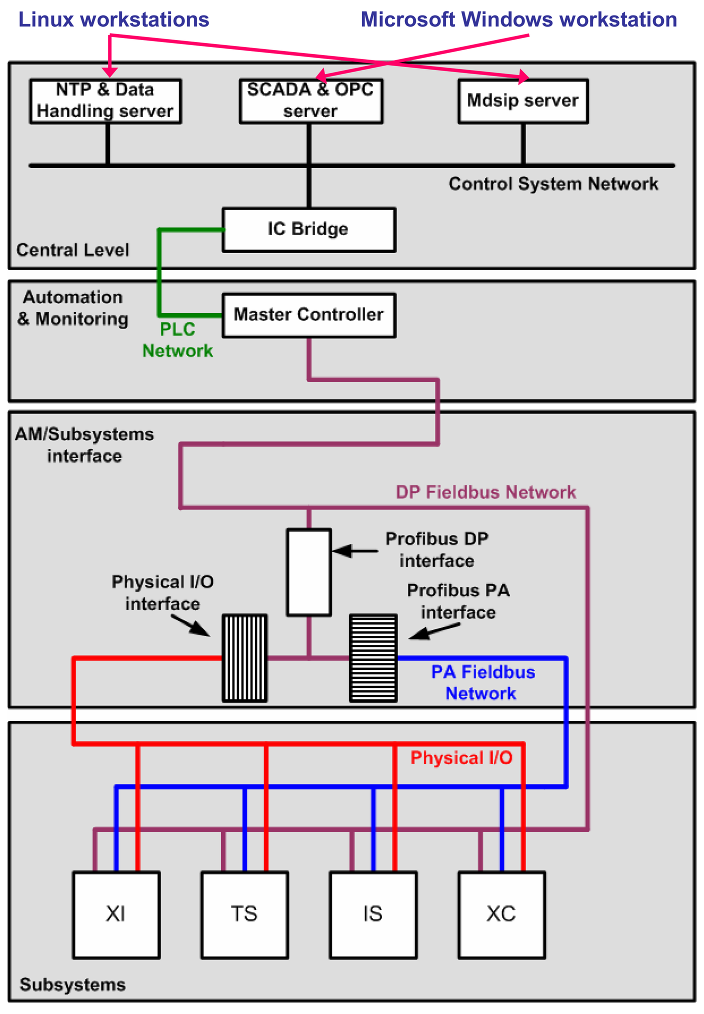
ICE breakdown structure scheme

- Definitions:
  - Elementary Unit: group of components functionally related.
  - Local Unit: group of elementary units with a specific purpose.
  - Subsystem: set of Local Units functionally related.
- ICE subsystems:
  - related to the test-bed equipment:
    - ✓ 1) experimental insulation (XI);
    - ✓ 2) experimental cooling (XC);
    - ✓ 3) technical supplies (TS);
    - ✓ 4) interlock and safety (IS).
  - a virtual one:
    - ✓ 5) control system (ICS).
- ICS Local Units:
  - automation and monitoring (AM);
  - supervision (SU);
  - data handling (DH);
  - communication (CO).



Layout of the ICE test bed

III. Control Architecture



Block diagram of the ICS architecture

General description of the ICS architecture

- **3 layers**
  - Central Level
    - ✓ it hosts workstations devoted to plant supervision and data management; in particular:
      - one manages the supervision task and hosts an OPC (Object Linking and Embedding for Process Control – [5]) server used as software interface with DH;
      - one hosts an NTP (Network Time Protocol) server, used to dispatch an absolute time reference, and a DH thread.
    - ✓ the Control System Network is IEEE 802.3 Ethernet [4].
  - Automation and Monitoring
    - ✓ it is the only layer coincident with a Local Unit;
    - ✓ the Master Controller is responsible for the process control and monitoring;
    - ✓ the Master Controller exchanges signals with the Central Level through the so-called PLC (Programmable Logic Controller) Network (IEEE 802.3 Ethernet) and the IC (Instrumentation & Control) Bridge.
  - AM/Subsystems interface
    - ✓ three kinds of signal interface:
      - Physical input/output (I/O) interface, for signals acquired through analogue/digital I/O cards;
      - Profibus PA [3] interface, for signals traveling on PA Fieldbus Network;
      - Profibus DP [3] interface, for signals exchanged through DP Fieldbus Network.
    - ✓ All the signals exchanged between the Master Controller and the plant equipment eventually transit on DP Fieldbus Network.

Automation and Monitoring Local Unit

- Tasks: industrial control and monitoring; acquisition of data from the field.
- It consists of the Master Controller and of a distributed periphery.
- The Master Controller is a Siemens SIMATIC S7-400 series PLC, equipped with Ethernet and Profibus-DP ports.
- The distributed periphery is managed by two Siemens SIMATIC ET200M interfaces (the Profibus DP interface).
- A small amount of signals travel directly on the DP Fieldbus Network.

Supervision Local Unit

- Tasks: visualization of the equipment state; setting of plant parameters, alarm and event handling.
- It consists of a server workstation and of client PCs running the PVSS-II SCADA (Supervisory Control And Data Acquisition) package from ETM [6].
- The server workstation is equipped with Microsoft Server 2003 as operating system, since it runs the OPC server.
- The experience gained using this software will be very useful in view of the final decision about the SCADA package to be used for SPIDER and MITICA.

Data Handling Local unit

- Tasks: to handle and store data and to manage their recall for visualization and analysis.
- A new functionality of MDSplus [7], the system for data management currently used at Consorzio RFX, is used to provide continuous data acquisition: the possibility of storing time-segmented records ("data appending" feature).
- A Java DH thread, running on a Linux workstation, acts as interface between the OPC server and a remote mdsip server hosted on a storage station.

Communication Local Unit

- Tasks: time distribution for plant synchronization; handling of the communication inside the plant.
- It consists of:
  - the communication networks (the Fieldbus Networks, the PLC Network and the Control System Network).
  - the IC Bridge, an off-the-shelf Ethernet switch (Hewlett-Packard ProCurve 2510 [8]).
  - the NTP server, hosted on the same workstation as the DH thread, which handles the time distribution.

IV. Requirements

Performance requirements

- Maximum experiment duration: 28800 s (8 hours).
- Minimum industrial control cycle time: 100 ms.
- Maximum real-time-feedback-control frequency: 10 Hz.
- Absolute-time accuracy: some milliseconds (NTP protocol).
- Acquisition of:
  - a) ~ 100 analogue signals:
    - ✓ maximum frequency: 2 Hz;
    - ✓ data logging throughput: ~ 2.4 kB/s (4 bytes per signal plus 8 bytes for the associated time stamp).
  - b) ~ 200 digital signals:
    - ✓ maximum frequency: 2 Hz;
    - ✓ data logging throughput: ~ 3.25 kB/s (considering also the 8-byte time stamp for each signal).
- Refresh frequency of the client user interfaces: at least 1 Hz.

Operational requirements

- ICS operation states: *OFF* and *Running*.
- In normal-operation conditions:
  - ICS is always in the *Running* state;
  - ICS has to maintain the equipment within its operating limits and conditions.
- Access levels to the SCADA user interfaces:
  - a) root - the user is allowed any kind of modification;
  - b) operator - the user is allowed only to change experiment-relevant parameters;
  - c) viewer - the user is only allowed to monitor the state of the ICE equipment.
- No distinction between local control mode and remote control mode:
  - ICE will be always in ICE control mode, allowing:
    - either local operations, close to the equipment;
    - or operations from a remote control station.
  - Implementation of an interlock, to prevent simultaneous local and remote operations.
- Manual operations allowed:
  - outside the normal conditions, for test and commissioning purposes;
  - in the *Running* state, but only performed by a user with root-level access and only in special cases.
- Recipes will be used as far as possible:
  - to standardize the parameter-setting phase;
  - to reduce the possibility of human errors.

V. Conclusions

- ✓ In view of the development of the SPIDER and MITICA control systems, the development and implementation of ICS is very important :
  - to be able to evaluate the PVSS-II SCADA package ;
  - to test and ameliorate the new MDSplus continuous data acquisition feature.
- ✓ Phases already terminated:
  - ICS design;
  - set-up of the control cabinet;
  - set-up of the SCADA workstation.
- ✓ Next steps:
  - development of:
    - ❑ SCADA programs;
    - ❑ PLC programs;
    - ❑ DH programs.
  - preliminary test of the field signals.

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