CONTROL SYSTEM DESIGN OF THE CHIMERA FUSION TEST FACILITY

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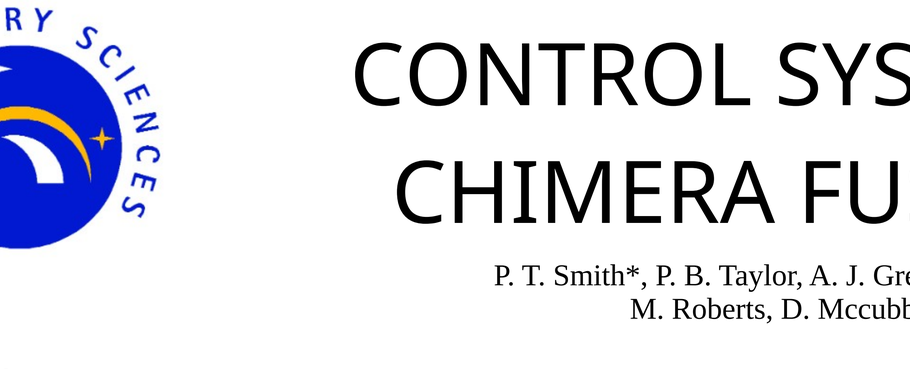
Abstract

CHIMERA is an experimental nuclear fusion test facility which aims to simulate the intense magnetic fields and temperature gradients found within a tokamak fusion reactor. The control system at CHIMERA is based on EPICS and will have approximately 30 input/output controllers (IOCs) when it comes online in 2024. It will make heavy use of CSS Phoebus for its user interface, sequencer and alarm system. CHIMERA will use EPICS Archiver Appliance for data archiving and EPICS areaDetector to acquire high speed data which is stored in the HDF5 format. The control philosophy at CHIMERA emphasises PLC based control logic using mostly Siemens S7-1500 PLCs with OPC UA to communicate with EPICS. There is a requirement for the CHIMERA control system will be installed entirely offline. Once operational, some access to experimental and archiver data is provided to authorised external users.

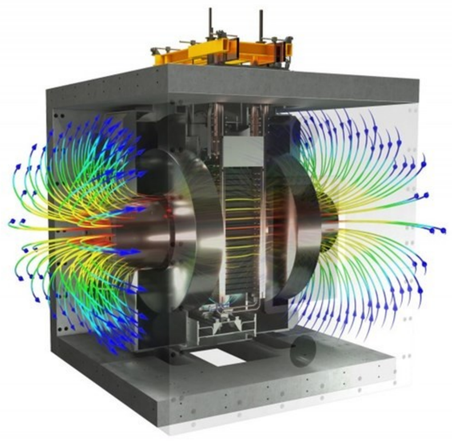


CHIMERA is being developed for the United Kingdom Atomic Energy Authority. Jacobs Clean Energy Ltd is the principle designer and constructor. Observatory Sciences Ltd are the designer and developer of the software control and data acquisition system (SCADA)

CHIMERA Specifications

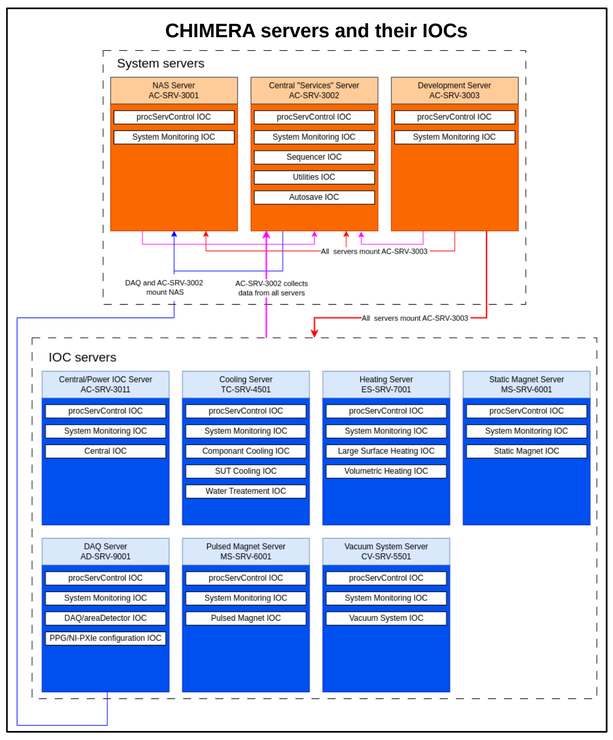
CHIMERA is being built to test components such as those being developed for the International Thermonuclear Experimental Reactor (ITER). Once completed, it will be capable of producing a peak static magnetic field of 5 tesla, a ± 0.25 tesla pulsed magnetic field, surface heating of 0.5 MW/m2, and volumetric heating of 100 kW. A high pressure water cooling system, running at up to 328 degC, 155 bar, is also being constructed to test ITER's Test Blanket Module.

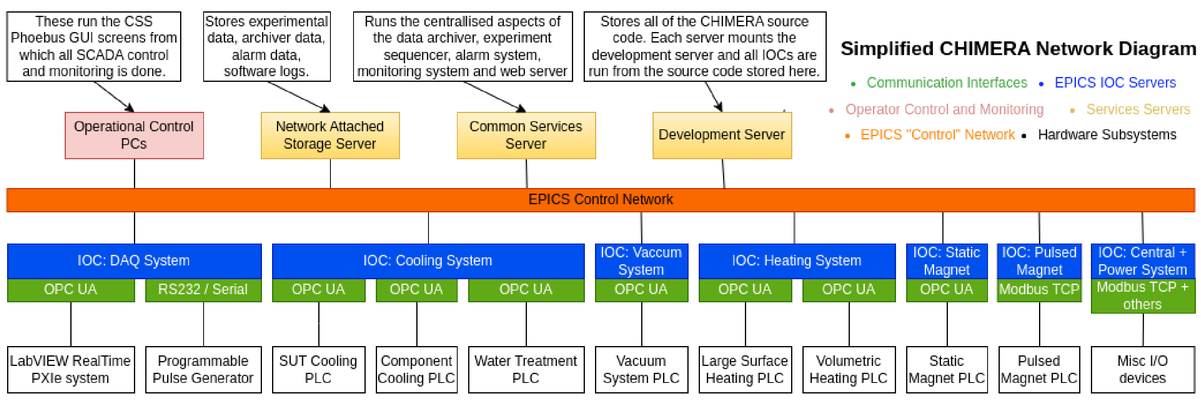
Later developments will introduce a high heat flux continuous-wave laser producing heat fluxes of 200 MW/m^2 over 100 mm^2 or 20 MW/m^2 over 1500 mm^2. It will also introduce a liquid metal loop which can be used to circulate liquid PbLi around a subject unter test (SUT), this is designed to test water cooled lithium lead (WCLL) blankets [2]. There are also plans for a high resolution camera system to image inside the test chamber, this will greatly increase the volume of data acquired. The images above and to the side show the designs for the CHIMERA facility and the test device itself.



SCADA system

The SCADA system is being developed under the Experimental Physics and Industrial Control System (EPICS) framework. The system wide components being implemented are the DAQ system, data archiver, server monitoring system, experiment sequencer, alarm handling system and web server for external access of data. Hardware devices are controlled by 7 low-level IOCs which directly control and monitor various hardware components. All of these SCADA systems communicate over a single air gapped controls network via TCP/IP and most communications are done with the EPICS channel access (CA) protocol. Communications with hardware use mostly the Modbus or OPCUA support modules.

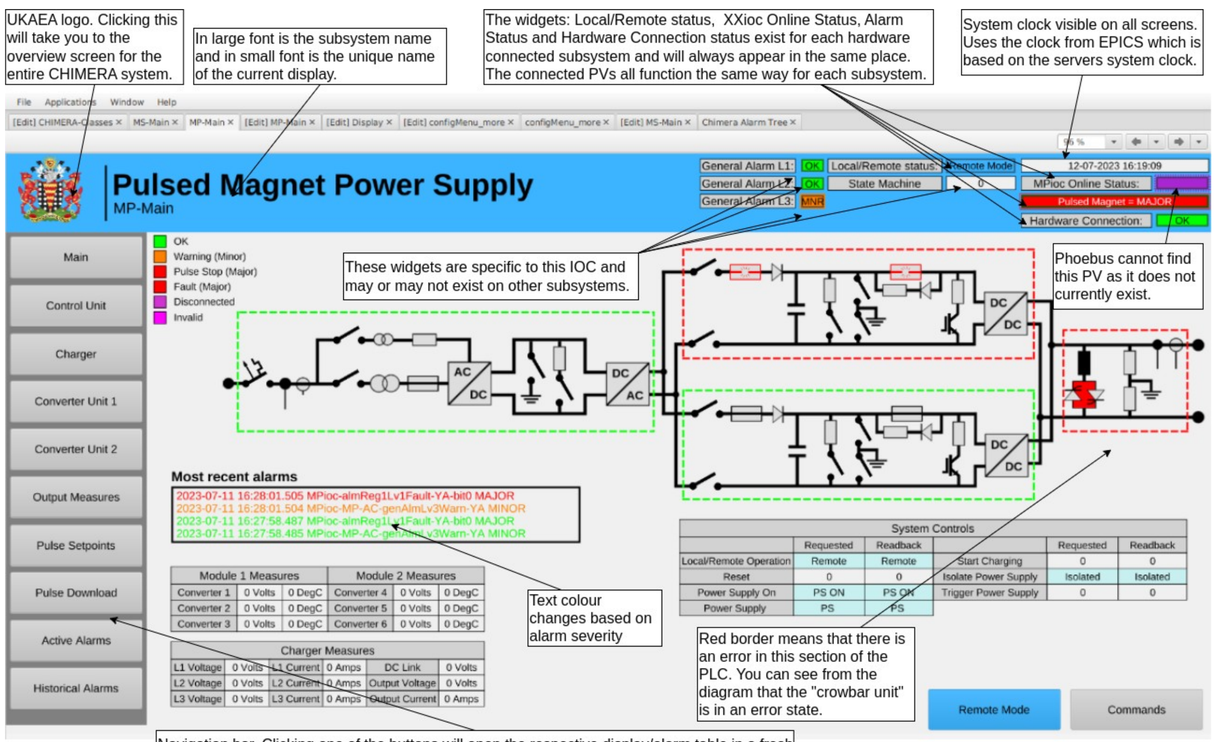


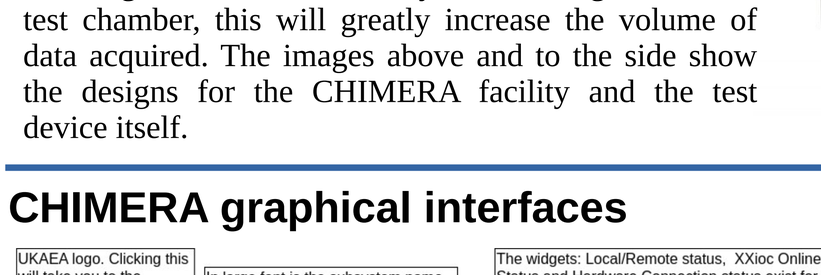


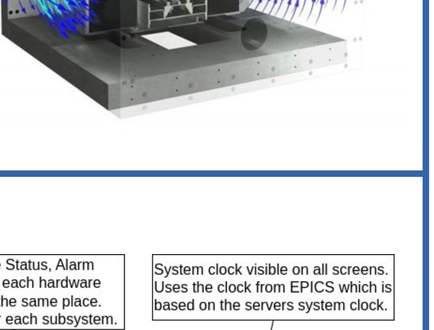
This diagram shows CHIMERA's seven hardware subsystem IOC servers (blue), the hardware devices that they control (white) and their associated communication interfaces (green). The control network layer is also shown (orange) as well as the three servers which allow the system-wide SCADA components to function (yellow) and finally the control room PCs (pink).

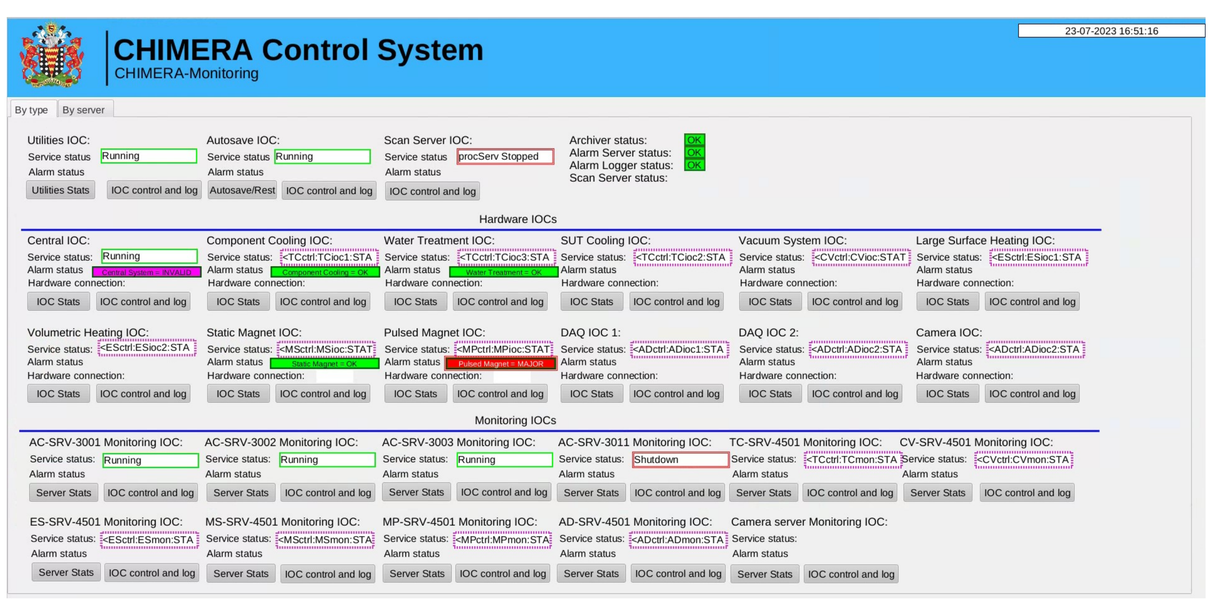
Requirements	Solutions
Provide an alarm system that alerts the operators of system errors	The Phoebus alarm server and Phoebus alarm logger. These include an annunciation system.
Manual control and monitoring of hardware	Custom Phoebus displays allow control and monitoring of all exposed PLC variables for maintenance and testing of the systems.
The ability to record and store high speed experimental data	A custom areaDetector driver collects data from an OPCUA interface and saves it as hdf5 files to a Network Attached Storage server.
To archive the state of the system	EPICS Archive Appliance
Monitoring of software and of software servers	Custom python softIOCs monitor server performance and the status of critical CHIMERA services. The EPICS procServControl module is used to monitor the status of IOCs and access their terminals.
Full automation of the control and sequencing of long duration experiments.	Achieved using the Phoebus scan server in conjunction with a series of state machines implemented using python soft IOCs. The state machines will tell the scan server when it can progress.
The ability to pause and resume running experiments	The python softIOC will provide this functionality, control will be done through a custom Phoebus display.
To restore the system state in the case of system outages and allow writing to a large set of PVs in preparation for an experiment.	The EPICS AUTOSAVE support module provides both of these functions.
IOC communication with hardware	The OPCUA and MODBUS support modules for EPICS

CHIMERA graphical interfaces









Conclusion

Due to the unique nature of CHIMERA, most hardware systems are being custom made and are being developed in tandem with SCADA. As such, software needs to be built with flexibility and future developments in mind, this is something that EPICS exceeds at. The data acquisition and data archiving system both use frameworks that can allow for massive increases in data volumes. An automated record generation system is being developed which makes use of the python epicsdbbuilder module to automate creation of EPICS records when spreadsheets of PLC variables are updated. The integrated nature of Phoebus allows us to reduce the amount of different apps that need to be managed, both by operators and engineers. An initial deployment of SCADA software to the CHIMERA site is expected in 2024. This will bring the high level SCADA functions to the facility as well as connecting the initial hardware subsystems with their controlling IOCs.

References: [1] T. R. BARRET et al., "CHIMERA Fusion Technology Facility: Testing and Virtual Qualifications", Fusion Science and Technology, Feb. 2023. [2] J. AUBERT et al., "Design and Preliminary Analyses of the New Water Cooled Lithium Lead TBM for ITER," Fusion Eng. Des., 160, 111921, Nov. 2020