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SIMULATION OF CRYOGENIC PROCESS AND CONTROL OF EAST BASED ON EPICS

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Abstract

The cryogenic system of Experiment Advance Superconductor Tokomak (EAST) is a large capacity system at both 4.5 and 80K levels at huge superconducting magnet system together with 80k thermal shields, complex of cryogenic pumps and small cryogenic users. The cryogenic system and their control are highly complex due to the large number of correlated variables on wide operation ranges. Due to the complexity of the system, dynamic simulations represent the only way to provide adequate data during transients and to validate complete cooldown scenarios in such complex interconnected systems. This paper presents the design of EAST cryogenic process and control simulator. The cryogenic process model is developed by the EcosimPro and CRYOLIB. The control system model is developed based on EPICS. The real-time communication between cryogenic process and control system is realized by OPC protocol. This simulator can be used for different purpose such as operator training, test of the new control strategies and the optimization of cryogenic system.

INTRODUCTION

The cryogenic system of Experiment Advance Superconductor Tokomak (EAST) is a large capacity system at both 4.5 and 80K levels at huge superconducting magnet system together with 80k thermal shields, complex of cryogenic pumps and small cryogenic users [1]. Pulsed heat load is the main different factor between the cryogenic system of full superconducting Tokamak system and other large cryogenic systems. The cryogenic system operates in a pulsed heat loads mode requiring the helium refrigerator to remove periodically large heat loads in time. It's very difficult to design the effective control algorithm to smooth the pulse loads and to improve the stability of the operation of the cryogenic system.

Dynamic simulation is as the only way to analyze the dynamic behavior and transient modes of a large scale of cryogenic system. From a simple Brayton cryogenic cycle to large scale cryogenic plants have been simulated. Maekawa R. et al have developed the C-PREST (Cryogenic Process REal-time SimulaTor) as a platform for process analysis and optimization tool to study coupled cryogenic phenomenon of helium refrigerator/liquefier for LHD [2]. Deschildre C. et al have simulated 400W@1.8K refrigerator at CEA based on hysys [3], and applied to refrigerator design to cope with the pulsed heat load [4]. A dynamic simulator, PROCOS (PROcess and COntrol Simulator), has been developed by Bradu B to improve knowledge on complex cryogenic systems for LHC [5].

This paper presents the design of EAST cryogenic process and control simulator. The cryogenic process model is developed by the EcosimPro and CRYOLIB. The control system model is developed based on EPICS. The real-time communication between cryogenic process and control system is realized by OPC protocol. This simulator can be used for different purpose such as operator training, test of the new control strategies and the optimization of cryogenic system.

CRYOGENIC SYSTEM OF EAST

As one of the important subsystems of EAST, the cryogenic system is mainly responsible for the cooling of the superconducting magnets and related components, ensuring the stable operation of superconducting magnets at various conditions. As shown in Fig. 1, the cryogenic system for EAST includes a helium refrigerator and the cryogenic distribution system. The helium refrigerator is composed of gas management system, compressors station, cold box and 10000 liter Dewar. All the heat exchangers, the absorbers and four turbine expanders are installed in the cold box. The design capacity of the helium refrigerator is 1050 W@3.5K +200W@4.5K +13g/s LHe +12~30kW@80K [1]. In order to maintain the proper cryogenic state of the EAST cold components, the helium refrigeration system (HRS) supplies three helium coolants: supercritical helium (SHe), liquid helium, and gaseous helium for the SC coils and their feeder lines, current leads, and thermal shield, respectively. The refrigerator usually operates at the mixed mode with liquefaction and refrigeration. The cryogenic distribution system is designed to distribute refrigeration to all of the cold components. The distribution system consists of a cryogenic valve box, four cryogenic transfer lines, supercritical helium feeders in the cryostat, two vacuum insulated tubes for superconducting buslines and two coldboxes for the high temperature superconductor current leads.

The EAST cryogenic control system was designed based on DeltaV DCS of Emerson Corporation. Fig. 2 shows the network of the cryogenic control system which is composed of three parts: cryogenic redundant control local area network (LAN), data exchange LAN and main control data server LAN. The control layer includes two local control cabinets for cold boxes and cryogenic

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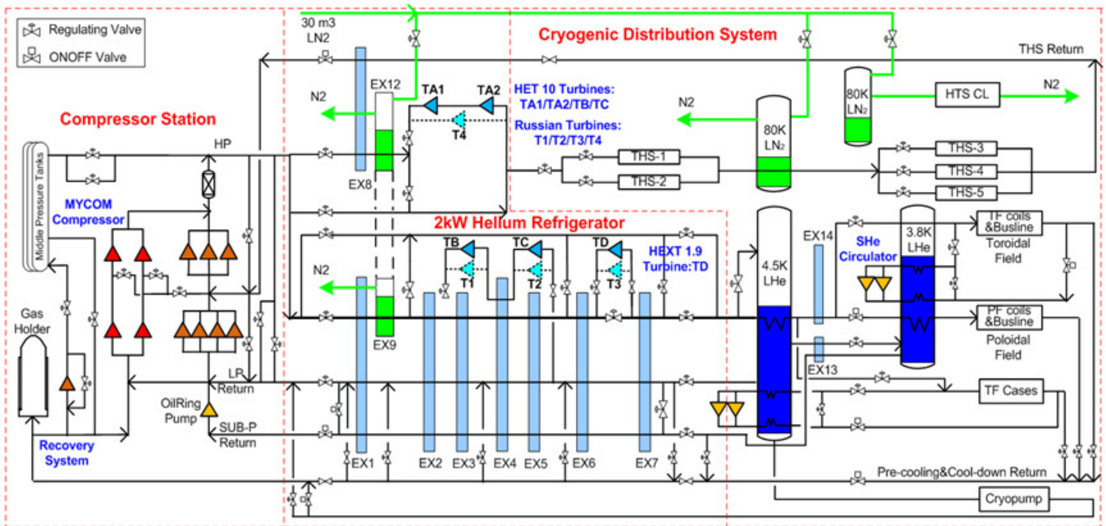

Figure 1: PFD of EAST cryogenic system.

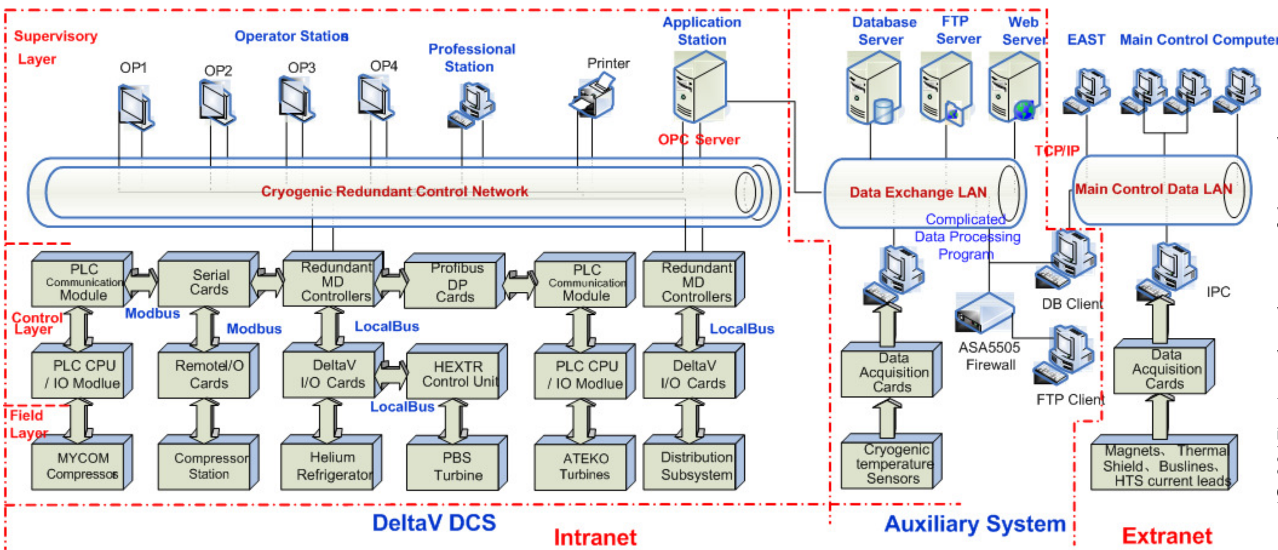

Figure 2: EAST cryogenic control system based on DelatV DCS.

distribution system and a remote control cabinet for compressor station. Local control cabinet includes redundant MD controller, power module and I/O cards. The remote control cabinet includes R5 remote I/O cards and serial card. The remote control system connects to local control by serial cards in terms of MODBUS protocol. New compressors are controlled by PLC and also connect to local control by MODBUS protocol. New PBS turbine is controlled by HEXTR provided by PBS Company and connects to DCS by local bus. New ATEKO turbine is controlled by PLC and as a profibus slave of DCS based on Profibus DP [6].

PROCESS AND CONTROL SIMULATION

EcosimPro is commercial software to model and simulate multidisciplinary continuous-discrete systems. It can be used to simulate any kind of system based on Differential Algebraic Equations (DAEs) such as thermo-hydraulic processes like cryogenic systems to study the steady state of models, transient behavior, and complex experiments using FORTRAN, C or C++ functions. With its clever wizards, EcosimPro provides modelers with an easy way to build consistent mathematical models. EcosimPro has an advanced Graphical User Interface and uses a high level, “engineer-friendly” Object-oriented and non-causal language (EL) for creating reusable libraries of components. Models can be constructed graphically by ‘dragging-and-dropping’ the required component symbols from the included libraries to a schematic window. Using EL, users can also create new components and libraries, or extend the existing ones. There are varieties of library

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have already been developed for several different domains such as: Cryogenics, Power, Space, Thermal, Control, etc [7]. CRYOLIB is a commercial Ecosimpro library which is specially designed to simulate cryogenic process and their control systems based on a library originally developed and validated at CERN. CRYOLIB allows users to perform dynamic simulations of cryogenic processes such as helium refrigerators or liquefiers [8].

The architecture of cryogenic process and control simulation is shown in Fig 3. The simulator of cryogenic process and control is based on EPICS. The cryogenic process model is developed by the EcosimPro and CRYOLIB. The real-time communication between cryogenic process and control system is realized by OPC protocol.

The OPC server is created in the EcosimPro. the purpose of the EcosimPro OPC Toolbox is to make conversion of a simulation model into an OPC server and exposing the data in the model to external clients, the connection architecture for the simulation systems is built finally by the OPC protocol. An OPC Server is generated from a Deck in EcosimPro, Deck is an encapsulated EcosimPro simulation model generated for running as a black box, the variables to be exposed by the OPC Server should be select when create the Deck. Through the process shown in Fig. 4, an OPC Server corresponding to the simulation represented by the deck is generated finally [6].

The IOC layer is implemented by soft IOC which is an instance of IOC Core running as a process on a "non-dedicated" computer and without real I/O hardware, soft IOC runs with the EPICS IOC shell that is used to interpret startup scripts (st.cmd) and to execute commands entered at the console terminal as a simple command interpreter. IOC OPC client has been developed to real time communication with OPC server.

In OPI layer, Control System Studio (CSS) is selected as the CA client application, CSS is an Eclipse-based collection of tools to monitor and operate large scale control systems, which provides integrated environment tool for engineering, configuration and operation.

The whole cryogenic simulation system run in one computer running Windows, two kinds of communication protocol based on the Client/Server model are applied for the data transport between neighboring layers, one is the Channel Access for CSS and IOC, another is the OPC for IOC and underlying model. The IOC appears revealing dual role can be regarded as either CA Server in term of CSS or OPC client in term of the cryogenic process model.

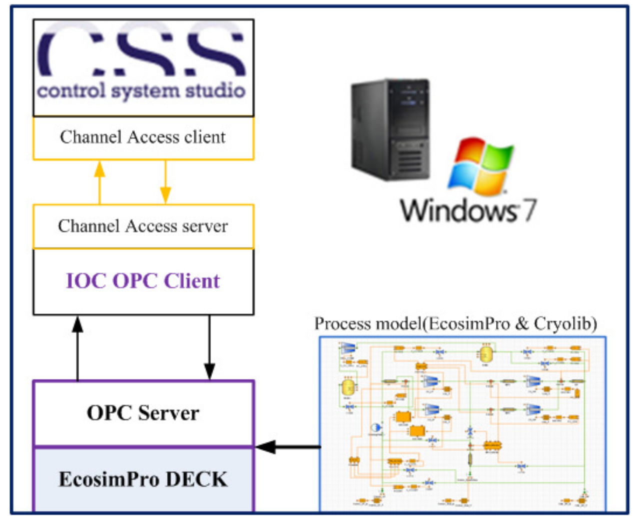

Figure 3: architecture of cryogenic process and control simulation.

Figure 4: The generation process of the OPC server in EcosimPro.

CONCLUSION

EAST cryogenic control system will be upgraded based on EPICS in the future. So the simulator of cryogenic process and control based on EPCIS has been developed. The real-time communication between cryogenic process and control system is realized by OPC protocol. This simulator is helpful for upgrade of Cryogenic control system of EAST. At same time, it can be used for different purpose such as operator training, test of the new control strategies and the optimization of cryogenic system.

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