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Simulation of Cryogenic Process and Control of EAST based on EPICS

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CASIPP

Content

- Introduction
- Simulator based on EPICS
- Cryoplant simulation experiments
- Results & Conclusions

EAST Tokamak & Cryogenic System

CASIPP

Warm Compressor Station & 10000 Nm3 helium gas tanks

EAST Superconducting Tokamak

2kW/4.5K Helium Refrigerator

EAST Cryogenic System (ECS)

Cool-down

One of Critical Sub-systems

- **EAST- Experimental Advanced Superconducting Tokamak**
- **EAST is the first full superconducting fusion device in the world**

Cryogenic distribution system

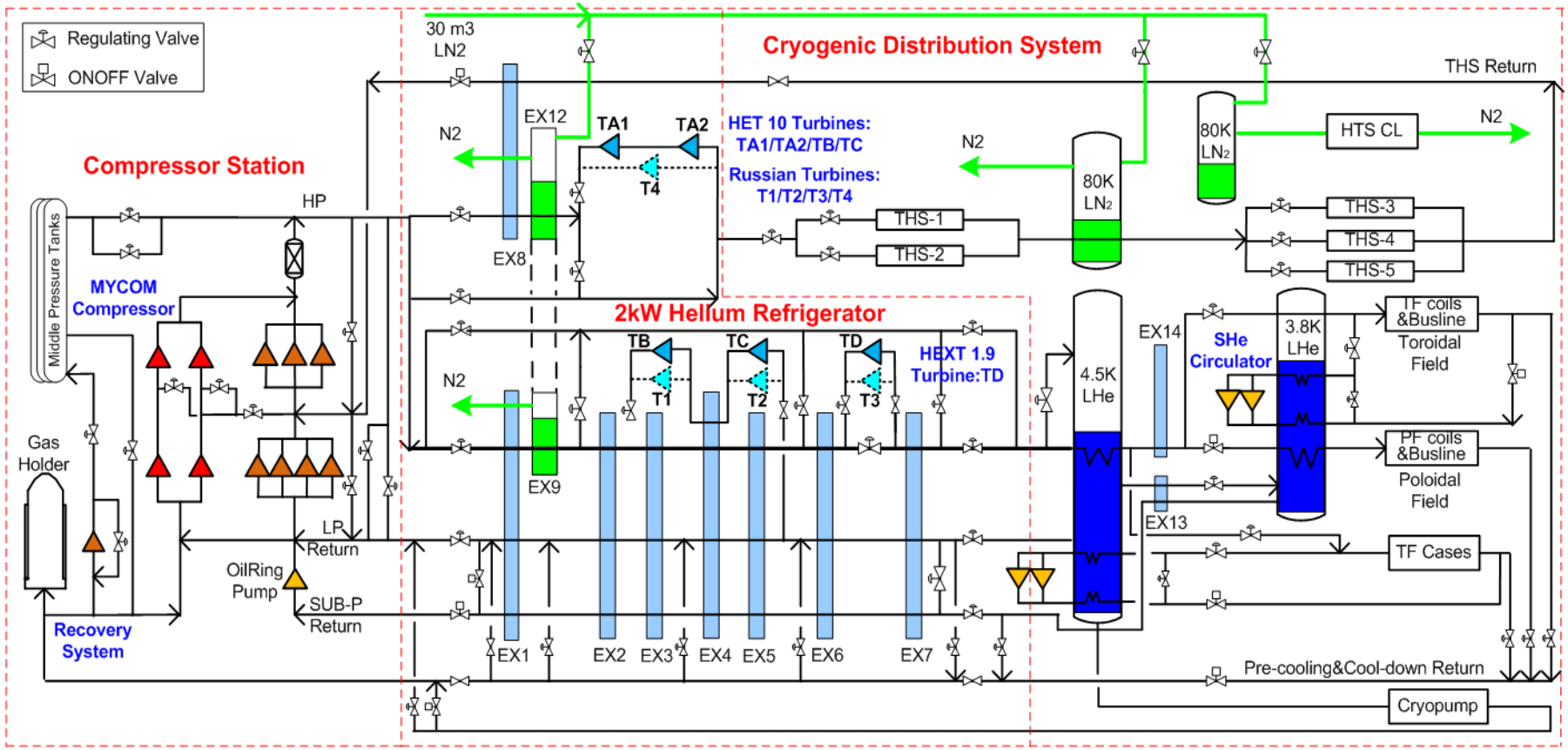
Cold Components

- PF Coils， TF Coils， TF Coil Cases，Thermal Shields
- Buslines，HTS Current Leads (CL)，Built-in Cryopumps

Total cold mass

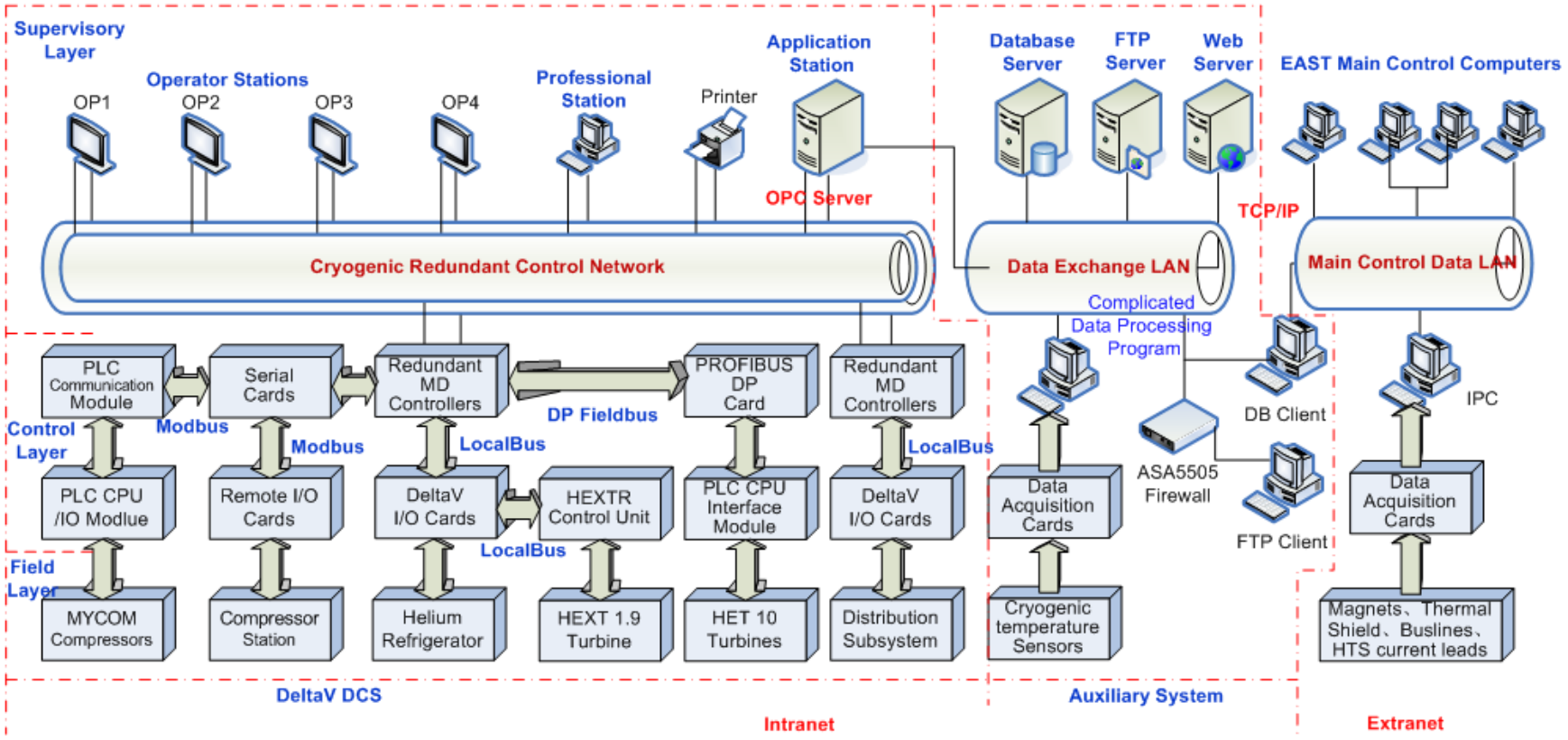
- 250 tons

Process Flow of ECS



- **Two refrigeration cycles with LN2 pre-cooling**
  - Claude cycle with 3 turbines to produce refrigeration power at 4.5K for SC
  - Reverse-Brayton cycle with two turbine in series to produce refrigeration power at 80K for THS
  - Equivalent refrigeration power: 2 kW/4.5 K

Cryogenic Control Network

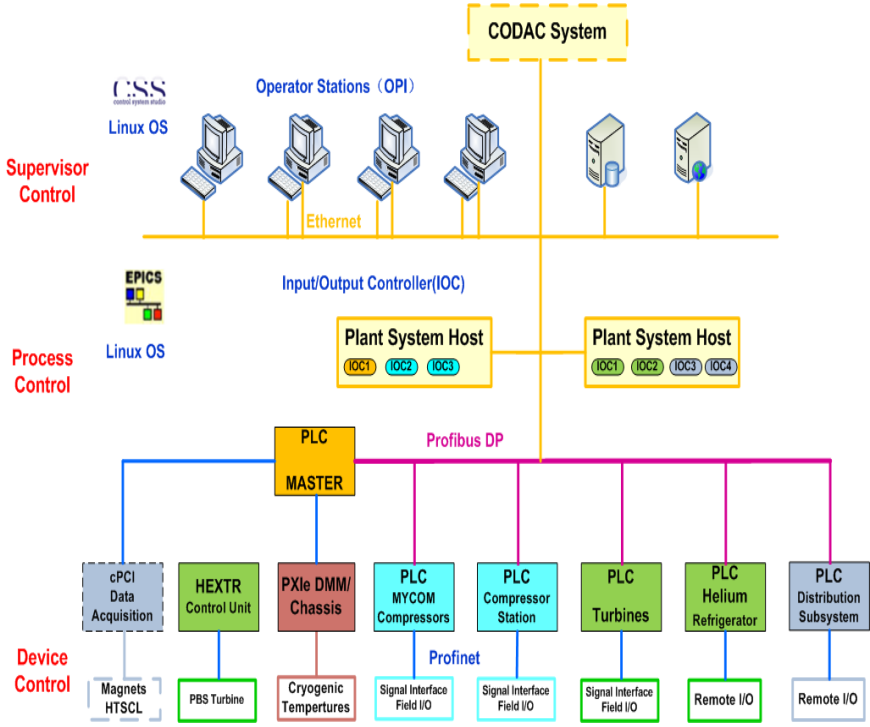


DeltaV DCS: centralized supervisory, distributed control

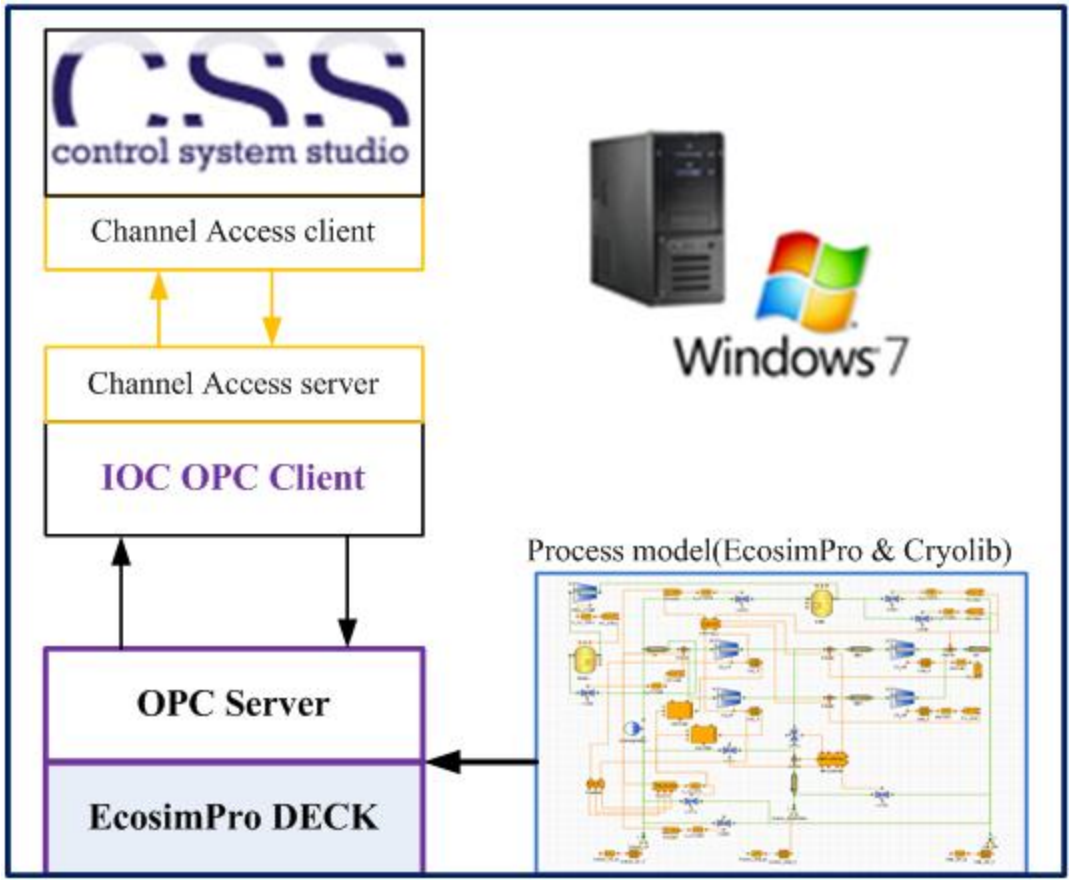
- Three-layer redundant control network and expands function through OPC protocol
- New compressors and turbines PLC communicate with DCS through MODBUS/PROFIBUS DP protocol

Motivations for Dynamic simulation

- **Refrigeration Process Design**
  Thermodynamic calculation, Equipment parameters
- **Control Strategies Design**
  Control sequences , Controller Parameter Tuning, Virtual commissioning
- **Performance Optimization**
  Operational optimization in Off-design condition
- **Management under abnormal conditions**
  Fault diagnosis, Smooth for heat-load
- **System Commissioning**
  Operator training, Refrigeration cycle re-optimization
- **Upgrade of Control system**
  DeltaV DCS upgraded to EPICS



Simulation architecture



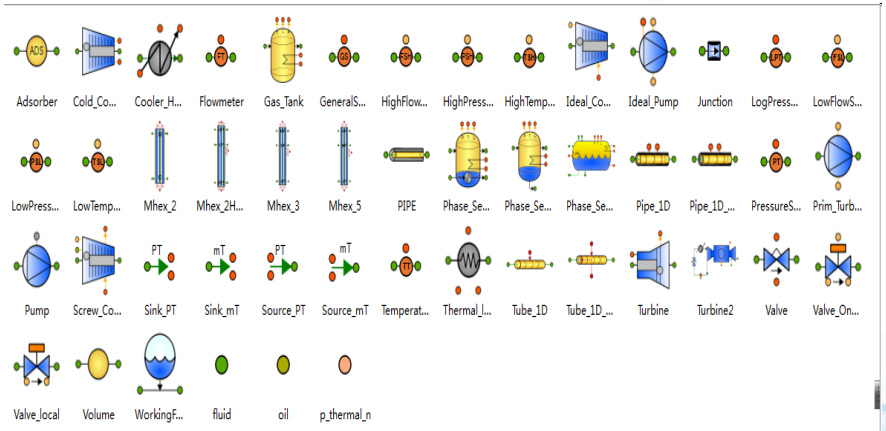
- CA client: CSS, same as the real cryogenic control system
- Soft IOC: IOC Core running as a process controller without real I/O hardware
- The field I/O device layer is integrated into the cryogenic process model

EcosimPro &CRYOLIB

EcosimPro
Modelling and Simulation Software

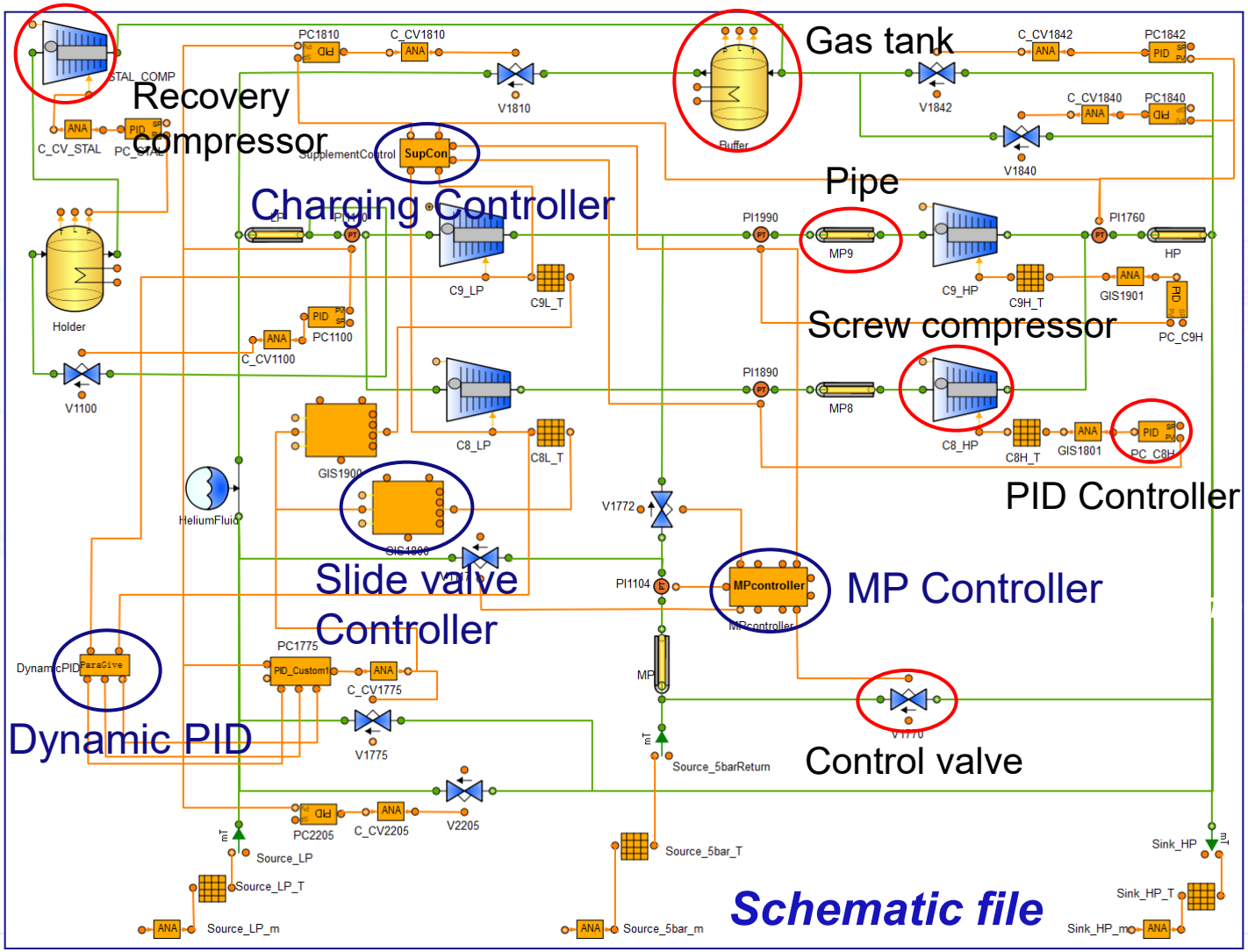
An advanced modelling and simulation tool for modelling any kind of system based on DAE (Differential–Algebraic Equations) and discrete events. Used by lots of famous institute:

- Based on the object oriented programming paradigm
- An intuitive, visual development environment
- It includes multidisciplinary libraries from fields like: Cryogenics, Power, Space, Thermal, Control

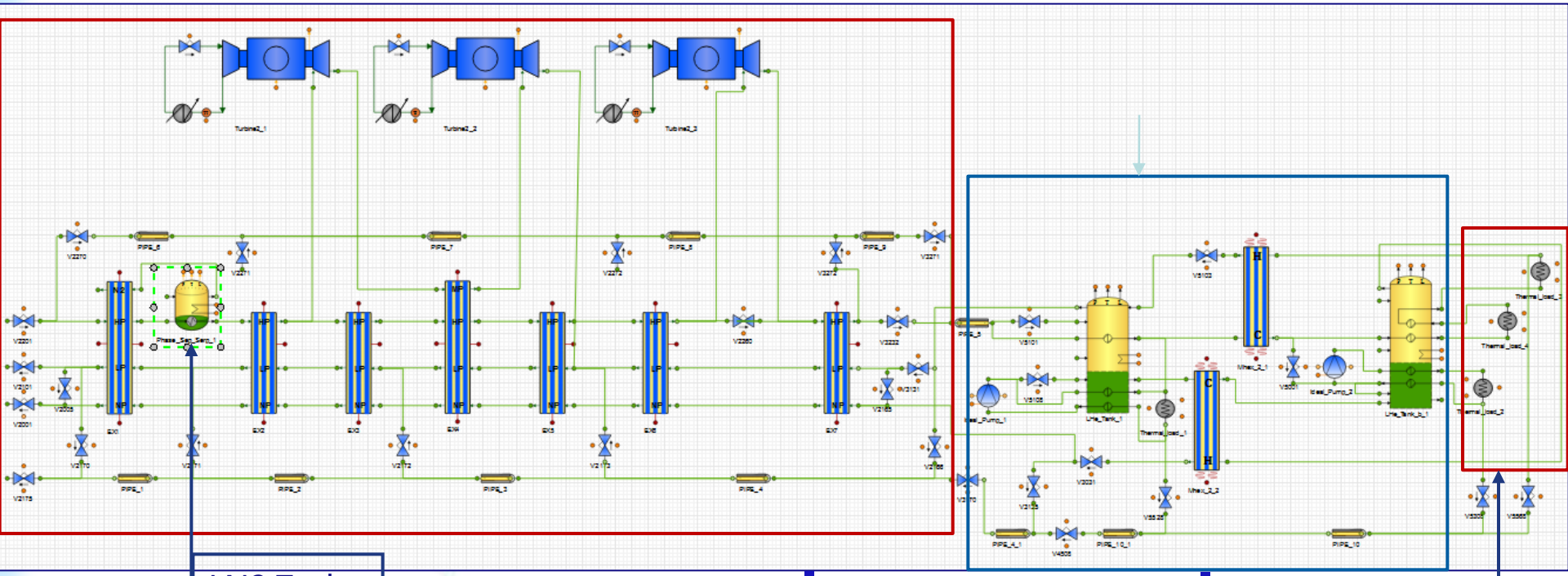


CRYOLIB is a commercial cryogenic library which is developed and validated at CERN

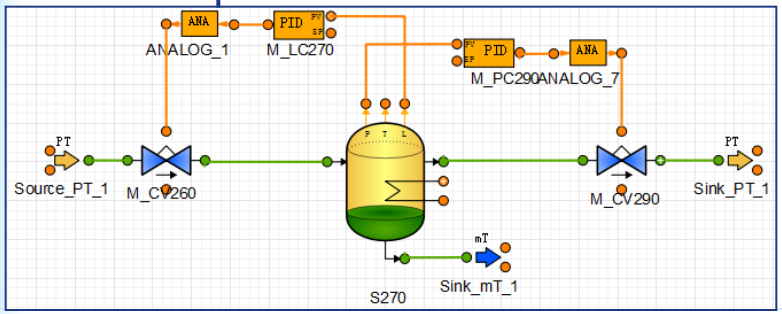
Model of WCS in EcosimPro



Modeling of coldbox & distribution system



LN2 Tank



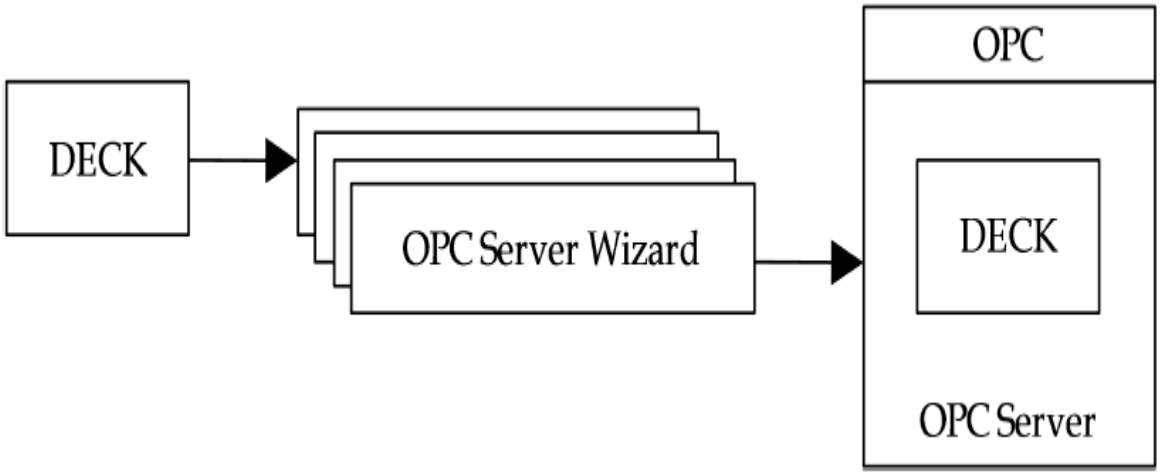
ColdBox

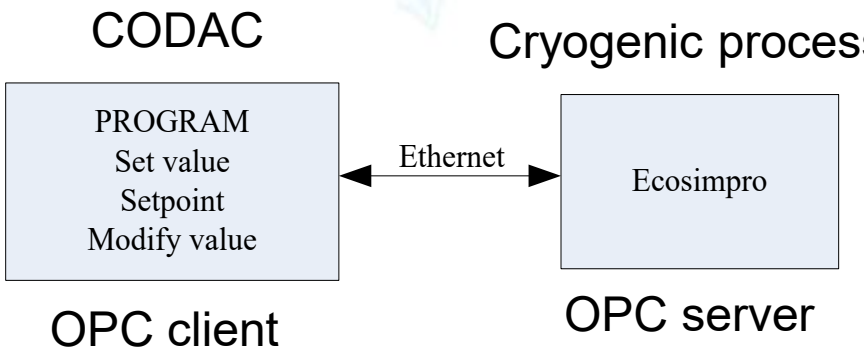
Distribution System

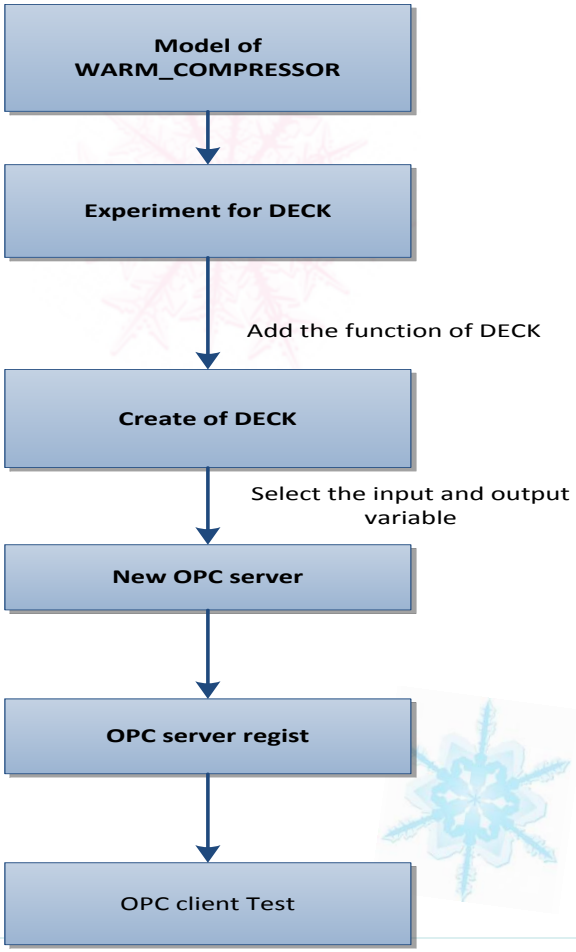
Load

OPC server generated in EcosimPro

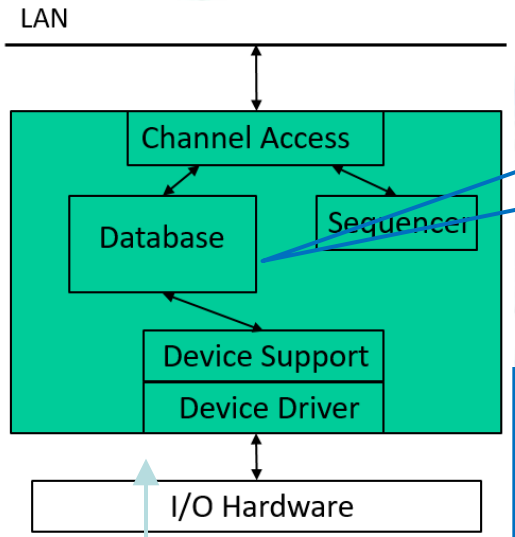
Ecosimpro OPC Toolbox: Make conversion of a simulation model into an OPC server







Software components of IOC



- A data file that's loaded into IOC memory
- A collection of various types of EPICS records

Records can be interconnected and are used as building blocks to create applications:

- Calculations
- Control loops
- Data reading & writing

Device Driver allows records to interact with hardware I/O

IOC Core: Computer run IOC

VxWorks® WIND RIVER, Linux POWERED, MacOS, Embedded With RTEMS www.rtems.org

Records configuration in IOC-OPC-Client

```
record(bi,
"Ecosim:CompressorStartSignal_bi") {
   field(DESC, "Start/ Stop Compressor")
   field(SCAN, "1 second")
   field(DTYP, "opc")
   field(INP, "@Deck
Variables.C1_start_signal_1_")
   field(ZNAM, "STOPPED")
   field(ONAM, "STARTED")
}
record(bo,
"Ecosim:CompressorStartSignal_bo") {
   field(DESC, "Start/ Stop Compressor")
   field(SCAN, "1 second")
   field(DTYP, "opc")
   field(OUT, "@Deck
Variables.C1_start_signal_1_")
   field(ZNAM, "STOP")
   field(ONAM, "START")
}
```

```
record(ao, "Ecosim:LP_Setpoint_ao") {
   field(DESC, "LP Setpoint")
   field(SCAN, "1 second")
   field(DTYP, "opc")
   field(OUT, "@Deck Variables.my_lp")
}
```

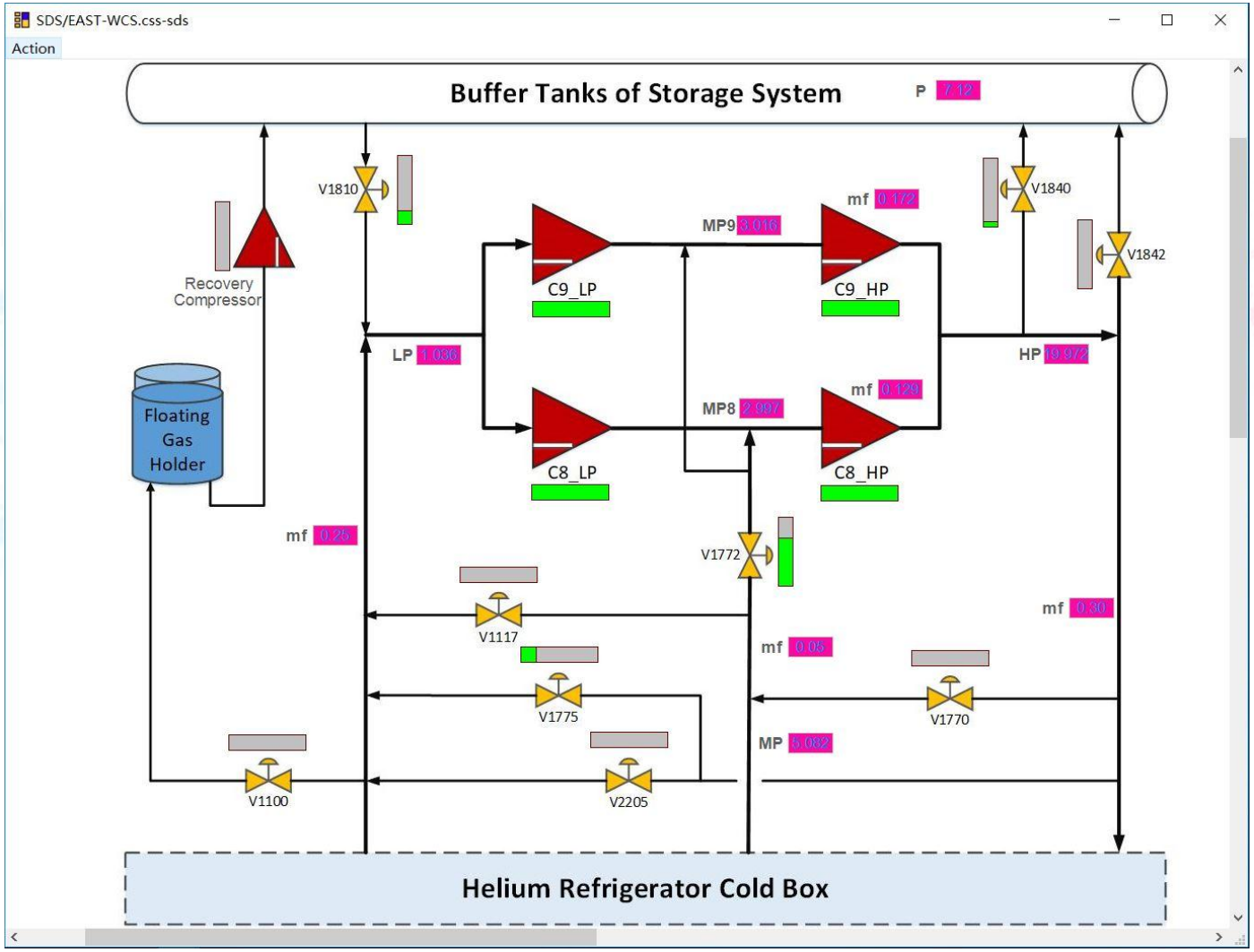
```
record(ai, "Ecosim:HP_ai") {
   field(DESC, "HP Measurement")
   field(SCAN, "1 second")
   field(DTYP, "opc")
   field(INP, "@Deck Variables.HP_P")
}
```

Records configuration in IOC-OPC-Client

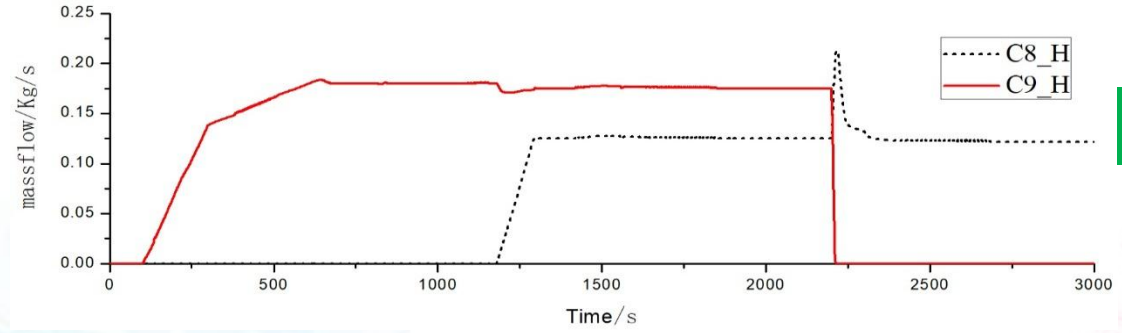
```
record(pid, "Ecosim:PC1100_pid") {
   field(DESC, "Regler")
   field(SCAN, "1 second")
   field(FLNK, "Ecosim:PC1100_ao")
   field(CVL, "Ecosim:LP_ai NPP MSI")
   field(PREC, "2")
   field(KP, "1")
   field(KI, "0.01")
   field(EGU, "bar")
   field(EGUF, "2")
   field(HOPR, "2")
   field(DLIM, "1")
   field(DLSV, "MINOR")
   field(DHYS, "0.01")
   field(RLIM, "0.5")
   field(RLSV, "MINOR")
   field(RHYS, "0.01")
   field(ADEL, "0.2")
   field(MDEL, "0.01")
   field(SOUT, "0")
   field(DRA, "Direct")
   field(SEMI, "S=S")
   field(AM, "A")
   field(INSP, "1.05")
   field(SRAT, "0.1")
#   field(SHUP, "50")
}
```

```
record(ao, "Ecosim:PC1100_ao") {
   field(DESC, "Ablade-Ventil 1. Str.")
   field(DTYP, "opc")
   field(OUT, "@Deck
Variables.IOC_PC1100_OUT")
   field(DOL, "Ecosim:PC1100_pid.OUT
NPP NMS")
   field(OMSL, "closed_loop")
   field(PREC, "1")
   field(EGU, "%")
   field(DRVH, "100")
   field(HOPR, "100")
}
```

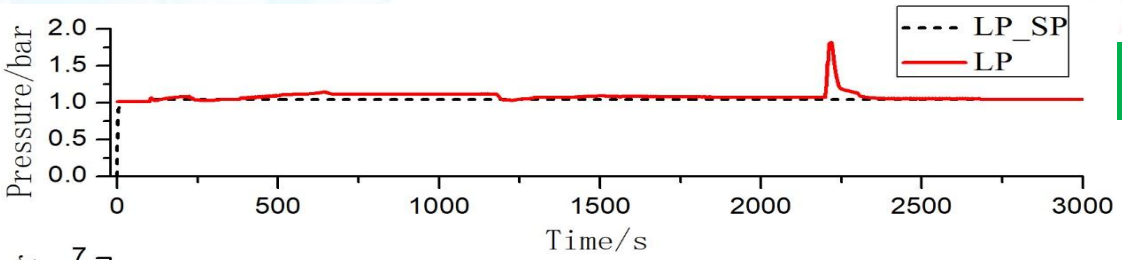
Interface in CSS



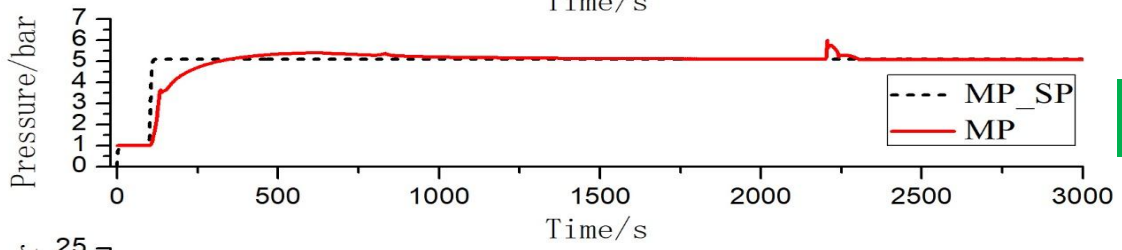
Simulation results-Pressure of WCS



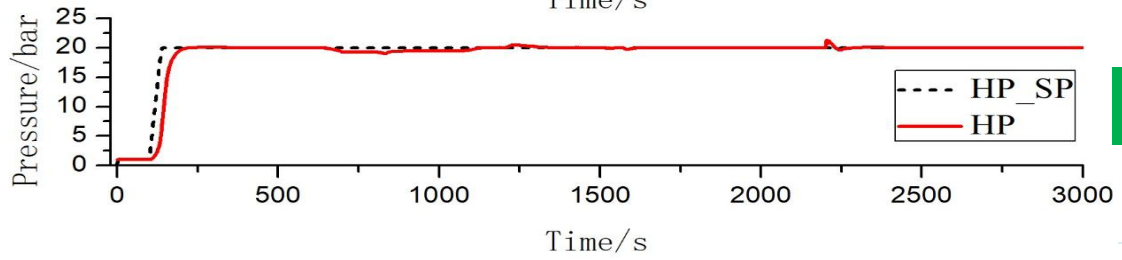
Mass flow



Low pressure



Middle pressure



High pressure

Conclusion and Perspective

- The simulator of cryogenic process and control based on EPICS has been developed by ASIPP and DESY
- The real-time communication between cryogenic process and control system is realized by OPC protocol.
- The simulator is helpful for upgrade of Cryogenic control system of EAST
- The simulator is an efficient platform to realize rapid design and stable operation of cryogenic system, and have guiding significance during the life-cycle of cryogenic system .

Acknowledgements

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Thanks for your attention !