EcosimPro: Dynamic Simulation Tool and its application to control

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What is EcosimPro?

- EcosimPro is a simulation tool developed by Empresarios Agrupados (EA) for modelling 0D-1D mathematical models based on Differential-Algebraic Equations and discrete events.
- EcosimPro is a user-friendly simulation tool for modelling simple and complex physical processes with an intuitive GUI and an acausal object-oriented modelling language.
- EcosimPro is based on more than 30 years of experience of many engineers working in simulation in the energy and aerospace sectors.
- EcosimPro is being used in complex models of Nuclear Power Plants, International Space Station, Ariane-5 rocket systems, etc.
- EcosimPro is the official tool of ESA in several disciplines: propulsion, ECLSS, power systems, etc.

ESA-EA Relationship

- EcosimPro project was originally an ESA project for modelling complex environmental control and life support simulation for the International Space Station (Columbus and Hermes)

- In 1995 EA decides to create a commercial product based on this software and move to the Windows operating system.

- ESA is funding every year a part of the new improvements of EcosimPro since it has become as the standard ESA tool in the areas of ECLSS, Propulsion (Launcher & Satellite) and Satellite Power Systems.

- EA and ESA maintains a close relationship in terms of exchanging information, proposing new improvements, creation of standard libraries, etc.

Main features

- EcosimPro provides a graphical user interface to develop components, build complex systems and perform dynamic simulations, parametric studies or steady-state calculations.

- The tool generates C++ code that can be used elsewhere to link the model to other applications. The models can also be connected to Matlab/Simulink and Excel.

- One of the main features that distinguish EcosimPro from other tools is having an **acausal** language. Instead of forcing the user to define a flow direction in the model, the tool operates at a higher level allowing symbolic manipulation of equations and allowing bi-directional information flow in models, which offers the user the following advantages:

  - Easier modelling process

  - Models are reusable and scalable

  - It benefits from all the advantages of object oriented languages

EcosimPro Applications

EcosimPro/PROOSIS: Main Industrial Applications_1

Use of EcosimPro/PROOSIS and its Component Libraries is ideal for performing any sort of studies within the same simulation platform.

Main industrial and scientific sectors :

- Space
- Aeronautics
- Energy and Process Sectors
- Science Infrastructure

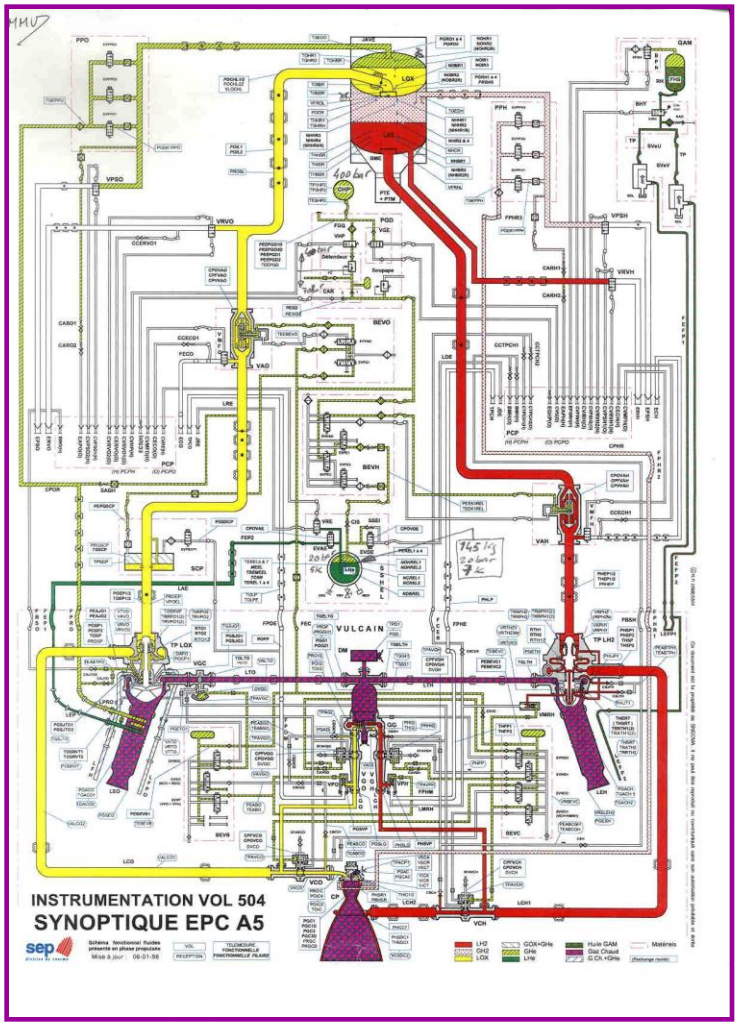
EcosimPro: Applications in Space

1. Space

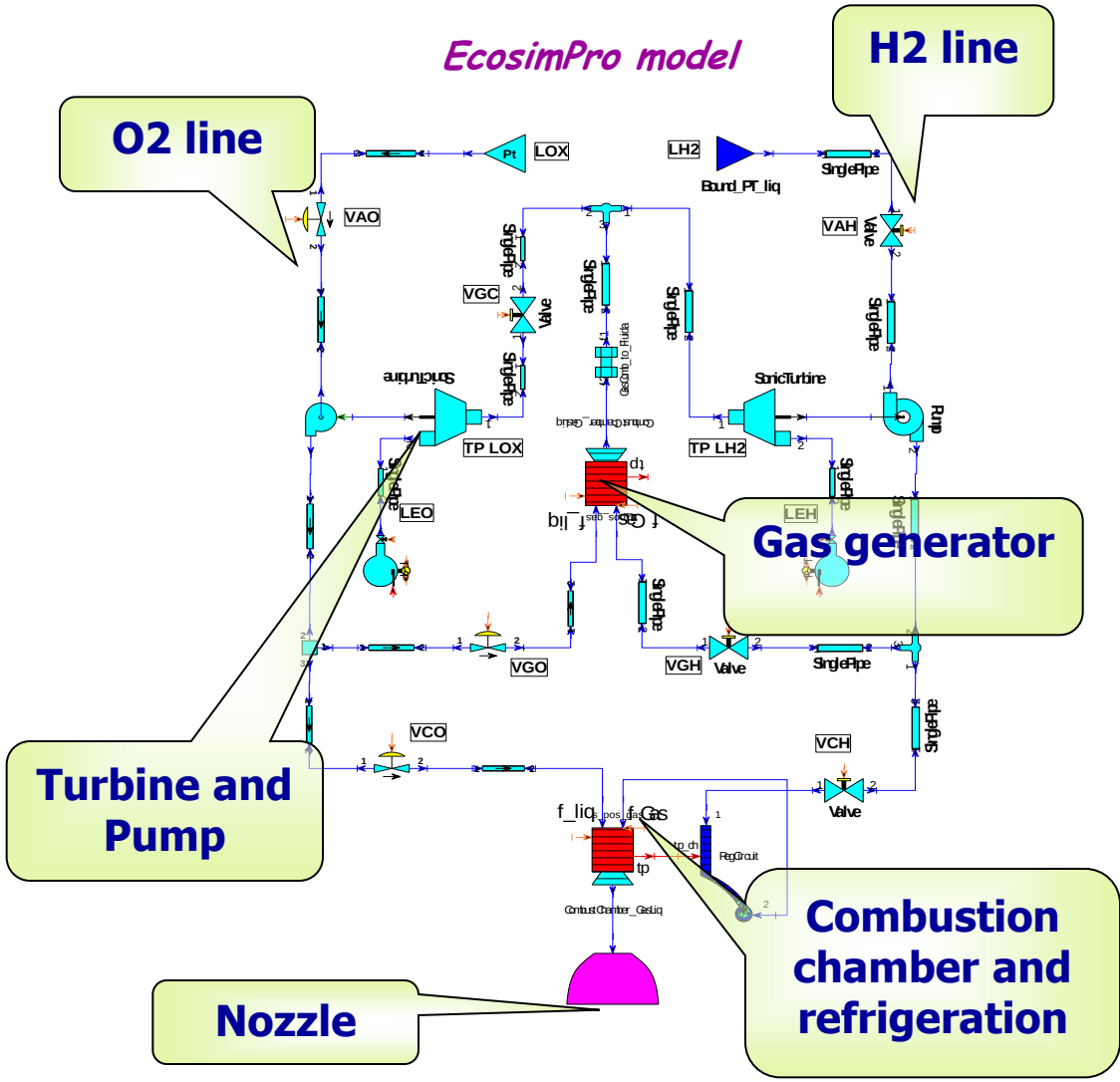
Applications	Available Libraries and Experience
Environmental Control and Life Support Systems (ECLSS)	Library of **ECLSS** components is currently being used in **ARES** (Air Revitalization System for ISS): - Oxigen production from water - Capture and control of CO2 in the cabin - Conversion of CO2 into water and methane - Reuse of produced water in the different processes
Chemical and Electrical Propulsion *(Launchers and Satellites)*	Libraries **ESPSS** (European Space Propulsion Simulation Software)
Hydraulic piping networks *(including compressible flows and two-phase flows)*	Library **FLUIDAPRO**
Power Systems *(Satellites)*	Library **ELEC_SYSTEMS:** solar panels, converters, control of loading and unloading of satellite batteries and distribution to users
Thermal Control	Library **THERMAL:** calculation of thermal loads due to conduction , convection and radiation heat transfer
	Library of **HEAT PIPES** (Not commercialized, and currently used by our subsidiary Iberespacio)
	Library of **LHP** (Loop Heat Pipes; sames comments as for Heat Pipes)

ESPSS applications: the Vulcain engine

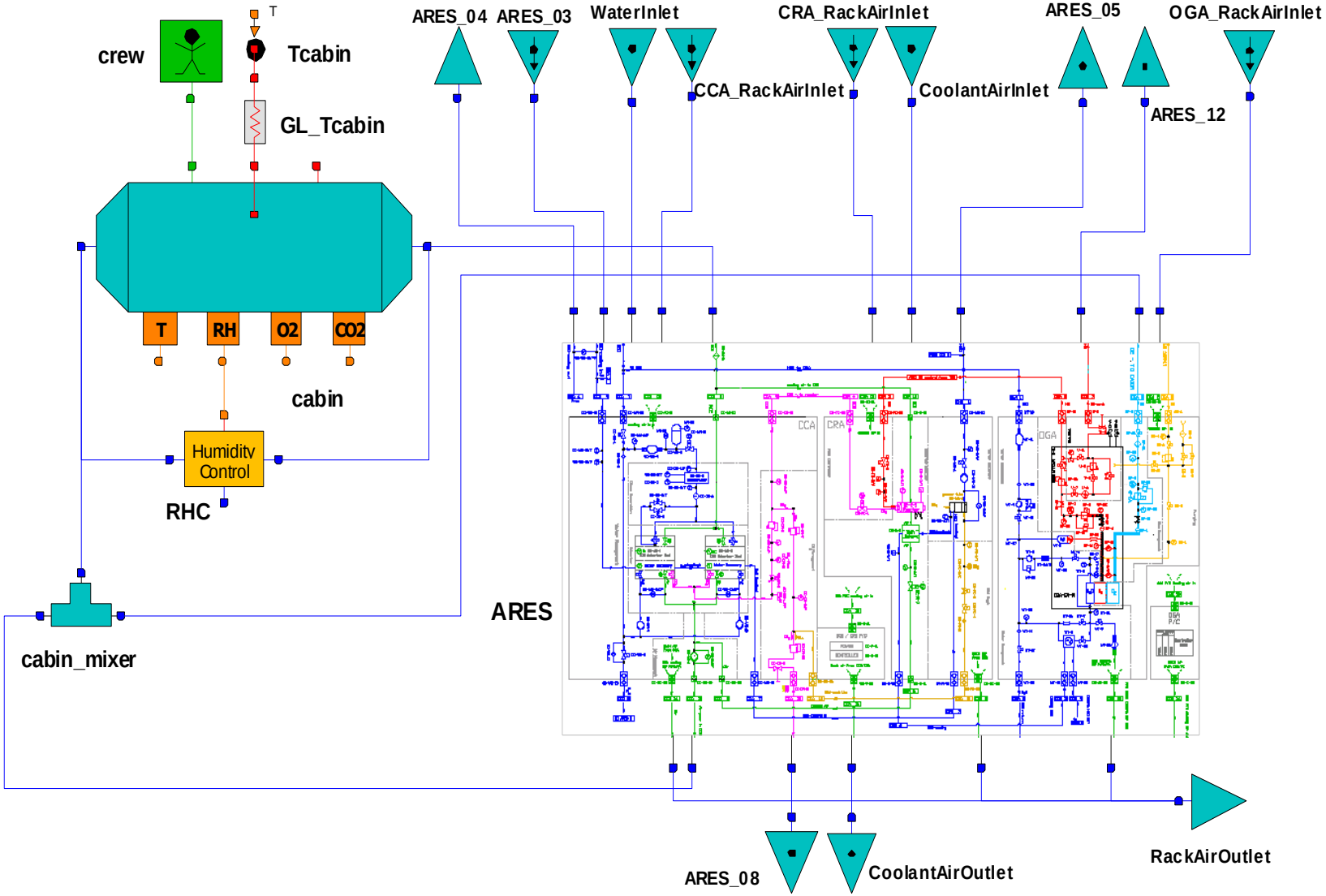
- **Example: Vulcain Main Stage**



EcosimPro model



ECLSS Industrial Applications: ARES_3

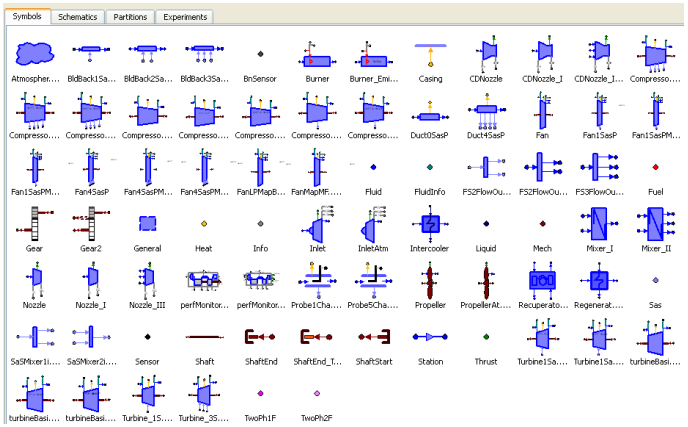


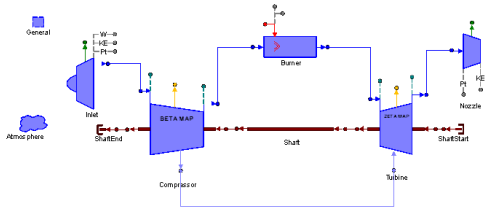
EcosimPro: Applications in Aeronautics

2. Aeronautics

Applications	Herramientas disponibles y/o experiencias de interés
Turboengines	Library **TURBO**
Cabin Environment Control and Life Support	Library **ECS**
Engine Auxilary Systems (Fuel, Pneumatic, Hydraulic, Electrical, etc)	Library **AUX_SYSTEMS** under development

www.proosis.com

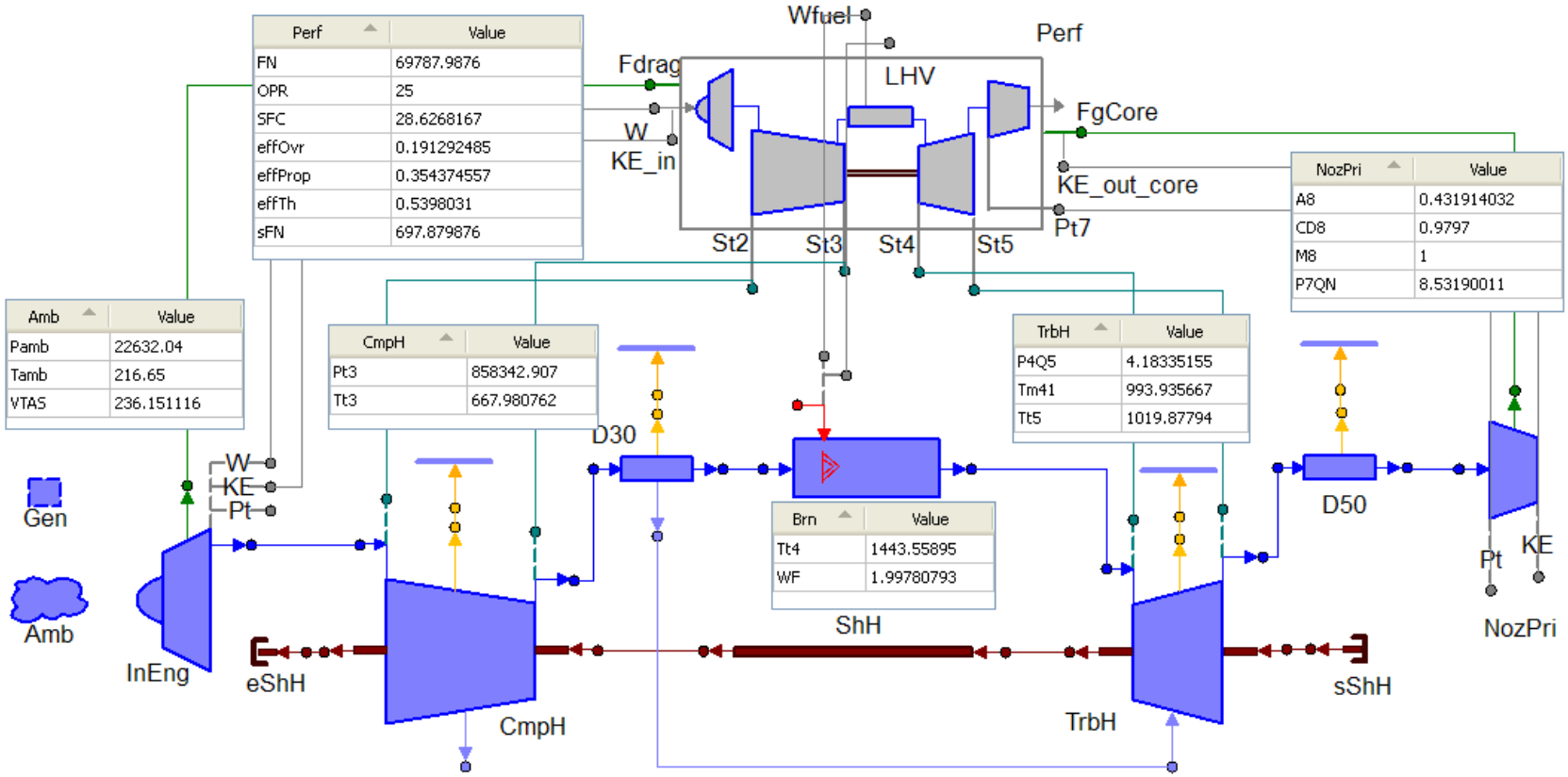




Turbojet

TURBO applications: Design Point Analysis

- Cycle design parameters: P3Q2=25, Tt41=1400 k
- Performance parameters: EP3=0.9, EP5=0.9
- Design A8 so that W2=100 Kg/s



EcosimPro: Applications in Energy

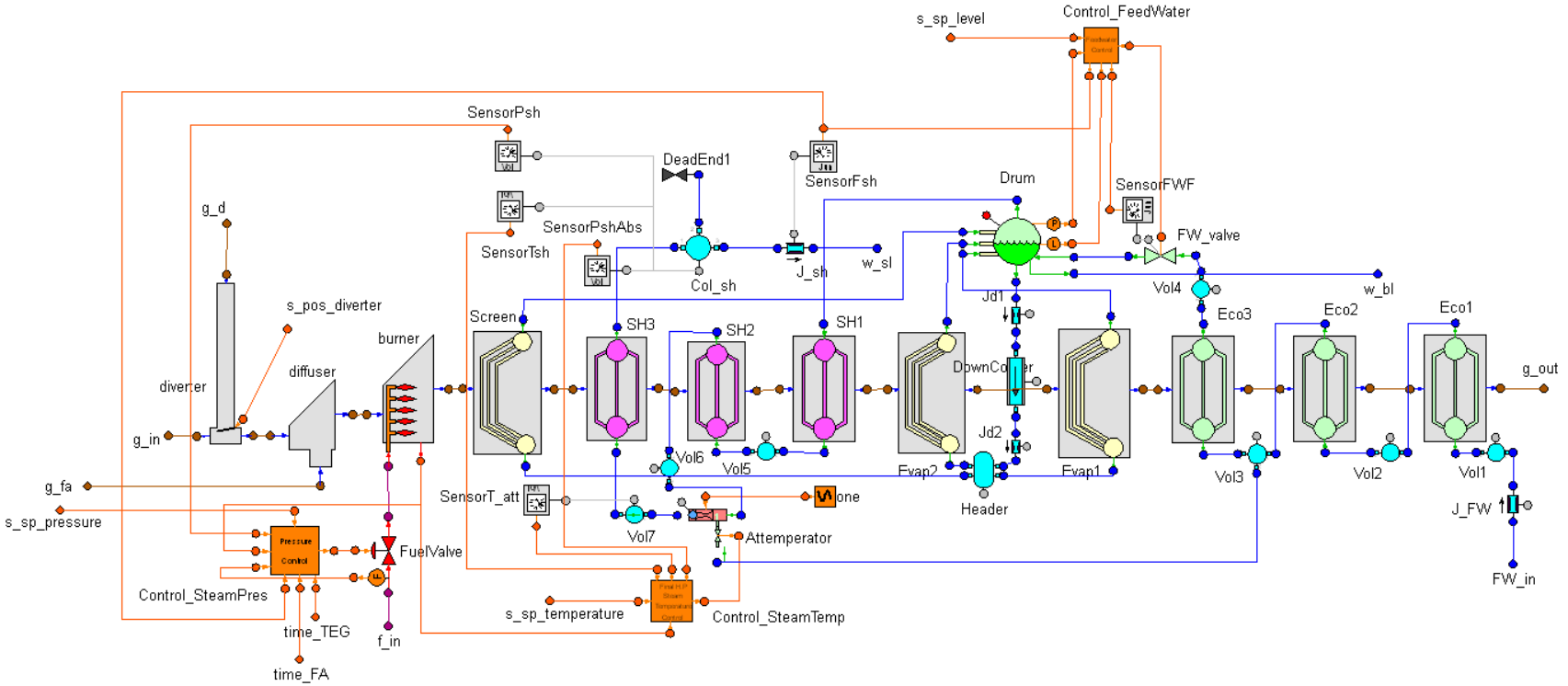
3. Energy

Applications	Available Libraries and Experience
Piping and Ducts Networks	Library **PIPELIQ** (semi-steady state)
	Library **PIPELIQTRAN** (transient studies - waterhammer)
	Library **FLUIDAPRO** (1 D fluid flow, uncompressible, compressible and two phase flow)
Energy Balances	Library **THERMAL_BALANCE (steady energy balance of Power Plant)**
Plant Systems	Library **PLANT_SYSTEMS**
Heat Recovery Systems	Library **HRSG**
Thermosolar Plants	Library **THERMOSOLAR**
OxyCombustion Coal) and CO2 capture Plants	Library **OXICOMBUSTION**
Reverse Osmosis Plant	Library **REVERSE OSMOSIS**

HRSG application: Steam Stability Study

Steam Stability Study (PORTO Refinery)

Schematic of the boiler (HRSG) model



EcosimPro: Applications in Process

4. Process

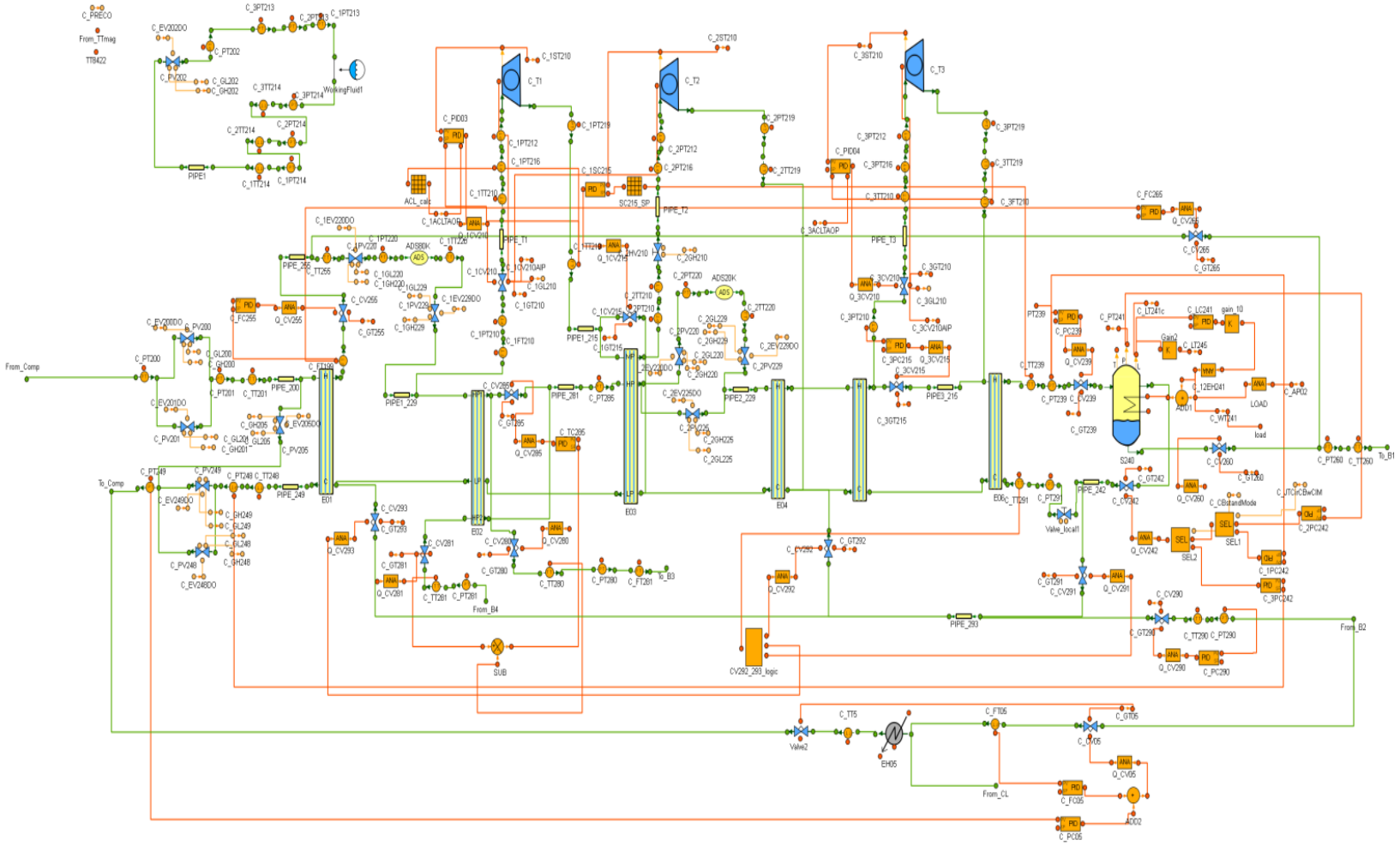
Applications	Available Libraries and Experience
Basic Chemical Process	Library **PROCESS**
Sugar factory	Library **SUGAR + Simulator** (Engineering + Training)
Control	Library **CONTROL**
	Library **PREDICTIVE_CONTROL**

5. Science Infrastructure

Applications	Available Libraries and Experience
Cryogenics	Library **CRYOLIB (developed in collaboration with CERN)** - Dynamic simulation of large scale cryogenic systems
Tritium	Library T**RITIO_SIM (developed in collaboration with Ciemat)** -Simulation of Test Blanket Modules (TBMs) of ITER - Analysis of tritium diffusion phenomena through several materials

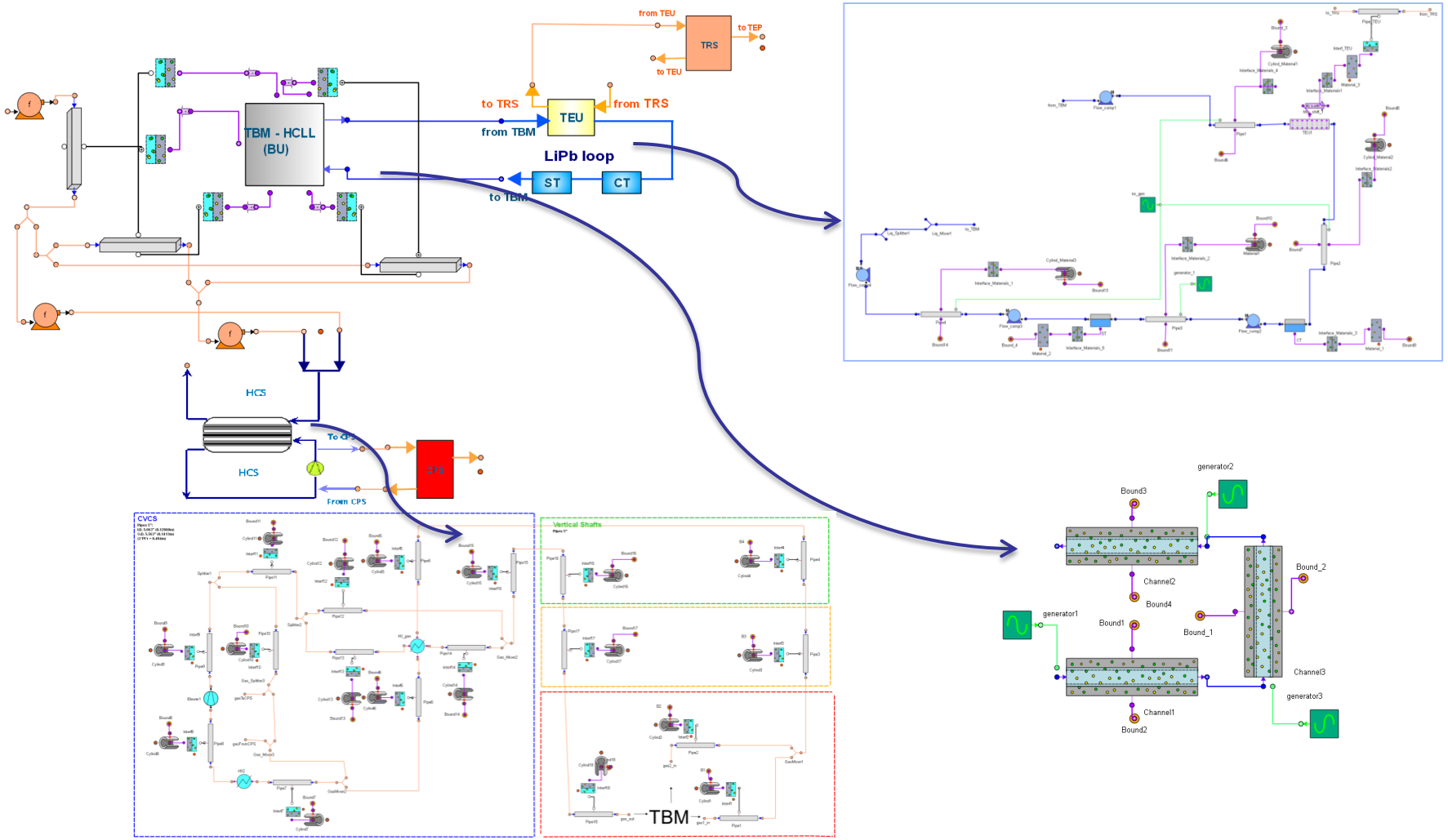
CRYOLIB application: simulation of cryogenic systems at CERN

Model of the coldbox of CMS cryoplant and its control system:



TRITIUM_SIM applications: TBS- HCLL model of ITER

The model of a TBS is made by connecting different subsystems:



Applications in control

Use of EcosimPro in control area

- EcosimPro is a multidisciplinary tool that allows the simulation of interactions between systems of many engineering fields, such as mechanical, electrical, thermodynamic, hydraulic, pneumatic, thermal and control systems. This means that users can build integrated models and have simulation results that better reflect the real system. Main applications in control:
  - Modeling of controllers: It allows checking new control strategies and working procedures in order to optimize the plant operation
  - Advanced control: The library Predictive control allows to modell advance control systems
  - Simulators: To simulate failure scenarios and prevent human reactions in case of failure. It allows:
    - Supporting the plant engineering
    - Projecting the behavior of the plant under unusual situations or during the start-up tests
    - Training operators and engineers in plant operation
  - Virtual commissioning: Verification of control programs before implementation on the real plant
  - Hardware in the Loop (HIL) systems

Use of EcosimPro in control area

Modelling of controllers

It allows control engineers to validate the operation of the process with the control associated, tune the different regulation loops and to develop new control strategies without disturbing the operation of the real plants.

An example of that is the model of the GALP-Porto Cogeneration Plant. The aim of the study was analysing the transients produced by changing between the boilers operating mode (TEG or Fresh Air Mode), the trip of a boiler and the rapid increasing in steam consumption.

The model included the cogeneration plant, steam distribution network and the control associated:

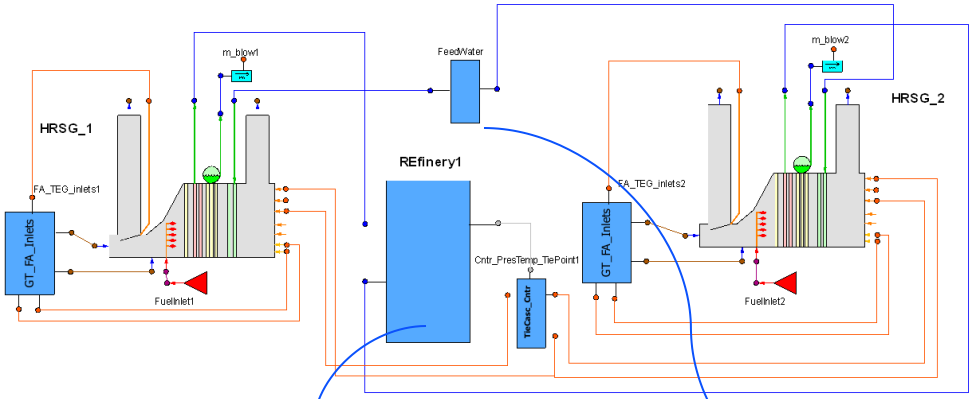
- Two GasTurbines (GT) feeding two Heat Recovery Steam Generators (HRSG)
- Steam consumers and steam turbines tied to the HP collector
- Steam turbines re-inject steam at lower pressure into MP collector
- Steam consumers tied to the Mp collector for providing the needs of the refinery
- In nominal conditions, P = 67 bar a and T = 450°C in HP collector

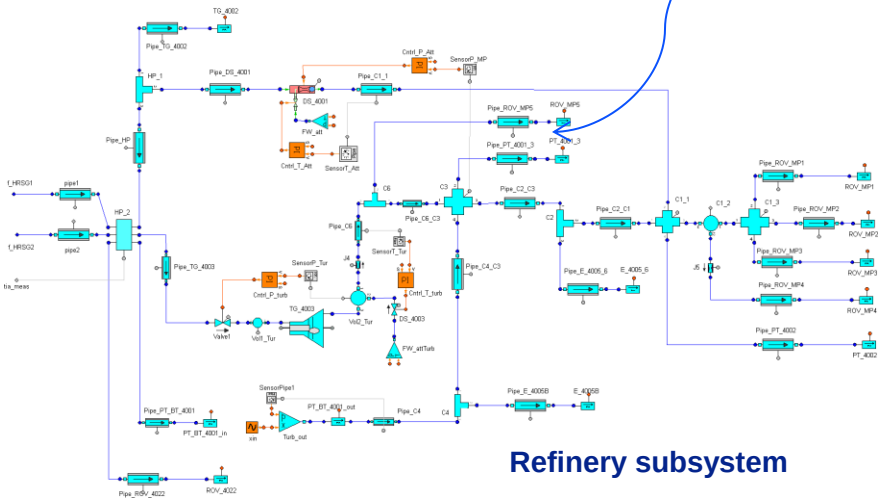
Verify the acceptance criteria on the HP collector under various accidental scenarios

Modelling of controllers

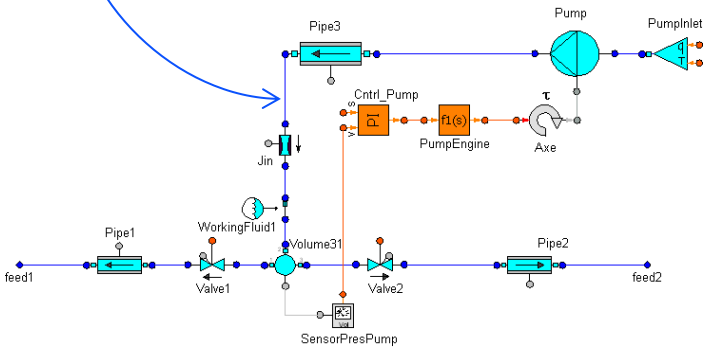
Steam Stability Study (PORTO Refinery)

Complete model in EcosimPro: both NEM boilers, the refinery steam distribution network with the associated control blocks





Refinery subsystem



Feedwater subsystem including pump transient model calculating axial speed and massflow from teh pump characteristic maps

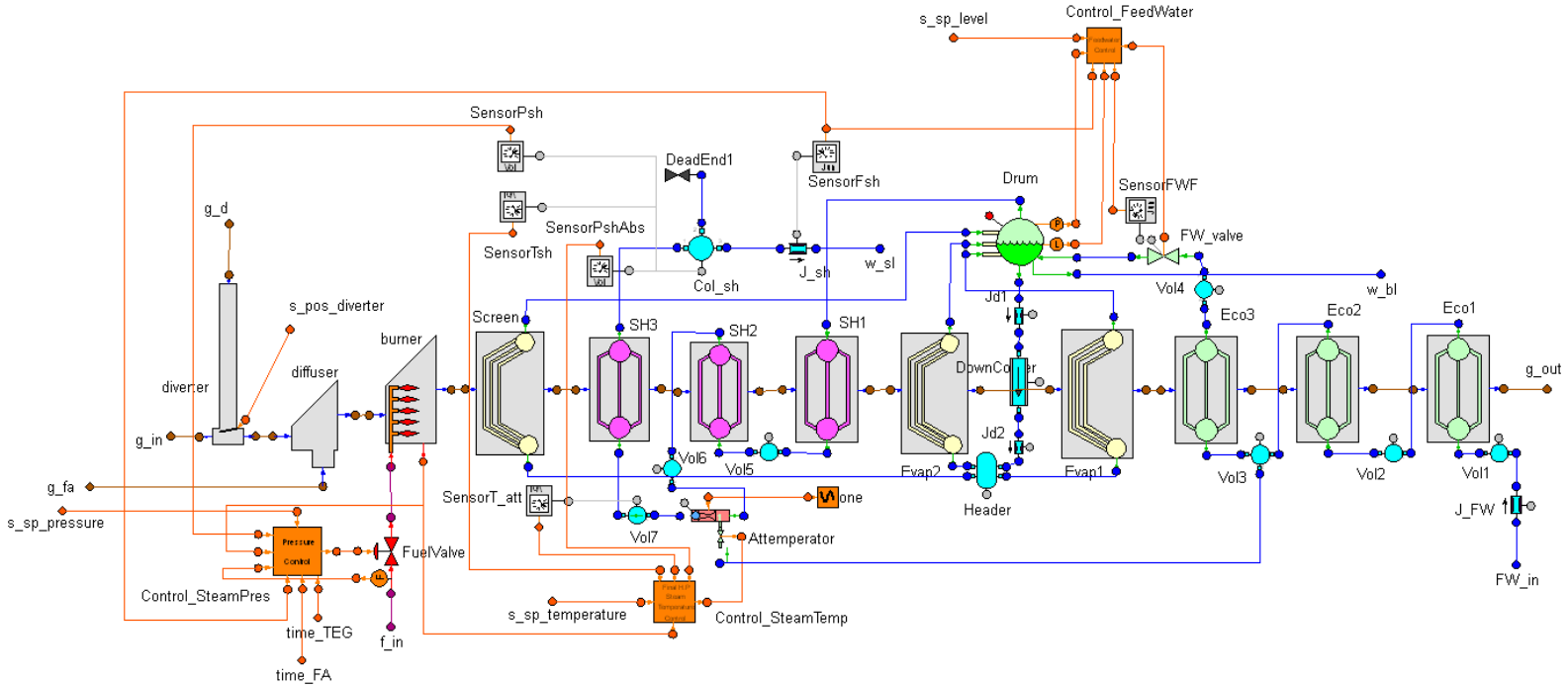
Modelling of controllers

Steam Stability Study (PORTO Refinery)

Model of the boiler (HRSG)

The boiler is a complete 1D thermo fluid dynamic model in which the elements (flue gas tubes, fins, water, controls, valves, etc) interact with each other in a physical way.

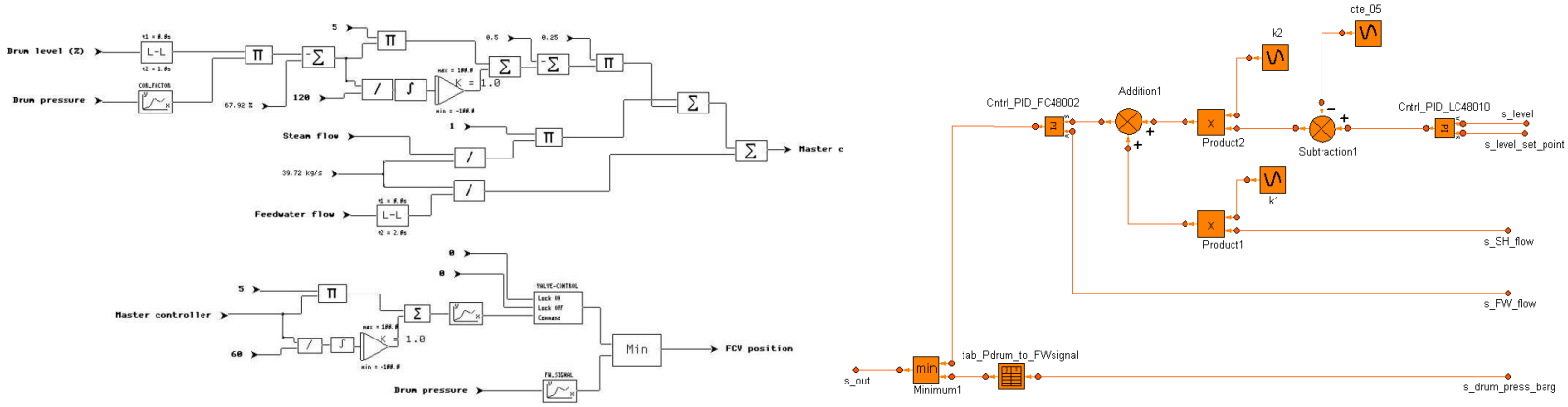
The control loop sub-models (in orange) have been developed using the specific EcosimPro library for modelling control systems (CONTROL)



Modelling of controllers

Steam Stability Study (PORTO Refinery): Control systems

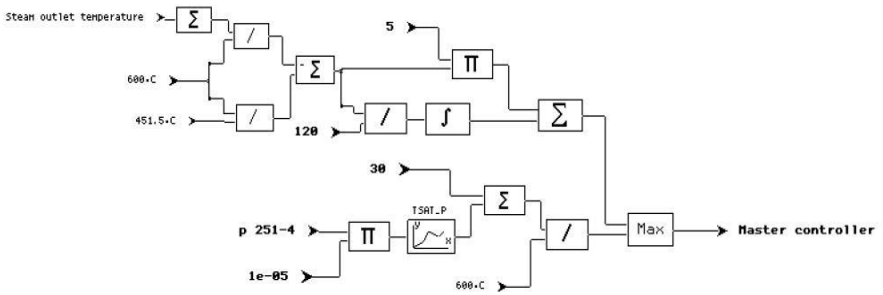
- **Feedwater control system**
  - Function: feed the drum with the appropriate water quantity in order to keep the drum level at a constant setpoint value
  - The drum level measure is used as the process variable of the master controller in a cascade control. The steam flow measure acts as a feed-fordward signal in the primary controller, which includes a correction to this measure. The process variable of the slave controller is the feedwater flow

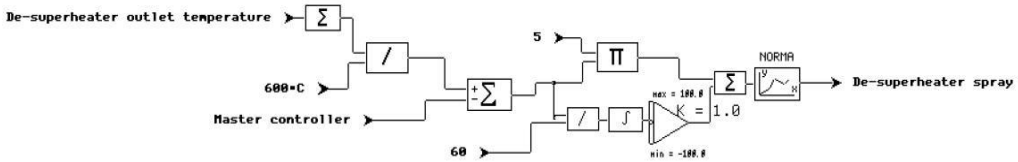


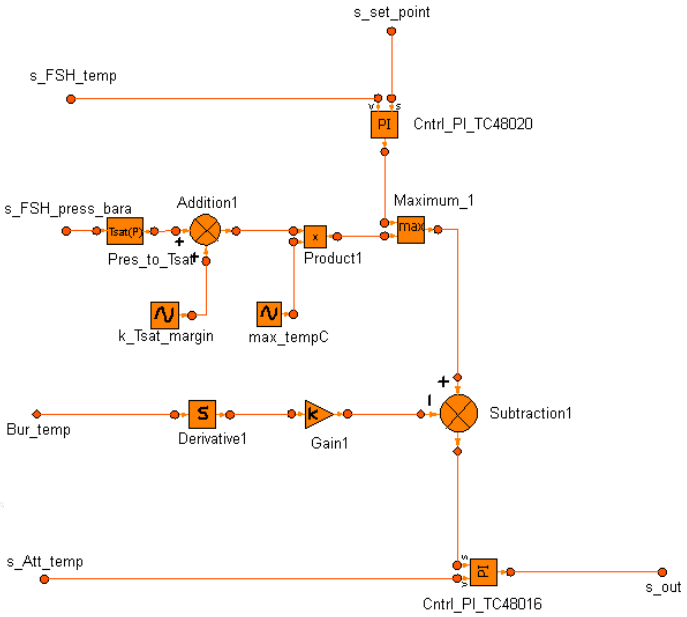
Modelling of controllers

Steam Stability Study (PORTO Refinery): Control systems

- **HP steam temperature system**
  - Function: maintain a desired and constant temperature at the outlet of the HRSG and prevent SH operation out of the temperature limits
  - The steam temperature measure is used as the process variable of the master controller in a cascade control. The set-point of the master controller is the desired HP steam temperature. The output of the master controller is the set-point of the slave controller that controls the attemperator outlet temperature. Also it is ensured that no liquid enters in the final superheater



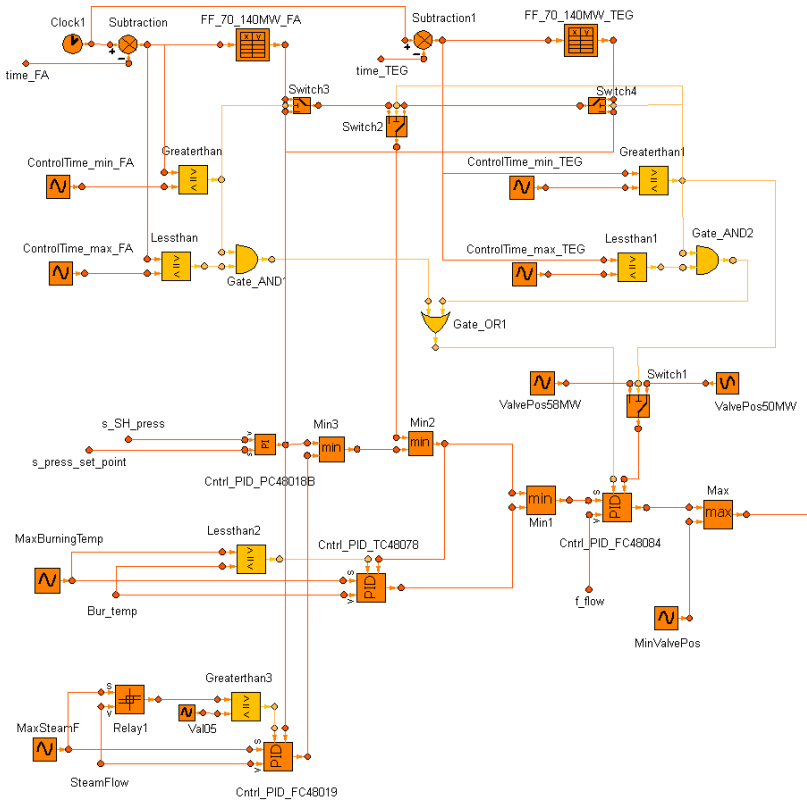




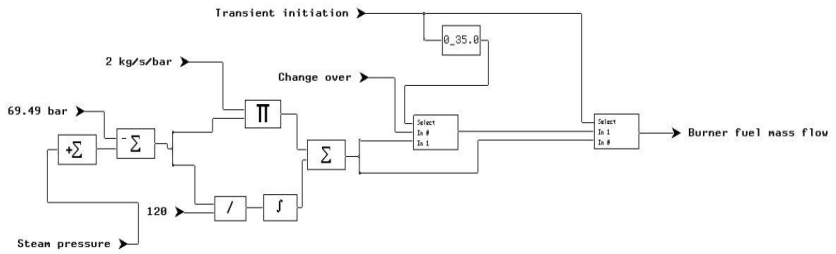
Modelling of controllers

Steam Stability Study (PORTO Refinery): Control systems

- **Burner Load Control System**
  - Function: maintain a desired and constant steam pressure at the HRSG's outlet
  - Function achieved by controlling the fuel mass flow injected by the burner



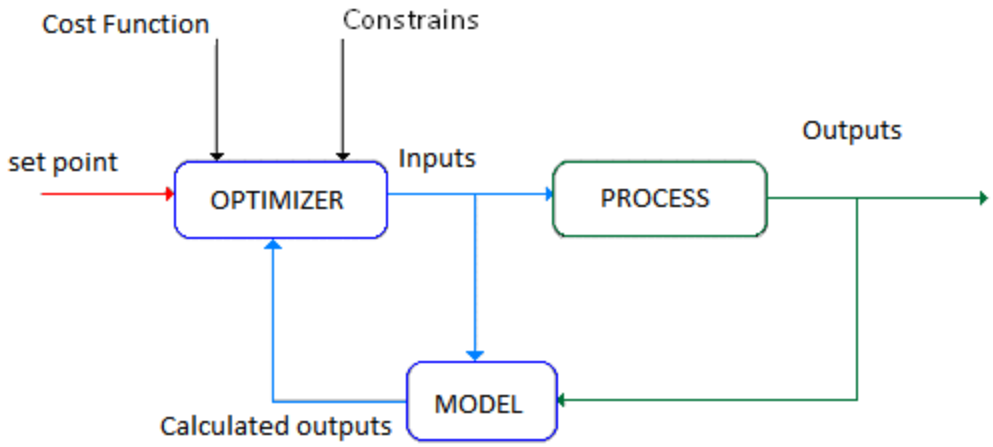
- Three PI master controllers are on charge of the steam pressure control, burner temperature limitation and steam mass flow limitation respectively
- A set of lookup tables interpolating the maximum fuel flow as a function of time under change-over situations
- A set of fuel valve positions imposes directly the fuel valve position with a predefined time window
- The set-point of the slave PI controller is the minimum of the master control and the output of the lookup tables



Use of EcosimPro in control area

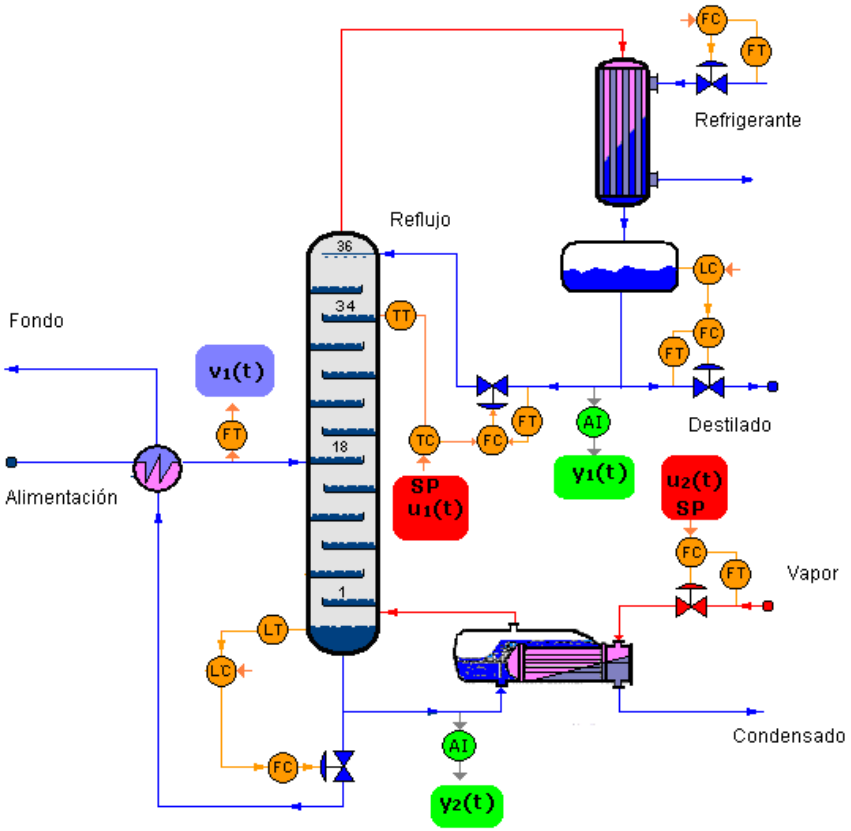
Advanced Control

- EcosimPro's library Predictive_control is a professional library for modelling advanced control systems. The main idea was to develop robust control algorithms based on simple, measurable process models, providing acceptable results along with constraints, noises and parameter uncertainties.
- These algorithms, using predicted future information, provide better control performance compared to the usual PID control especially in the case of known reference signals and with a great amount of plant dead time



Use of EcosimPro in control area

Advanced Control (DMC) applied to a Despropanizer Distillation Column

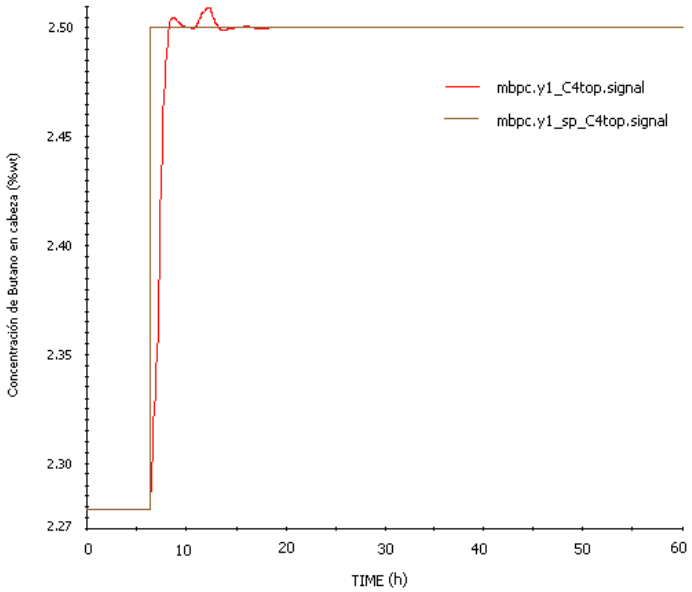


- ***Controlled variables:***
  - Impurity concentration in reflux flow, butane ($y_1(t)$)
  - Impurity concentration in residue flow, propane ($y_2(t)$)
- ***Measurable perturbations:***
  - Feed mass flow ($v_1(t)$)
- ***Manipulated variables:***
  - Vapor mass flow ($u_2(t)$)
  - Reference of the temperature control loop ($u_1(t)$)

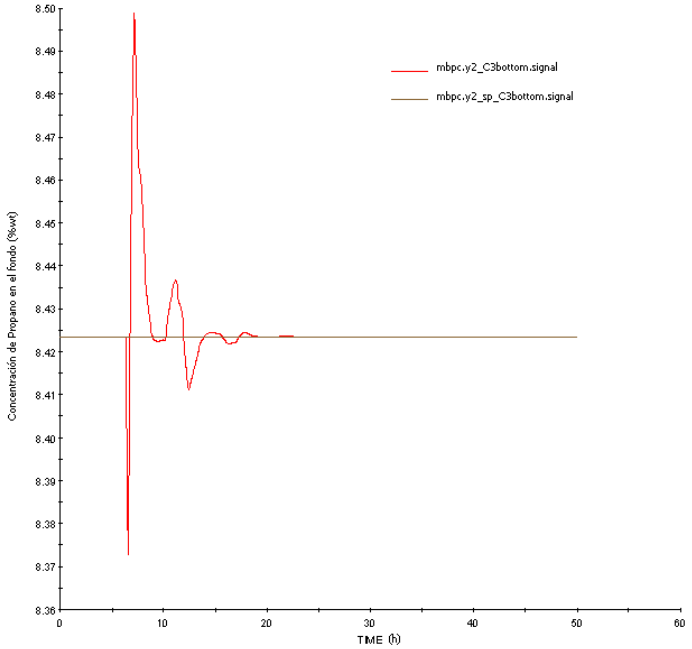
Use of EcosimPro in control area

Advanced Control (DMC) applied to a Despropanizer Distillation Column

Controlled variables



Reference change in the impurity concentration in reflux flow, butane

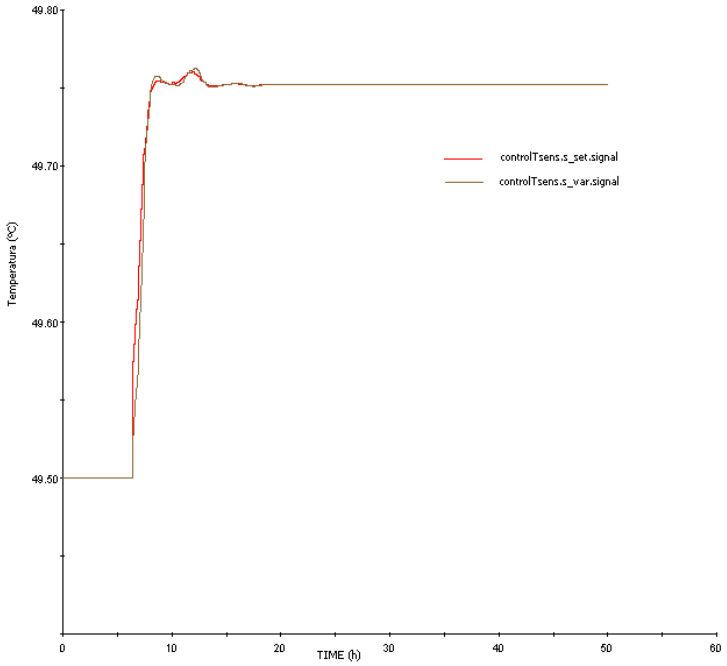


Evolution of the impurity concentration in residue flow, propane

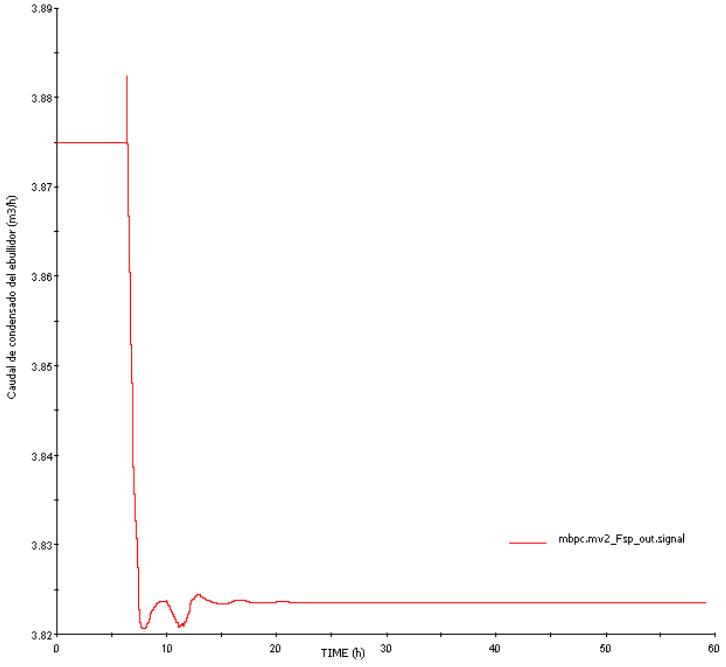
Use of EcosimPro in control area

Advanced Control (DMC) applied to a Despropanizer Distillation Column

Manipulated variables



Temperature control loop

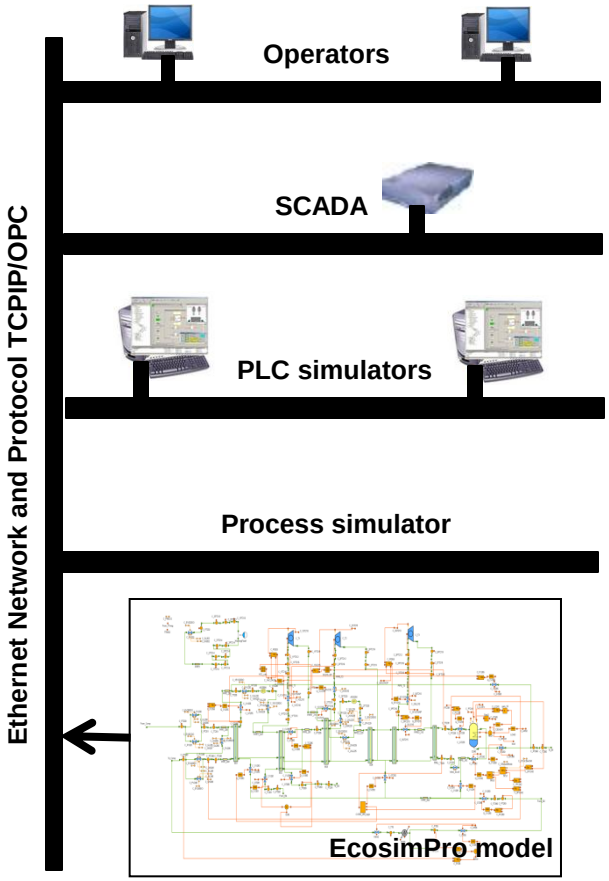


Vapor mass flow

Use of EcosimPro in control area

Simulators

- Models can also be used to help operation teams by providing operator training platforms.
- The C++ automatically generated by EcosimPro in a transparent way can be connected to a SCADA in order to obtain a simulator with training purposes.
- The simulators can be connected to a copy of the control systems and be used to train operators in the regular operation of the plant and to test their reactions in the case of simulated failures which are infrequent occurrences on a real plant.
- PROCOS, a real time simulator developed at CERN, is based on an EcosimPro model of the real plant and train operators on the operation of the cryogenic systems at CERN.



Structure of PROCOS simulator (CERN)

Simulators: Parabolic Through Power Plant

- An example of EcosimPro model used in industry as simulation engine in operator training is the simulator of a parabolic through solar power plant based on the thermosolar plant at Orellana (Badajoz, Spain)

- The developed simulation model represents the transient behaviour of the following parts of the parabolic trough solar power plant:
  - HTF Circuit
  - Steam generator trains
  - Steam cycle and circulating water system
  - Control loops and control sequences

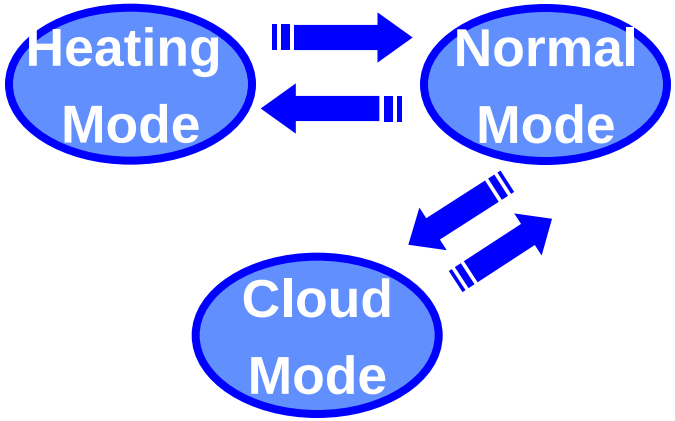
- The model includes the representation of weather conditions: direct normal insolation (DNI), wind speed, etc

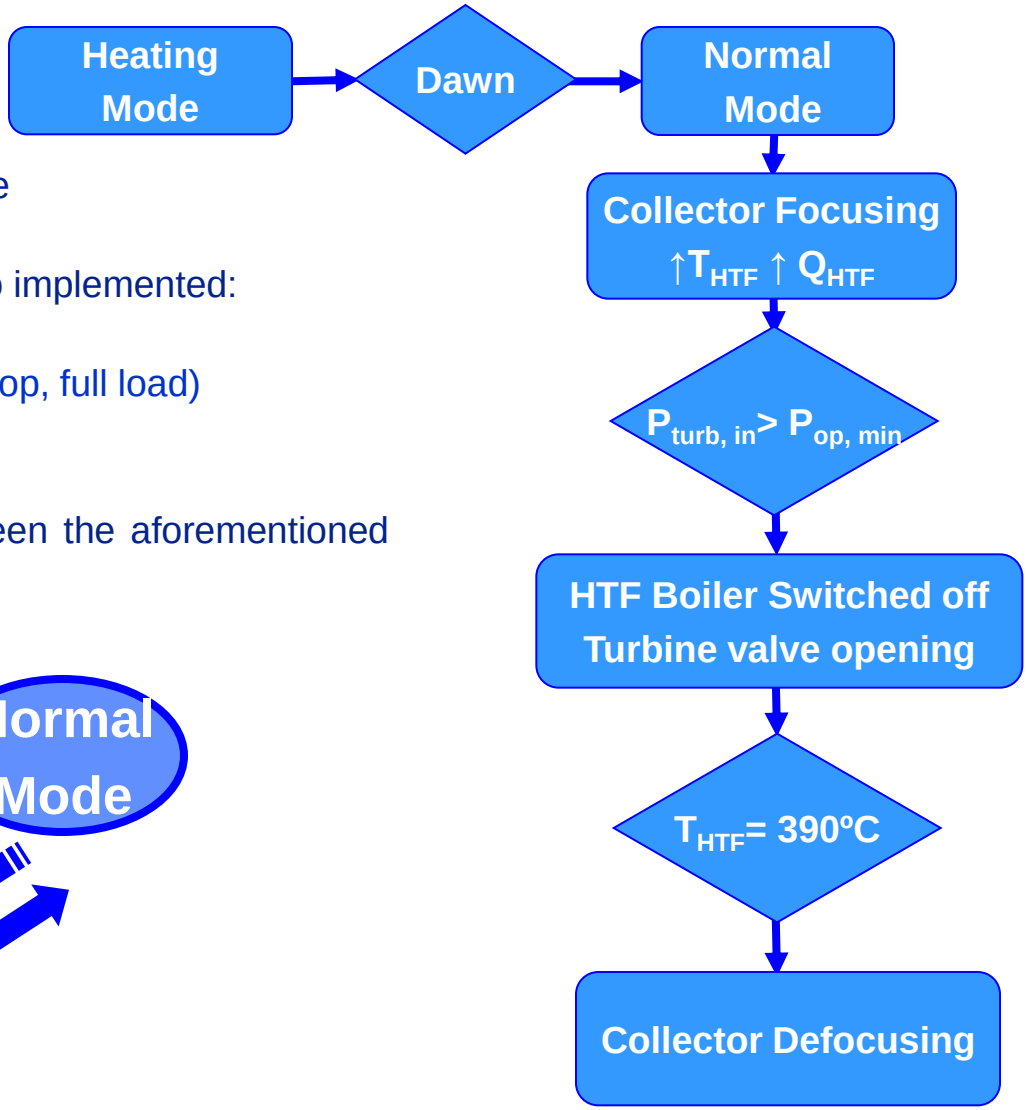
- The main control loops of the HTF system are also included:
  - HTF flow control to the solar fields
  - HTF flow control to the heating boilers
  - HTF flow control to the reheaters
  - Control of the solar collector focus
  - Temperature control of the heating boilers

Simulators: Parabolic Through Power Plant

OPERATION

- The model includes an start-up sequence
- The following operating modes were also implemented:
  - Heating/Anti-freezing mode
  - Normal operating mode (start-up, stop, full load)
  - Cloud cover mode
- The model includes the transition between the aforementioned modes

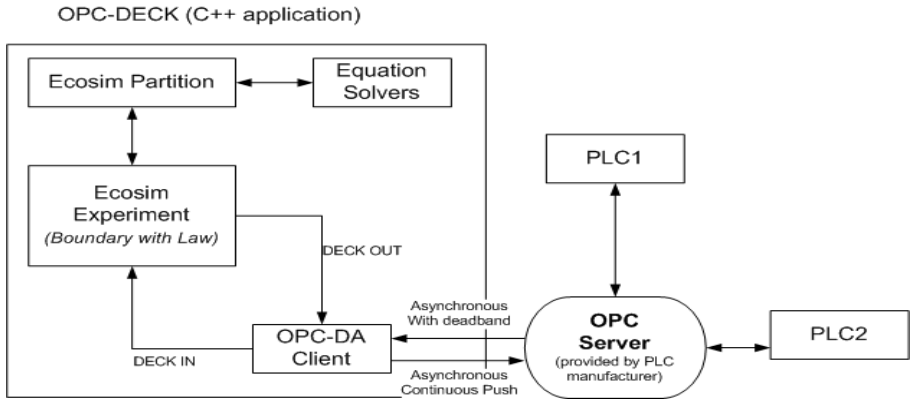




Simulators: Parabolic Through Power Plant

- It is possible to generate an OPC server from the C++ class of the model generated by EcosimPro and this provides different working possibilities:
  - To connect several simulation models using OPC servers
  - To connect an OPC server to SCADA to develop a human-machine interface (HMI)
  - It would also be possible to connect the simulation model to the actual control system of the plant when the OPC interface is available

- The configuration of the plant **SCADA** has been developed and the OPC server of the model has been linked to this SCADA to run the model from a SCADA environment

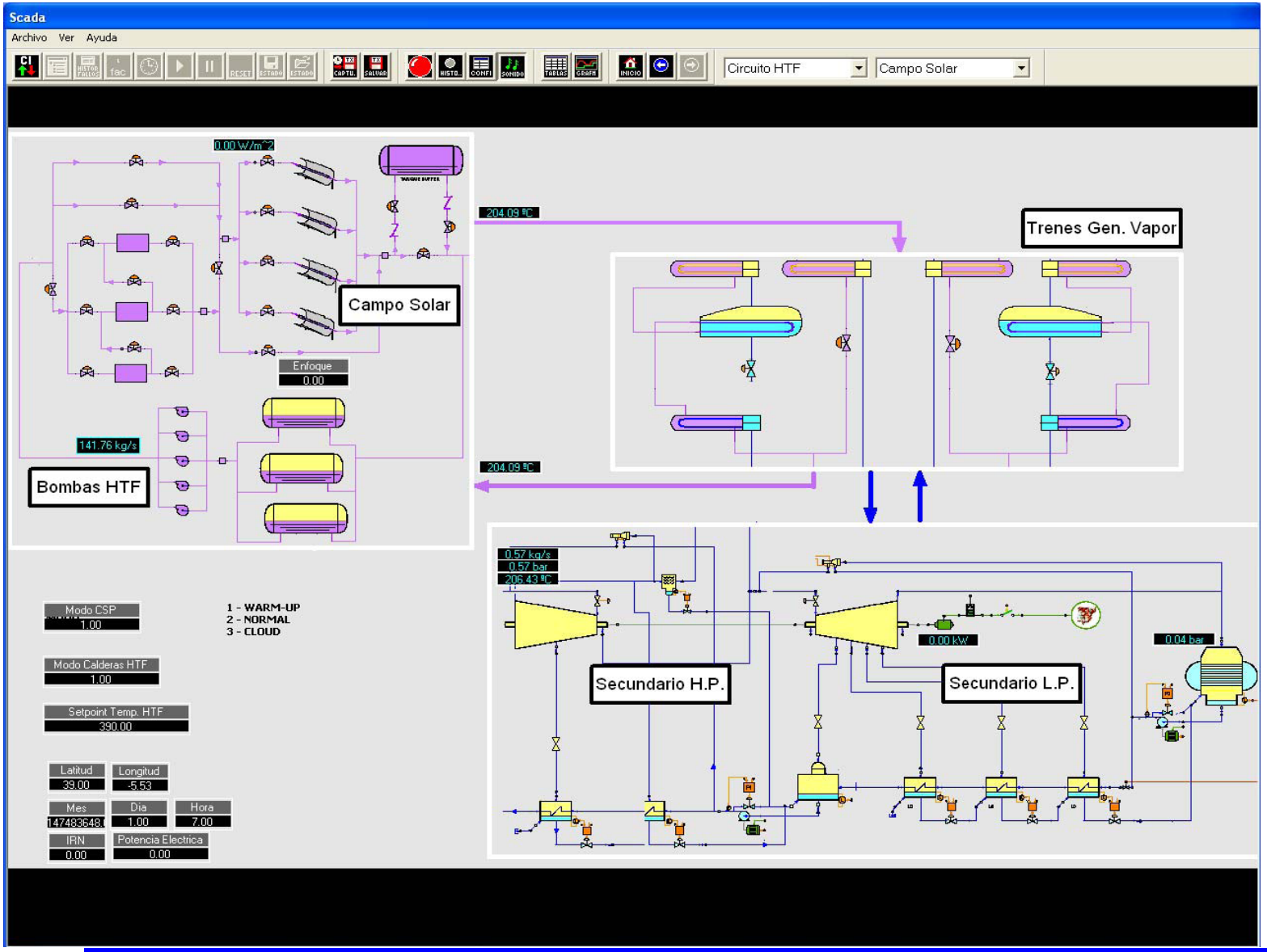


Simulators: Parabolic Through Power Plant

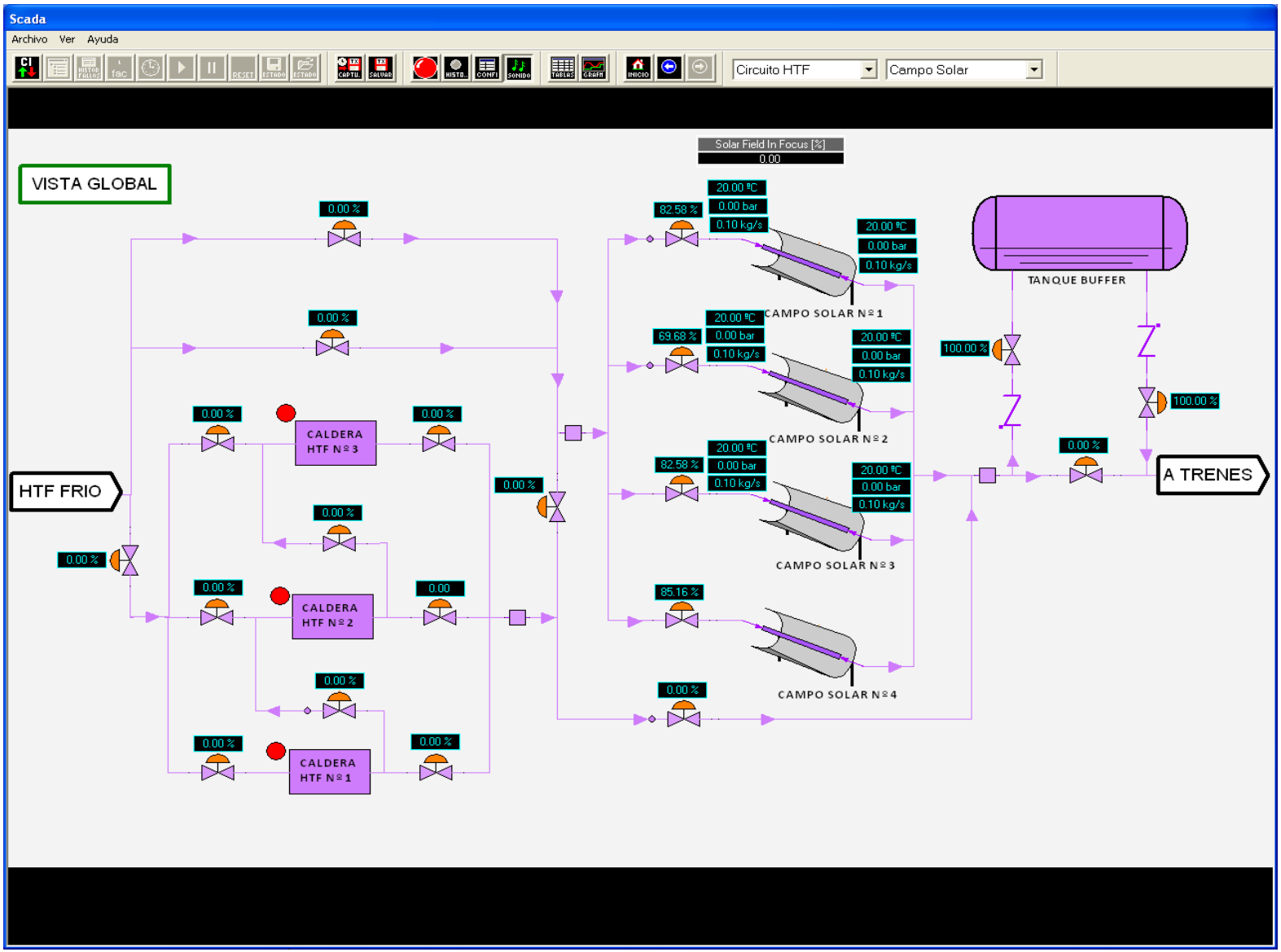
SCADA DESCRIPTION

- The simulator SCADA consists of six synoptic panels that represent the main systems of the solar power plant:
  - Solar Field
  - Steam generator trains
  - Expansion tanks and HTF (Heat Transfer Fluid) pumps
  - High pressure steam cycle
  - Low pressure steam cycle
  - General overview of the plant
- The SCADA allows:
  - Navigation between the different synoptic screens
  - Visualisaton of the value of the most meaningful variables of the system
  - Modification of control variables and operating modes
  - Triggering of alarms

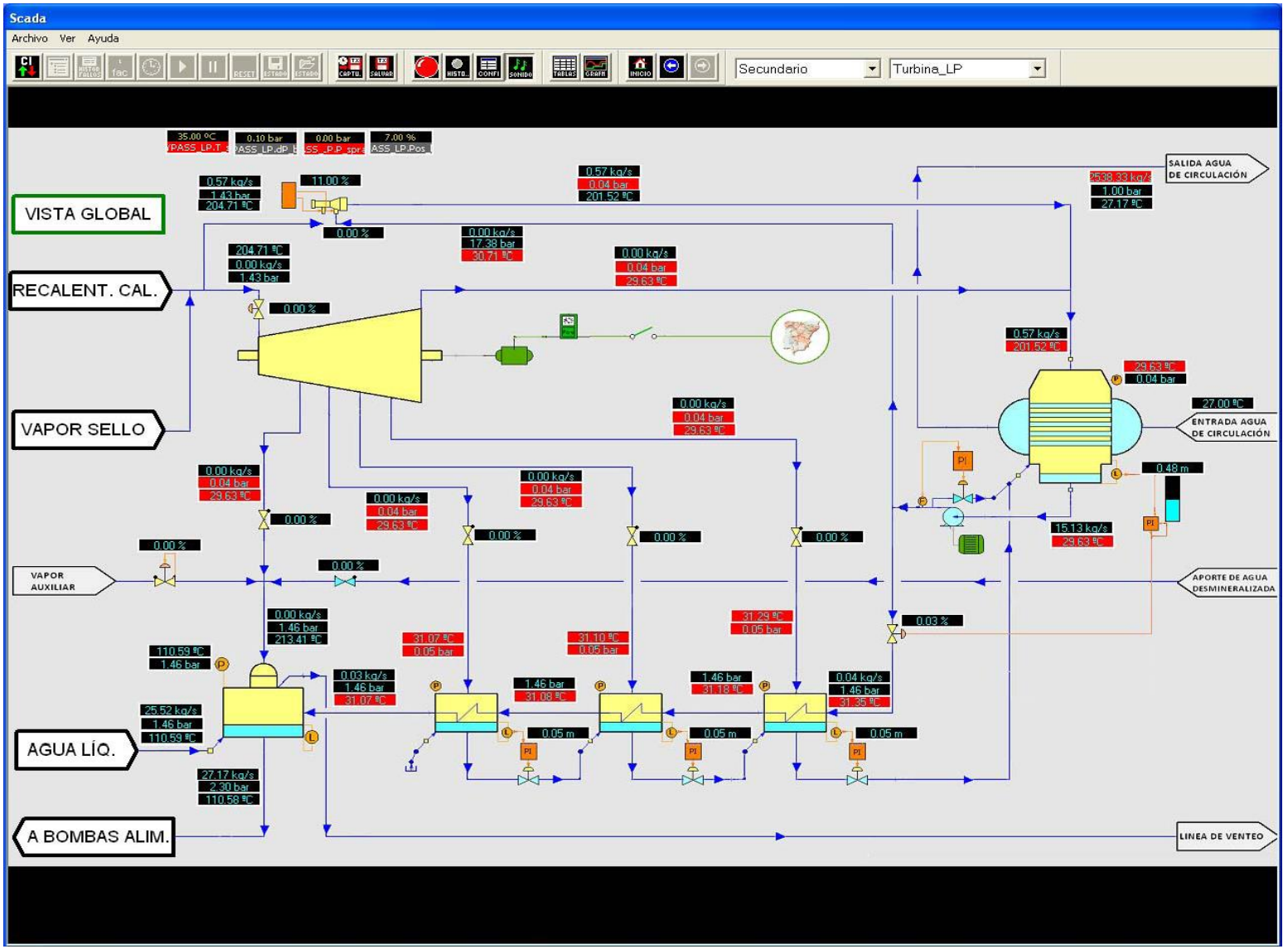
Main Synoptic Panel



Synoptic Panel of Solar Field



Synoptic Diagram of LP Steam System



Simulators: Parabolic Through Power Plant

MAIN ADVANTAGES

- Easy comunication with other types of software:
  - OPC Servers
  - SCADA
  - PLC Emulators
- The models and the SCADA can be run in a PC, i.e. no special hardware requirements are needed
- Easy maintenance and improvement of the simulator (modular and object-oriented structure)

Use of EcosimPro in control area

Virtual Commisioning

- The virtual commissioning of control systems linked to a model minimizes the real commissioning time and reduces the subsequent risk

- One of advantages of EcosimPro is the flexibility to modify the simulation model and adapt it to other configurations of the plant or implementing new control strategies
  - The simulation model is based on knowledge models of the equipment (mass, energy and momentum conservation equations) and not on identification models (experimental input and output data fitting to transfer functions)
  - The knowledge models are more generic and flexible to adapt to other plant configurations or operating points

- Several operating cases can be generated from the same model with different initial conditions or operating sequences

EcosimPro: Dynamic Simulation Tool and its application to control

EcosimPro

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