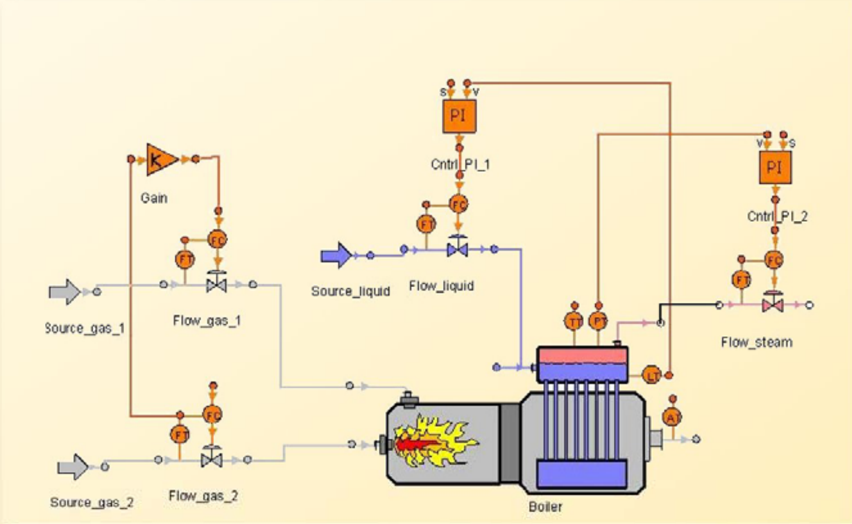
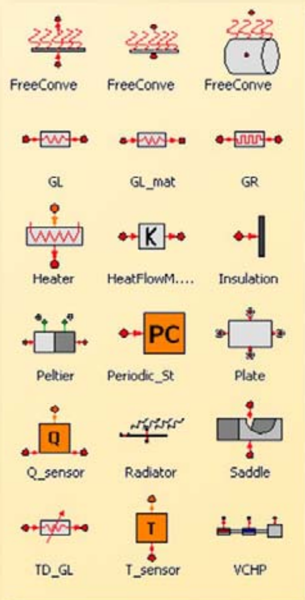
EcosimPro

Modelling and Simulation Software

1st Conference on Power Plant Simulation





EMPRESARIOS AGRUPADOS

PRESENTATIONS IN THIS DOCUMENT

EcosimPro Simulation Environment
Pedro Cobas, Empresarios Agrupados AIE
THERMAL_BALANCE library
Eusebio Huélamo, Empresarios Agrupados AIE
PIPELIQTRAN library
Eusebio Huélamo, Empresarios Agrupados AIE
Heat Balance of a Thermoelectric Solar Power Plant
Alfonso Junquera, Empresarios Agrupados AIE
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Almaraz Nuclear Power Plant Steam Generator Level Control Study
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Laura Arenas, Empresarios Agrupados AIE
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Alfonso Junquera, Empresarios Agrupados AIE
Designing ITER Tritium Plants with EcosimPro
Carlos Moreno, CIEMAT - ITER

1st Conference on Power Plant Simulation using EcosimPro

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SIMULATION ENVIRONMENT EcosimPro

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What is EcosimPro?

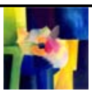
EcosimPro is a state of the art modelling and simulation tool developed at EA over the last 19 years.

EcosimPro uses cutting-edge technology for acausal modelling of systems that can be depicted by differential algebraic equations and discreet events.

EcosimPro has a human-machine interface that makes it easy to create models intuitively.

It was originally developed for the European Space Agency to simulate environmental control and life support systems (ECLSS) in the International Space Station.

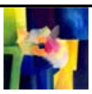
Today, it is ESA's standard modelling tool for ECLSS, Propulsion (satellites and rockets) and biological systems for long-term missions.



What is EcosimPro?

EcosimPro can be used to simulate any 1D phenomenon that can be portrayed by differential algebraic equations, such as:

- •Fluids in piping networks
- •Heat transfer
- •Chemical reactions
- •Control systems
- •Electric circuits
- •Aeronautical or space propulsion systems
- •Biological systems
- •Economic models
- •Process plants
- •Mass and energy balances
- •Mechanical systems
- •etc.



EcosimPro Users

International businesses and organizations:

ESA, NASA, Canadian Space Agency, EADS Astrium, Thales Alenia, Snecma, Swedish Space Agency, ITP, Teuchos, NTE, ASML, VOLVO, STORK, ALENIA, AVIO, CASA, etc.

Universities:

Valladolid, Córdoba, Esc. Ingenieros Sevilla, Autónoma de Barcelona, Girona, Leon, Cantabria, Las Palmas, UNED, Cadiz, Complutense, Politécnica de Madrid, Almeria, Lovaina, Stuttgart, Eindhoven, Liege, Beijing, Athens, Cranfield, etc.

Technological centres:

INTA, NLR, CERN, CTA(Tecnología Azucarera), Von Karman Institute, CENER, CIEMAT, CSIC, etc.

Overview

Modelling

- •Applicable to 0D and 1D modelling problems
- •Differential-algebraic equations
- •Easy-to-learn acausal-object-oriented modelling language
- •Graphics-based tool for creating components "by drawing"
- •Math wizards for generating robust final models

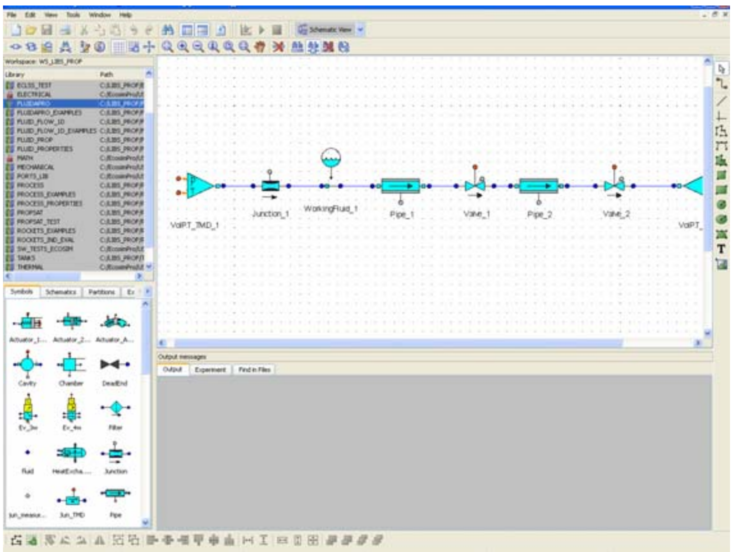
Core

- •Equation solvers thoroughly tested on complex problems
- •Symbolic and numerical handling of equations
- •Calculation of steady states and transients
- •Complete debugging information in HTML

Interface

- •Calls to external functions C, C++ and Fortran
- •Automatic generation of DLLs and C++ to re-use models
- •Add-in to execute the models from Excel
- •Module to execute the models from Matlab

Graphic Modelling Environment



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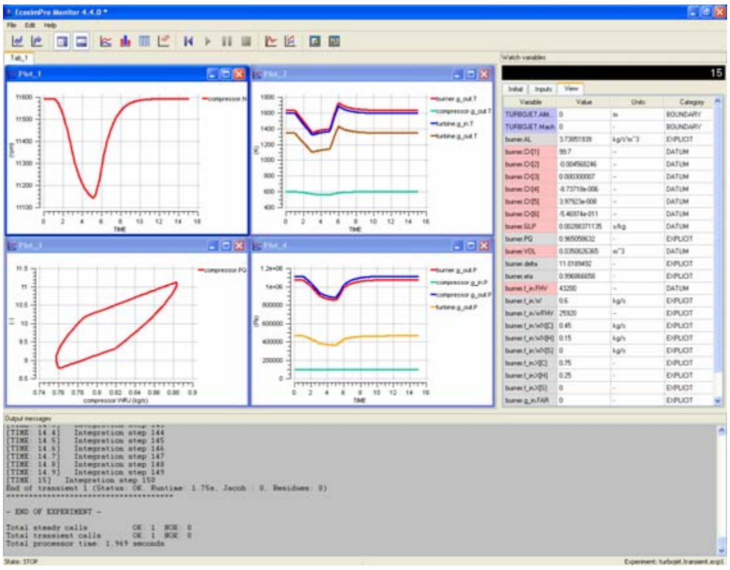
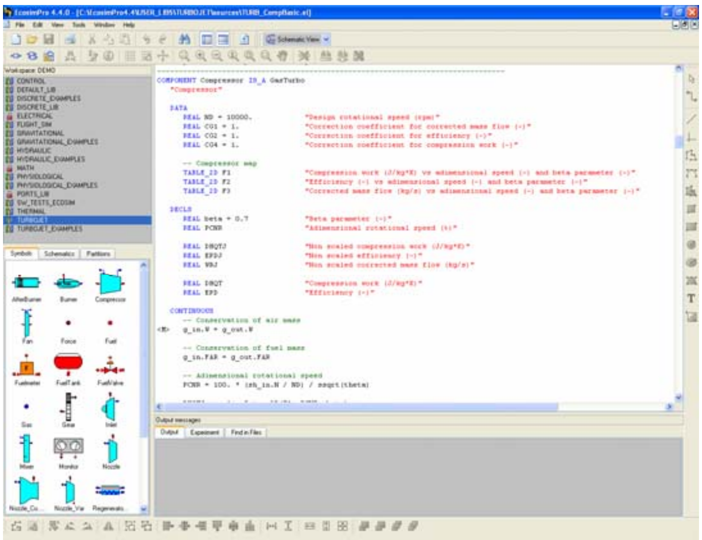
Interactive Simulation Environment



Basic Library Development Environment



Modelling of Components

EcosimPro lets you model components in two different ways:

- By re-using already made components by aggregation and inheritance
- Create new components from their modelling equations or experimental data.

With acausal modelling, equations can be entered not as assignations but as physical equivalencies.

For example, you can write:

F = m * a

o

F – m * a = 0

o

a= F/m

This is key to reusing the same components for different studies, because:

the equations are changed automatically!

Mathematical algorithms

EcosimPro has powerful differential algebraic equation (DAE) solvers.

DAEs

$$\vec{f}\left(\vec{x}, \frac{d\,\vec{x}}{dt}, t\right) = \vec{0}$$

Individual cases:

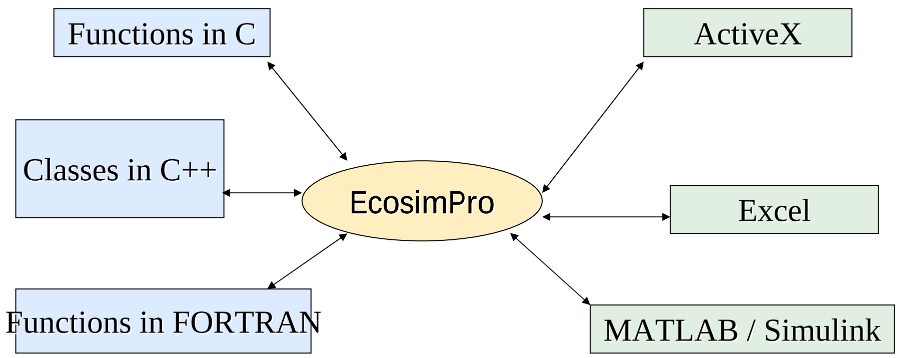
ODEs

$$\frac{d\,\vec{x}}{dt} = \vec{f}(\vec{x}, t) \longrightarrow \vec{f}(\vec{x}, t) - \frac{d\,\vec{x}}{dt} = \vec{0}$$

Algebraic Equations

$$\vec{f}(\vec{x}, t) = \vec{0} \rightarrow \vec{f}(\vec{x}, \vec{0}, t) = \vec{0}$$

Interfaces with external programs



Four types of users

LEVEL 1 : Library modellers; they need thorough knowledge of the math of the components and the modelling language

LEVEL 2 : Users of finished libraries. They graphically design systems.

LEVEL 3: They create multiple experiments on a closed mathematical model. Transient, steady-state studies, optimizations, etc.

LEVEL 4 : They use EcosimPro models in Excel, Matlab, C++, Visual Basic, etc. They do not need to have EcosimPro installed on their PC.

Components and Ports

•What is a component?

•The component is the most elementary building block in EcosimPro.

•It is the equivalent concept to class in programming.

•The difference is that instead of encapsulating methods or functions, it encapsulates a mathematical model.

•What is a port?

•A port encapsulates a set of variables that are interchanged together

•The components are connected by means of ports (electric, control fluid, heat, etc.).

•This greatly facilitates the modelling of complex systems, since it does not require working at the level of variables.

Components and Ports

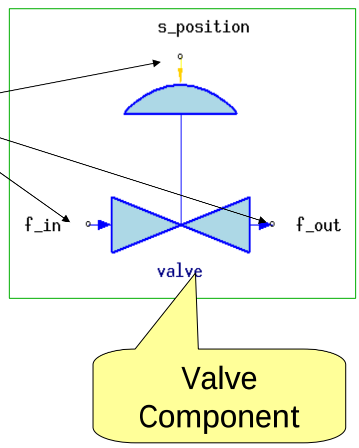
•Components are defined by:

•Input/Output ports

•The declaration of data and variables (valve area, pressure difference,....)

•The equations that portray behaviour

$$Q = Cv\sqrt{\frac{\Delta P}{\rho}}$$



Components and Ports

```
PORT Fluid
    SUM REAL w "mass flow (kg/s)"
    EQUAL REAL p "pressure (Pa)"
END PORT
```

Fluid Port interchanges:
-mass flow
- pressure

```
PORT Signal SINGLE IN "Analog signals 1D port"
    EQUAL OUT REAL signal       "Analog signal values (-)"
END PORT
```

Signal Port interchanges:
-Analog signal

Components and Ports

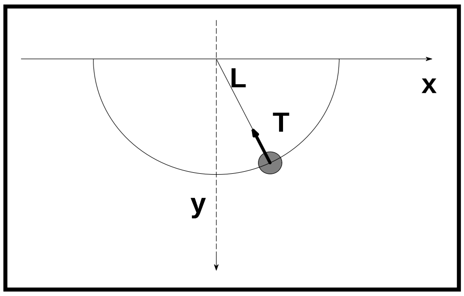
```
COMPONENT Valve
    PORTS
        IN   Fluid  f_in        -- Fluid port input
        OUT Fluid  f_out        -- Fluid port output
        IN   Signal position   --  Control port input
   DATA
        REAL Cv                 -- Maximum flow area
   DECLS
        REAL dP                 -- Difference in pressure
        REAL m                  -- Mass flow
   CONTINUOUS
        f_in.P - f_out.P = dP  -- differential pressure calculation
        m / sqrt(dP * f_in.rho) = Cv * position.signal
        f_in.m = m
        f_in.m = f_out.m
END COMPONENT
```

Mathematical model of the valve

The equations can be written in any order and format. EcosimPro then converts them into symbols

Components and Ports

•**Dynamic model of a pendulum**



$$m\,x'' = -T\,\frac{x}{L}$$

$$m\,y'' = m\,g - T\,\frac{y}{L}$$

$$x^2 + y^2 = L^2$$

•EcosimPro lets you intuitively model the equations in derivatives

Components and Ports

- **Dynamic model of a pendulum**

```
COMPONENT pendulum "Pendulum example"
  DATA
    REAL g = 9.806      UNITS "m/s**2" "Gravity"
    REAL L = 1.         UNITS "m" "Pendulum length"
    REAL m = 1.         UNITS "kg" "Pendulum mass"
DECLS
    REAL x           UNITS "m" "Pendulum X position"
    REAL y           UNITS "m" "Pendulum Y position"
    REAL T           UNITS "m" "Pendulum wire tension force"
  CONTINUOUS
    m * x'' = - T * (x / L)
    m * y'' = M * g - T * (y / L)
    x**2 + y**2 = L**2
END COMPONENT
```

→

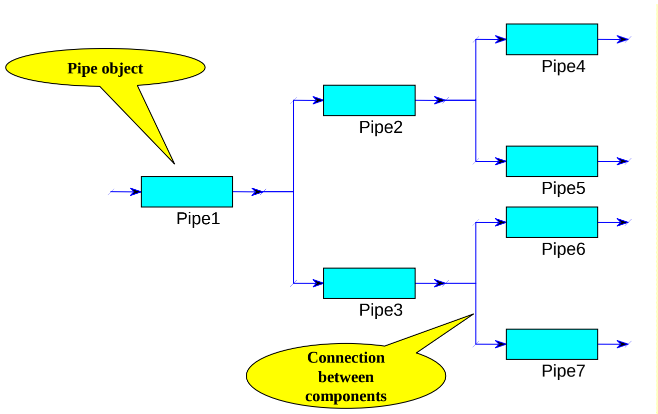
$$m\,x'' = -T\,\frac{x}{L}$$

$$m\,y'' = m\,g - T\,\frac{y}{L}$$

$$x^2 + y^2 = L^2$$

Modelling the Hydraulic System

- **Example of complete modelling and simulation of the hydraulic system based on a single Pipe component.**



Modelling the Hydraulic System

- **Step 1: Define a fluid port that exchanges mass flow and pressure**

```
PORT Fluid

      SUM    REAL w        "mass flow (kg/s)"
      EQUAL  REAL p        "pressure (Pa)"

END PORT
```

Variables that are exchanged in each connection

Modelling the Hydraulic System

- **Step 2: An abstract basic parent component is modelled (one that can not be instantiated)**

```
ABSTRACT COMPONENT Channel

        PORTS
                IN Fluid hp_in           "hydraulic port inlet"
                OUT Fluid hp_out         "hydraulic port outlet"

        DATA
                REAL z_in = 0.           "geometric elevation of inlet (m)"
                REAL z_out = 0.          "geometric elevation of outlet (m)"

        TOPOLOGY
                PATH hp_in TO hp_out

END COMPONENT
```

Define two connection ports

Declare any common data

Modelling the Hydraulic System

- **Step 3: The Pipe component is modelled**

```
COMPONENT Pipe IS_A Channel
        DATA
                REAL f = 0.020          "friction factor ()"
                REAL l = 1.             "pipe length (m)"
                REAL d = 0.1            "pipe diameter (m)"
                REAL dp_lam = 1000.     "pressure drop for laminar flow (Pa)"
        DECLS
                REAL A                  "area (m**2)"
                REAL w_lam              "mass flow corresponding to dp_lam (kg/s)“
        CONTINUOUS
                 -- Geometry
                A = 0.25 * PI * d**2

                 -- Laminar flow condition
                w_lam / A =  sqrt(2 * d * dp_lam * rho / f / l)

                 -- Conservation of mass
                hp_out.w = hp_in.w

                 -- Conservation of momentum
                hp_in.p - hp_out.p + rho * g * ( z_in - z_out ) = \
                         0.5 * f * l * fpow2(hp_in.w, w_lam) / d / rho / A**2
END COMPONENT
```

Inheriting from the Channel

Declare the data

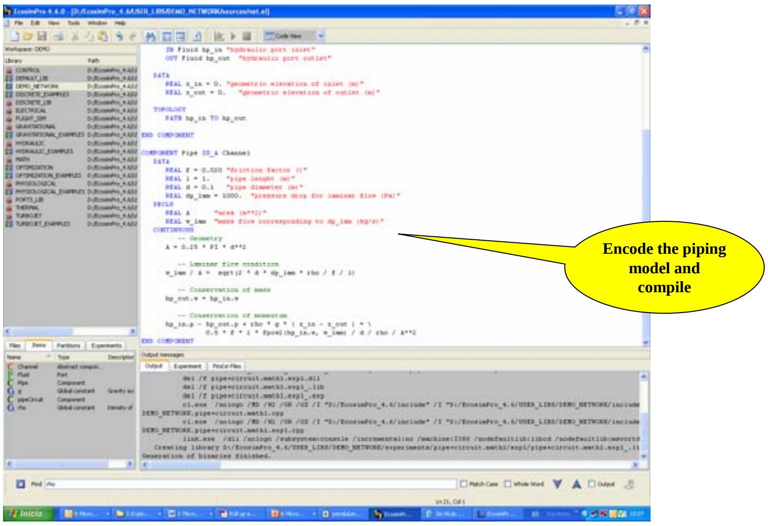
Declare the variables

Write the equations

CAREFUL! These are equations, NOT ASSIGNATIONS

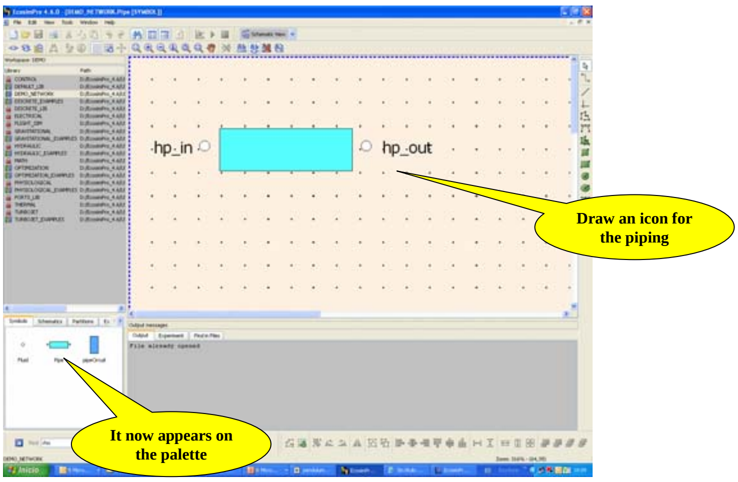
Modelling the Hydraulic System

- **Step 4: Write the code in EcosimPro and compile**



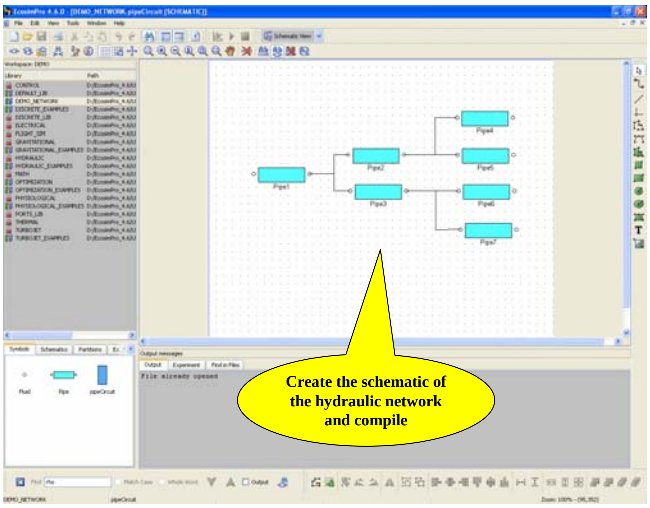
Modelling the Hydraulic System

- **Step 5: Create an icon for the component**



Modelling the Hydraulic System

- **Step 6: Design the piping network (which will be another component).**

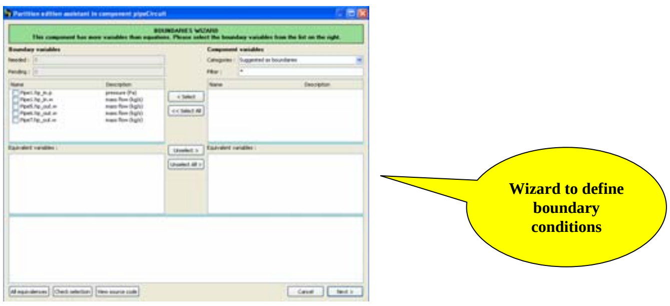


Modelling the Hydraulic System

■ Step 7: Create a valid mathematical partition

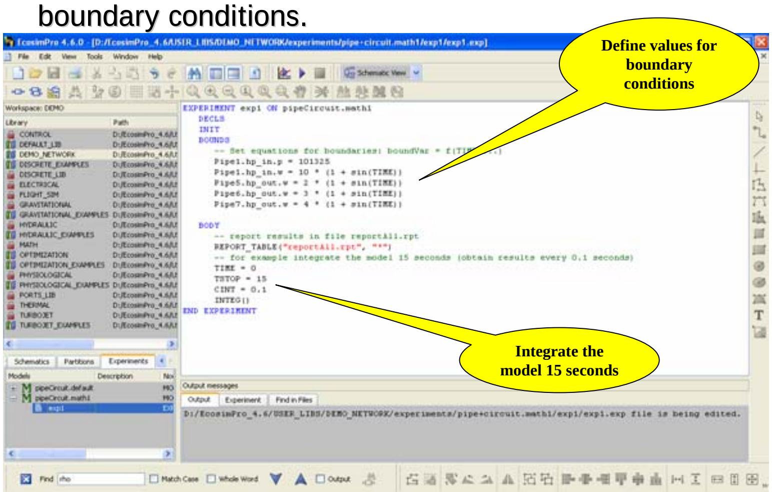
• EcosimPro has wizards to help the user define robust final mathematical models. They are in charge of making a dialog with the user to define:

- Variables boundaries
- Break algebraic links
- Reduce high index mathematical problems



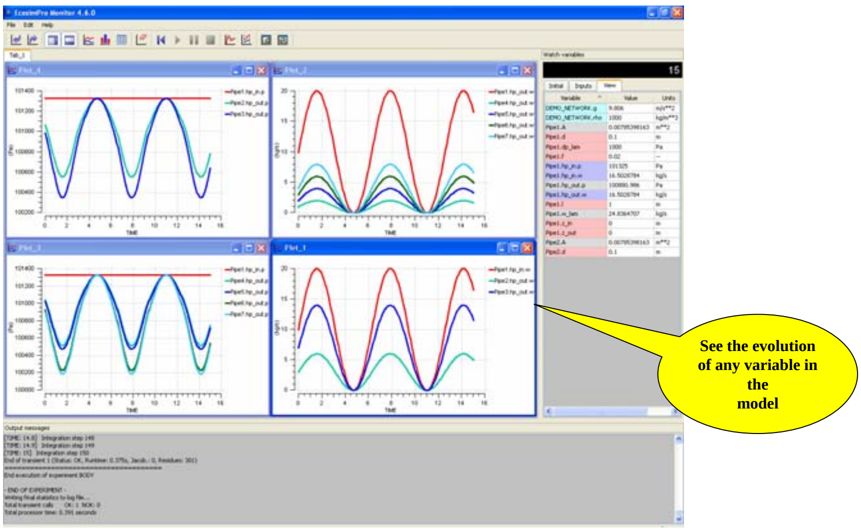
Modelling the Hydraulic System

- Step 8: Create an experiment that integrates 15 seconds of the model imposing a set of laws on boundary conditions.



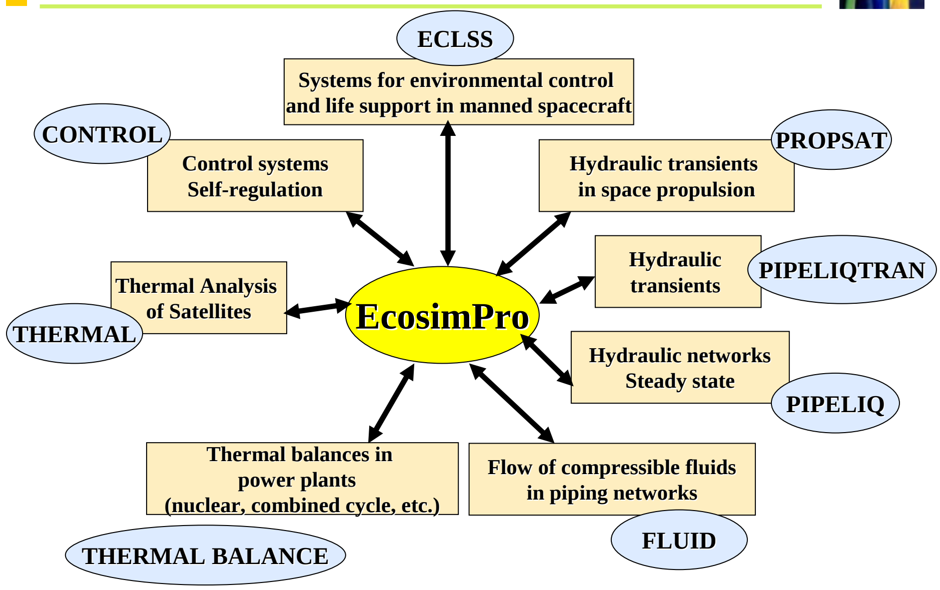
Modelling the Hydraulic System

- **Step 9: Run the simulation**

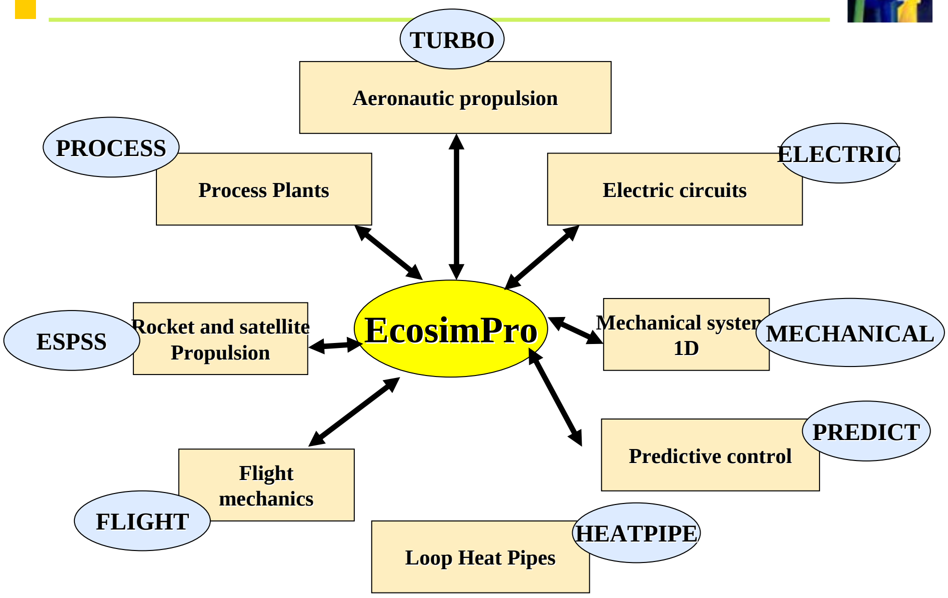


CURRENT AREAS OF SIMULATION

Current Libraries (I)

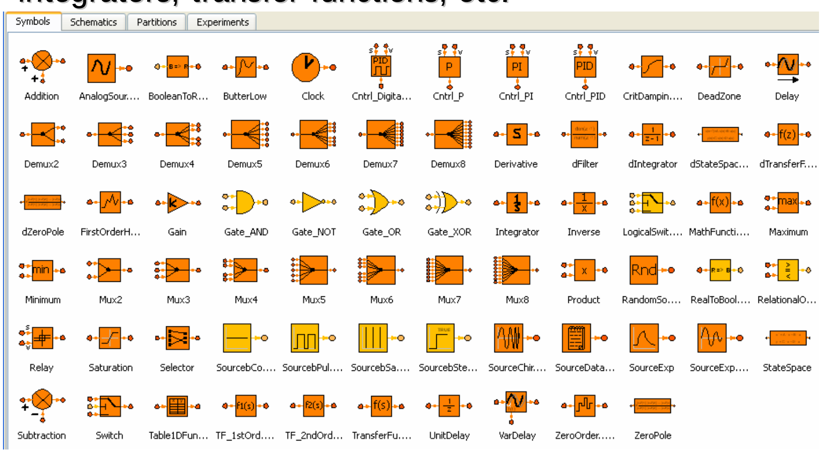


Current Libraries (II)



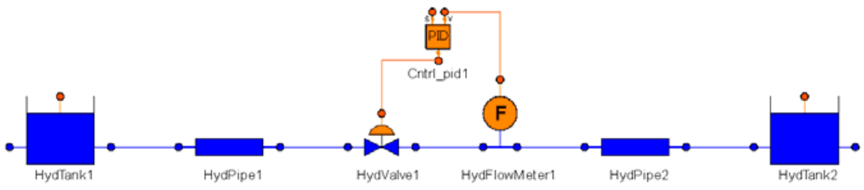
CONTROL library

Library with the standard control components such as P controllers, PI & PIDs, signal generators, logic gates, integrators, transfer functions, etc.



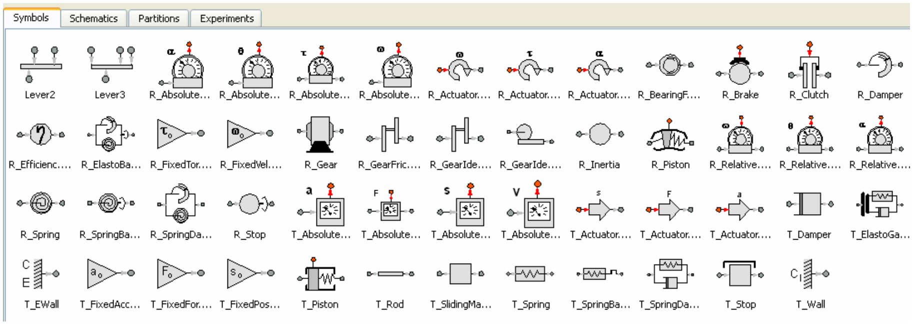
CONTROL library

Example of two water tanks connected by a pipe with a valve to regulate the flow, a flowmeter and PID controller



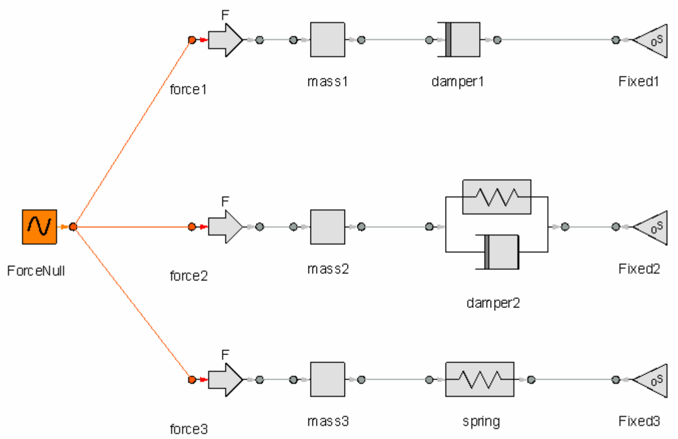
MECHANICAL Library

Library of 1D traversing mechanical components and rotational mechanical systems such as masses, force and momentum generators, springs, actuators, sensors, pistons, levers, brakes, etc.



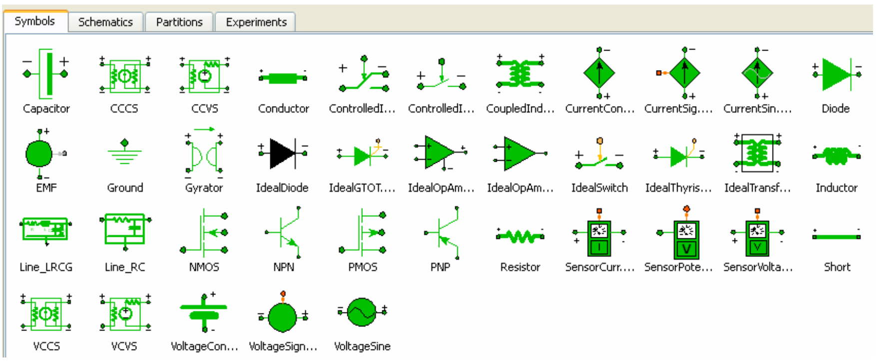
MECHANICAL Library

Example: A transmission system with 3 masses: brake, clutch, and a spring with a shock absorber



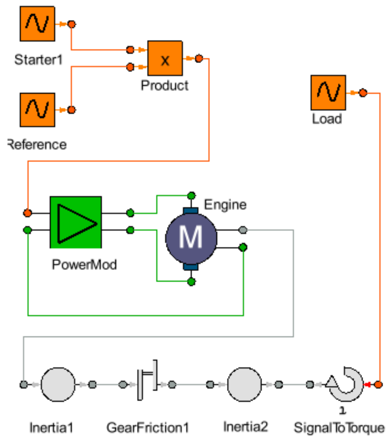
ELECTRICAL library

Library of electrical and electronic components such as signal generators, capacitors, inductors, diodes, transistors, etc.



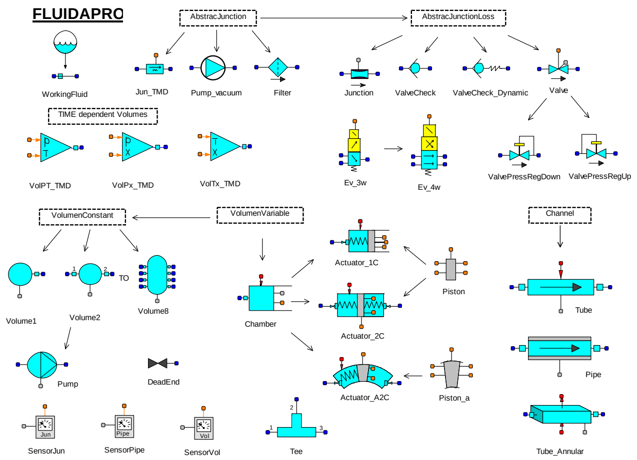
ELECTRICAL library

Example: a motor powered by power stages
and a mechanical unit connected to the drive shaft



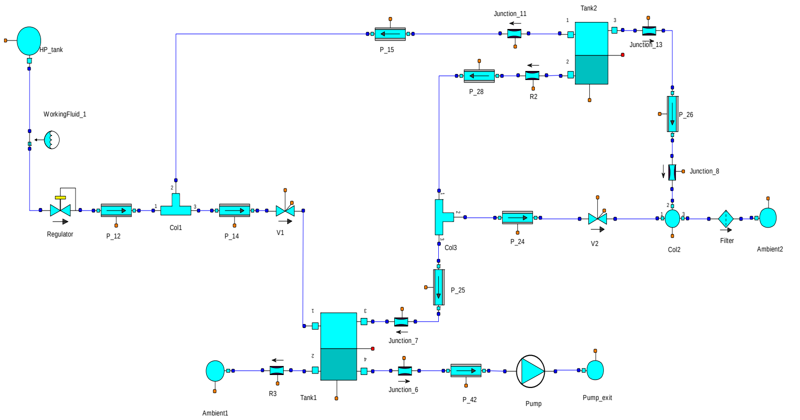
FLUIDAPRO library

Library for modelling the dynamics of systems of fluids (gas, liquid, or two phase), reverse flow, inertia, heat transfer, pneumatic and hydraulic actuators, heat exchangers, etc.



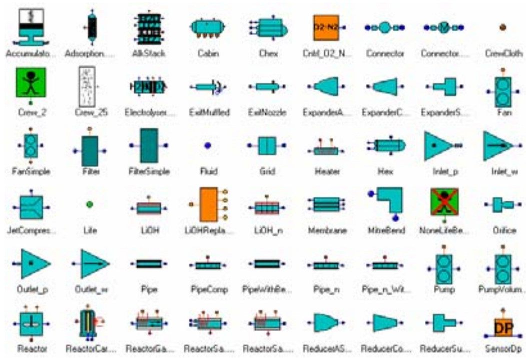
PipeLiqTran Library

Example: Modelling a vacuum network



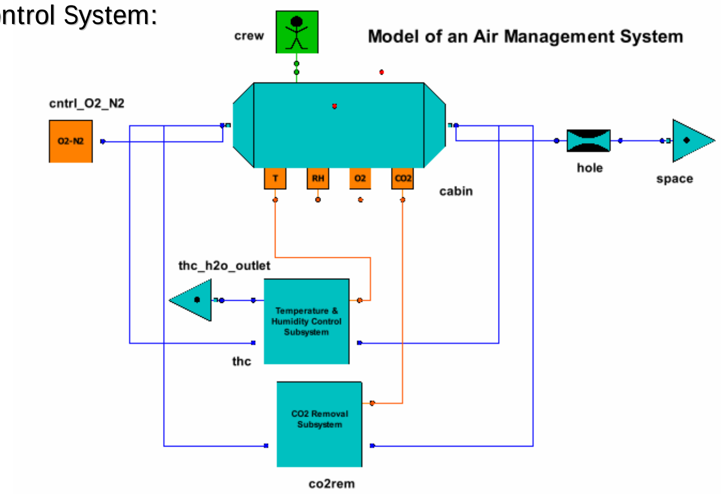
ECLSS Library

- ECLSS (Environmental Control and Life Support System) is a standard ESA library for modelling ECLSS in manned spacecraft.
- It has been extensively used to model various COLUMBUS subsystems.
- Its components include cockpit, pumps, crew physiological model, chemical reactors, etc.



ECLSS Library

Modelling the Columbus
Air Control System:



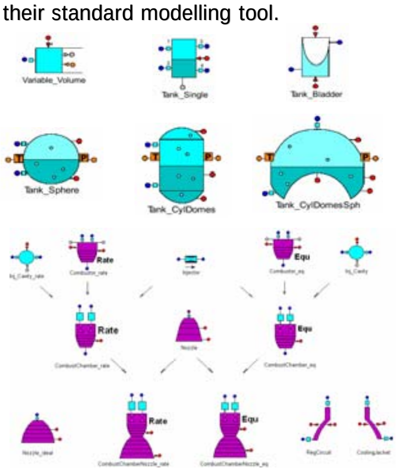
ESPSS Library

ESPSS (European Space Propulsion System Simulation) is a set of libraries for modelling and simulating propulsion systems for satellites and rockets.

ESPSS belongs to the ESA and is their standard modelling tool.

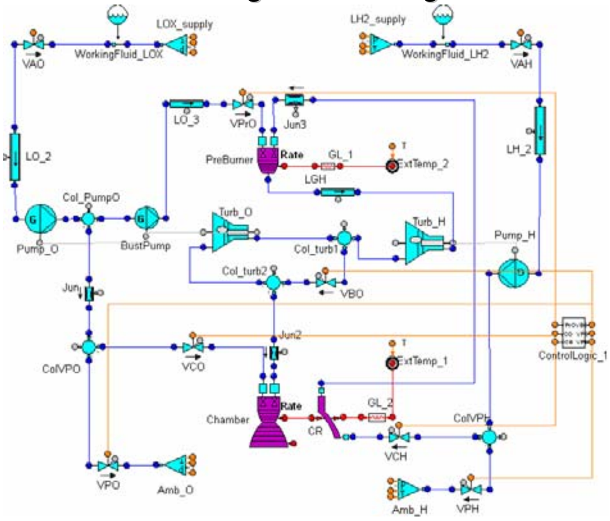
It includes the following libraries:

- Fluids (one and two phases)
- Thermodynamic properties
- Combustion chambers and nozzles
- Tanks
- Turbine machinery



ESPSS Library

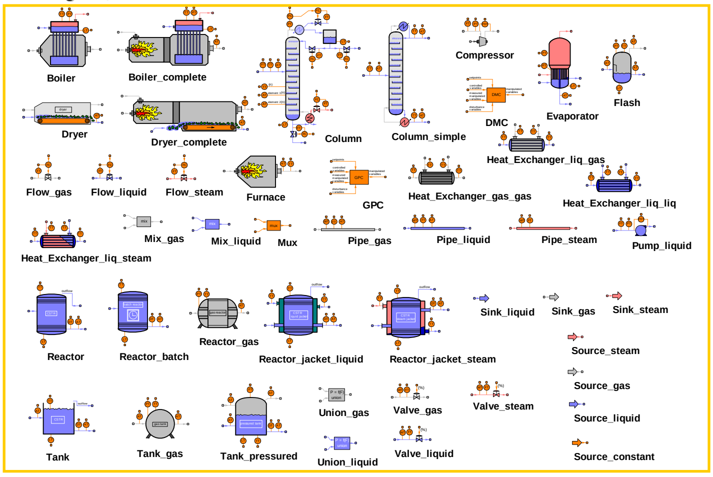
Model of a multi-stage rocket engine model



PROCESS Library

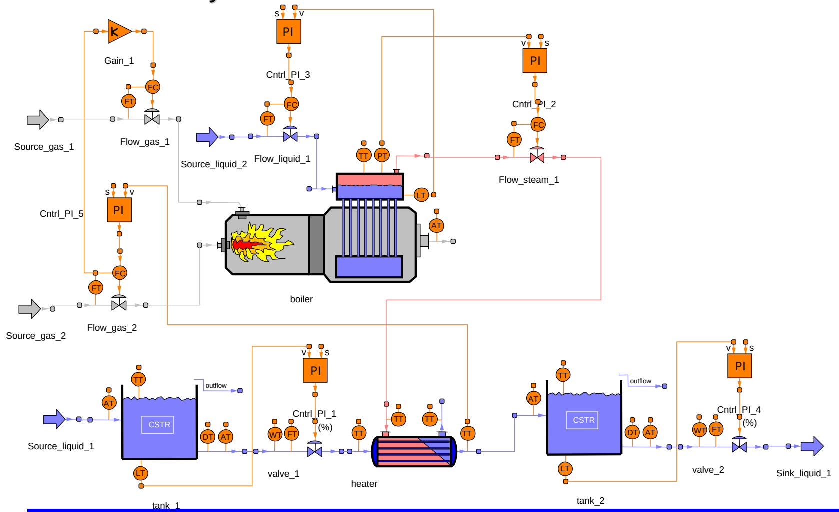
The PROCESS library has the typical components for modelling industrial processes.

It has components such as boilers, distillation columns, reactors, heat exchangers, etc.



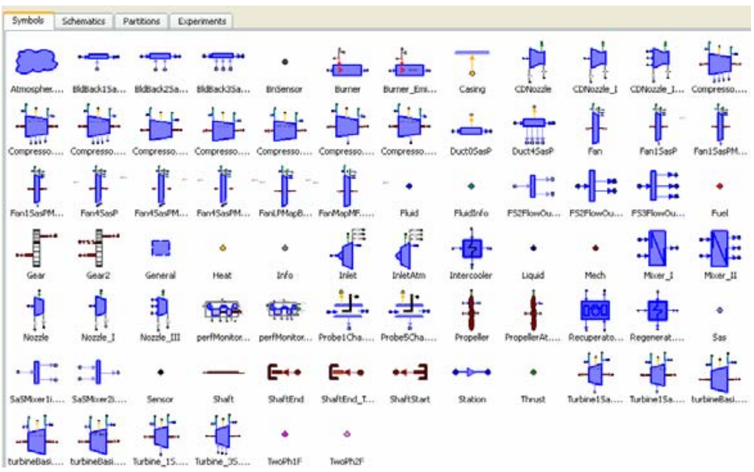
PROCESS Library

Model of a steam boiler
with a control system



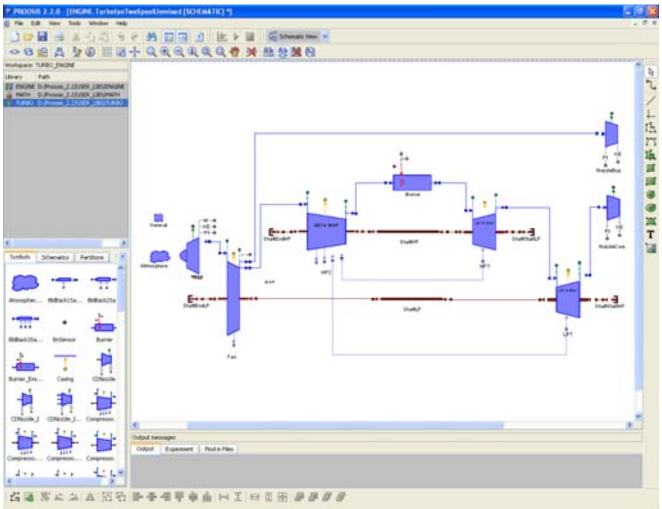
TURBO Library

A complete library for modelling aeronautical gas turbines with components such as compressors, turbines, combustion chambers, heat exchangers, shafts, etc.



TURBO Library

Example: Modelling a twin-shaft turbofan engine



THERMAL BALANCE LIBRARY

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Eusebio Huélamo
26th November 2009

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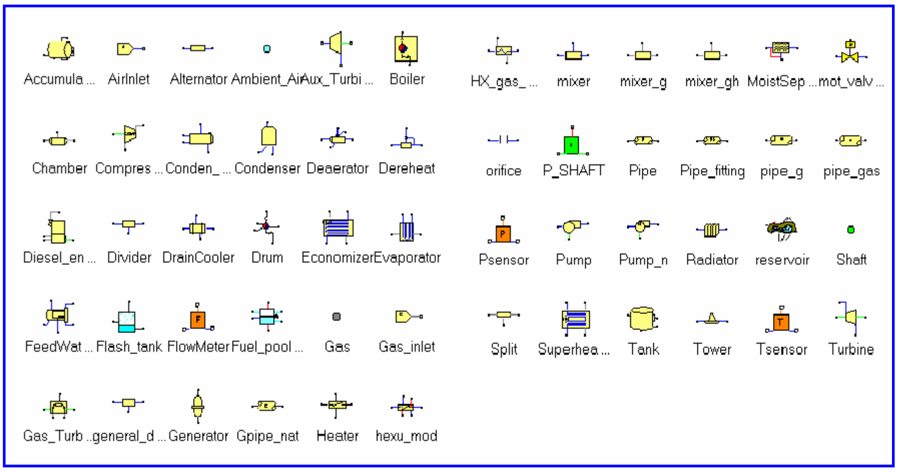
Origin of the library

- Originally the intention was to unify different known thermal balance programs in a generic EcosimPro library called THERMAL_BALANCE. The programs were:
  - Thermal Balance calculation program HBAL
  - Thermal Balance calculation program ANTEO
- The formulation of the old programs was adapted to acausal modelling and based on components of EcosimPro.
- A much easier interface was attained, both for data entry and for inicialization of variables and resolution of the model generated.
- THERMAL_BALANCE has the ability to expand the library with new static or dynamic components.

Description of the library

- The THERMAL_BALANCE library is used for stationary thermal balance studies in typical power plants (water-steam, co-generation, etc).
- The library contains a wide range of pre-modelled components that cover all modelling requirements for these types of systems, such as: pumps, compressors, valves, pipes, motors, heat exchangers, condensers, turbines, evaporators, electric generators, cooling towers, etc.
- Apart from water, the library can work with air, oxygen, carbon dioxide, cabon monoxide, helium, argon, methane, propane, butane, and sulphur dioxide. The user can easily add new fluids.
- The diagrams of the models created are similar to the plant diagrams, which makes it easy to identify any part of the model.

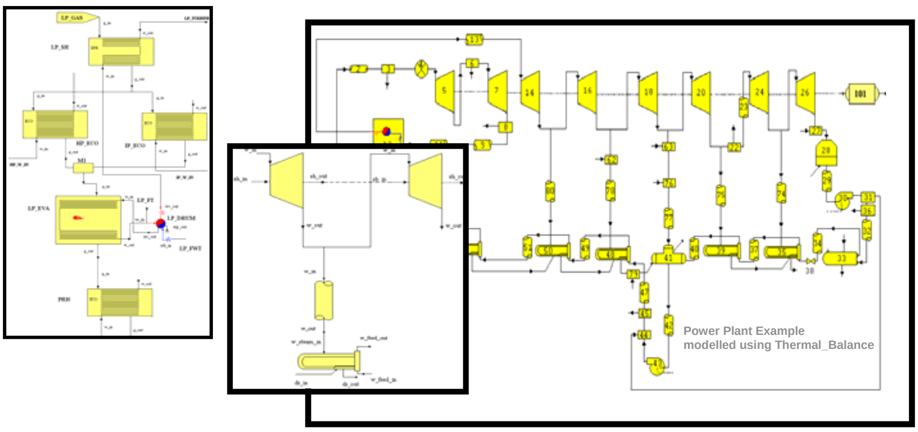
Toolkit of the library



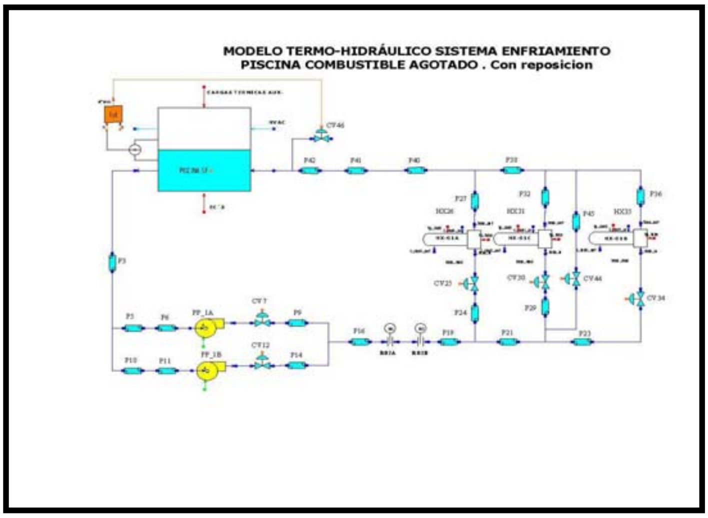
Examples

SOME EXAMPLES

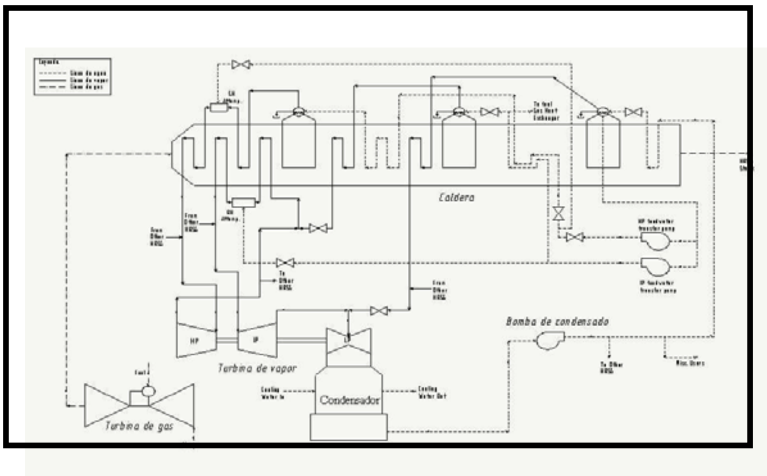
Example of modelling cycles



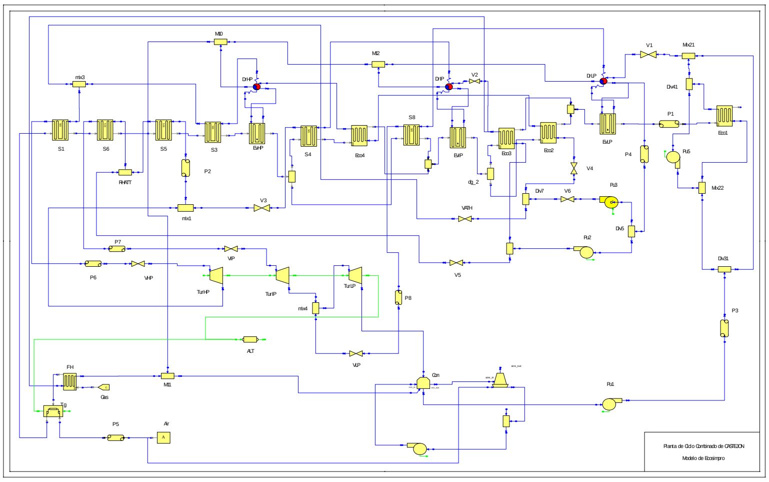
Modelling of Fuel Treatment Pool



Model of Combined Cycle



Model of Combined Cycle



Thermo-hydraulic model of the feedwater heaters

- **PURPOSE: An NPP considers a power upgrade. It is necessary to consider which equipment items can be used and which need to be replaced.**

- **No data is available for the thermo-hydraulic behavious of the feedwater heaters at higher loads than those with valves fully open.**

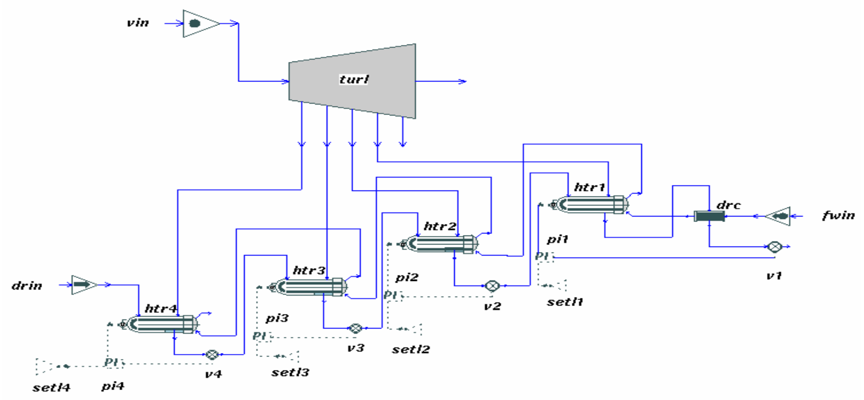
Thermo-hydraulic model of the feedwater heaters

- **The manufacturers, in accordance with the regulations of the Heat Exchange Institute, in order to facilitate the behavioural calculations, provide Terminal Temperature Difference (TTD) curves and Drains Cooler Approach (DCA) depending on the flow of condensate.**

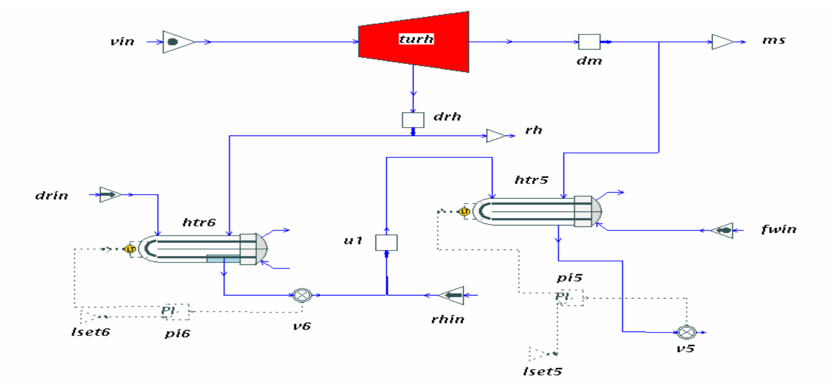
The question is:

- **Can the original curves from the suppluier be used, with a simple extrapolation?**

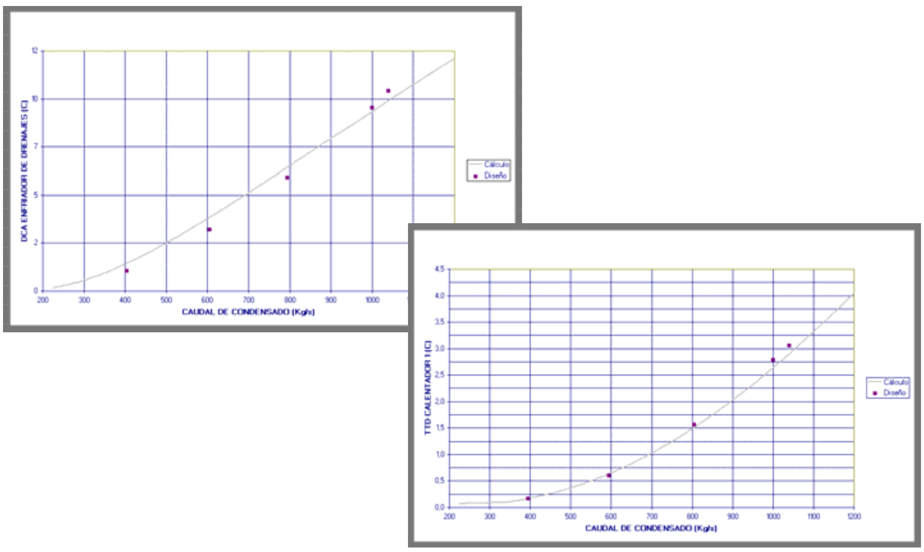
Thermo-hydraulic model of the feedwater heaters



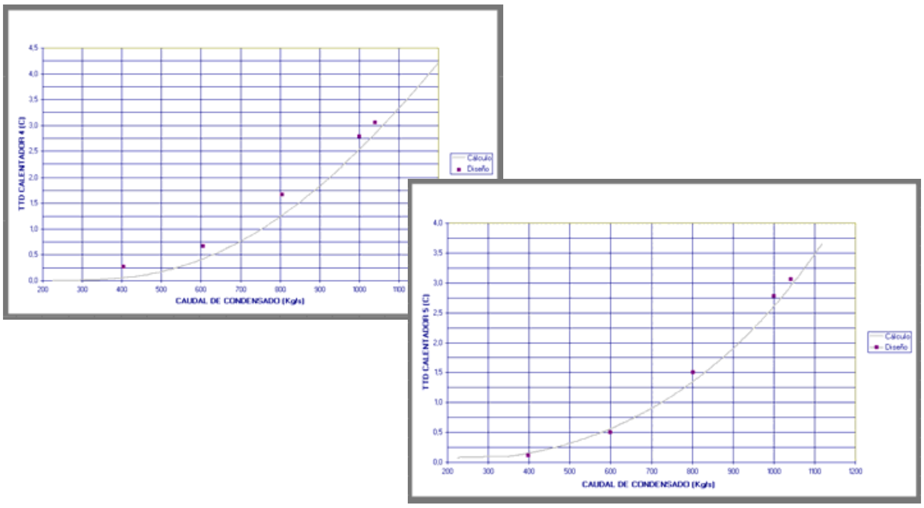
Thermo-hydraulic model of the feedwater heaters



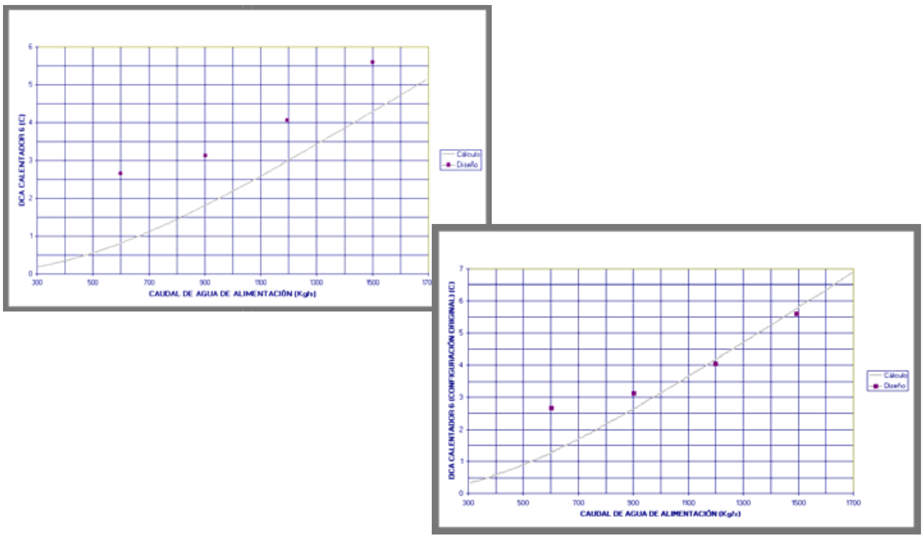
Thermo-hydraulic model of the feedwater heaters



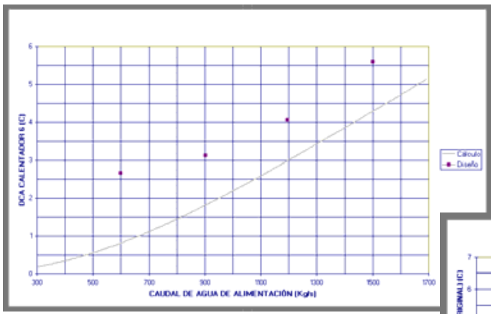
Thermo-hydraulic model of the feedwater heaters

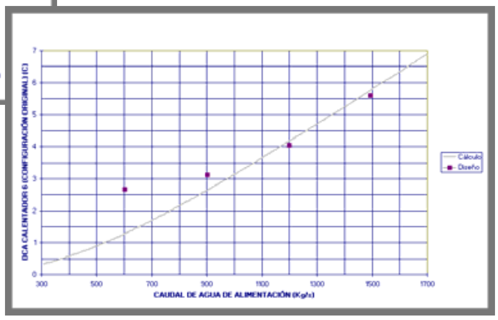


Thermo-hydraulic model of the feedwater heaters

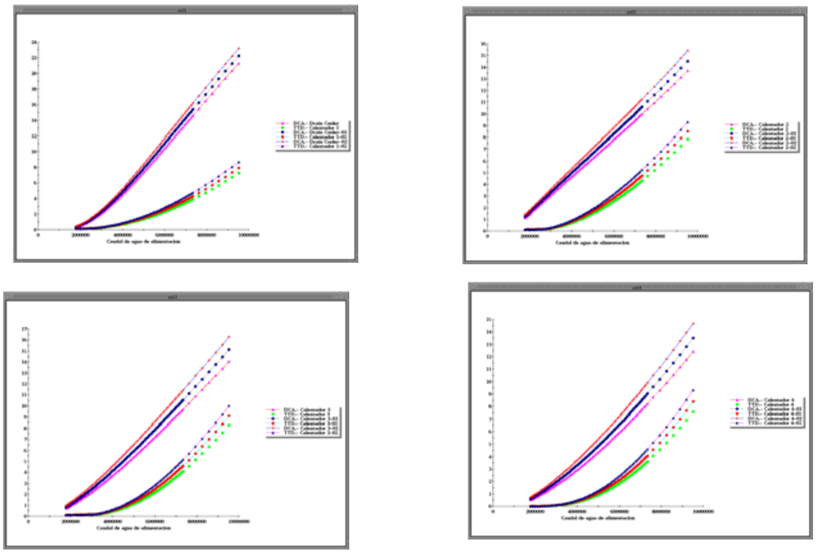


Thermo-hydraulic model of the feedwater heaters

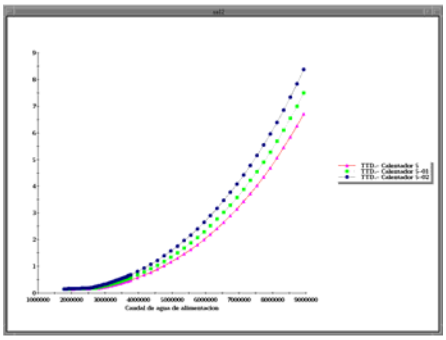


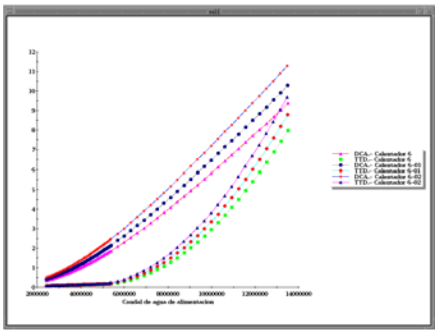


Thermo-hydraulic model of the feedwater heaters



Thermo-hydraulic model of the feedwater heaters

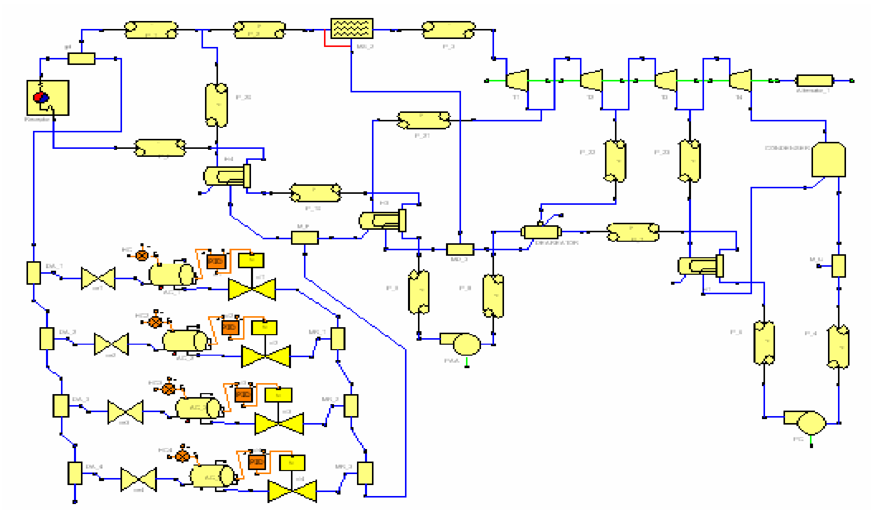




Thermo-hydraulic model of the feedwater heaters

- Using EcosimPro and the THERMAL-BALANCE library some validated models were obtained, which simulate quite accurately the thermo-dynamic behaviour of the feedwater heaters.
- It is possible to obtain from these models, values of TTD and DCA for greater loads and different layouts then the originally planned ones, and can be used for other calculations with the same program or with other thermal balance programs.
- These models can be used to check the effect of pipe blockages on the TTD and DCA curves of the heaters.

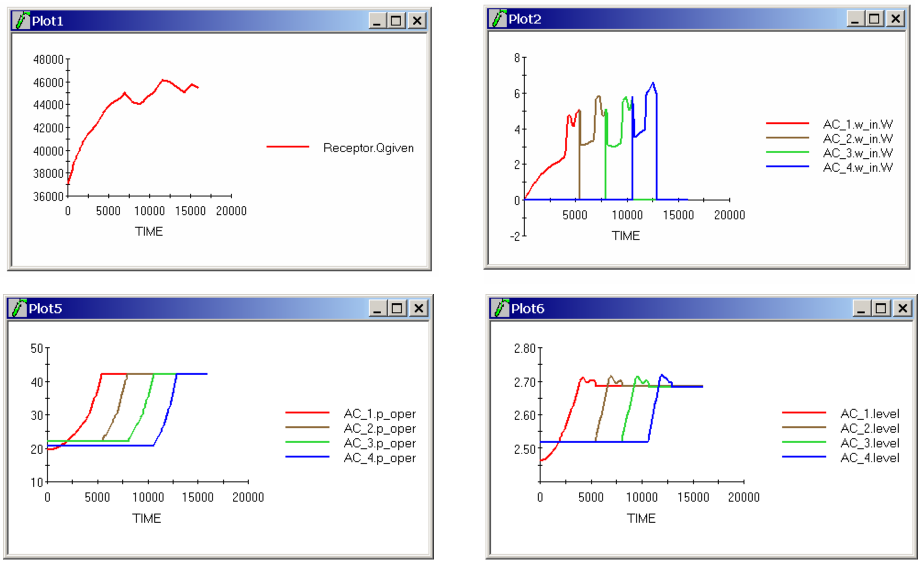
Solar Plant Model with accumulators



Solar Plant Model with accumulators

- Model of operation of solar plant with direct supply to the cycle and charging of the accumulators.
- The cycle is maintained at 100% power, charging the accumulators with the excess energy supplied.
- When the first accumulator is fully charged, the excess flow is derived to the second accumulator, and so on until all are full. The accumulators are discharged in the same way, ie sequentially.
- The following graphs show, for the filling sequence, the evolution of the energy transmitted by the receptor, the flow entering the accumulators, the pressures, and the levels.

Solar Plant Model with accumulators



Conclusions

EcosimPro's THERMAL_BALANCE library is a very powerful tool for modelling conventional thermal cycle systems in fossil-fired, nuclear, co-generation, combined cycle or any other kind of power plant.

PIPELIQTRAN Library

Empresarios Agrupados Internacional (EAI)

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26 de November de 2009

Phone: 34 – 91 448 85 98
http: www.ecosimpro.com

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- Overview of PIPELIQTRAN Library
- Model Building Rules
- Components of the PIPELIQTRAN Library
- Examples
- Conclusions

Index

- Overview of PIPELIQTRAN Library
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Overview of PIPELIQTRAN Library

- Purpose of the PIPELIQTRAN Library
  - To simulate hydraulic transients in hydraulic systems of industrial plants
- Applicability of the PIPELIQTRAN Library
  - Valve Waterhammer
  - Pipe Filling Waterhammer
  - Transient conditions caused by various pump operations

Overview of PIPELIQTRAN Library

Phenomena and assumptions:

- **Working fluid is a liquid**
- **One-dimensional flow**
- **Reverse flow**
- **Constant composition of the fluid**
- **Fluid properties depend on the temperature**
- **Quasi-stationary loss pressures**
- **Heat accumulation in the liquid and in the tube walls**
- **Fluid dynamic pressure**

Overview of PIPELIQTRAN Library

- **Available working fluids:**
  - **H2O** **Water**
  - **UserDef1** **User Defined Fluid Number 1**
  - **UserDef2** **User Defined Fluid Number 2**

It is possible to define new working fluids

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- Overview of PIPELIQTRAN Library
- Model Building Rules
- Components of the PIPELIQTRAN Library
- Examples
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Model Building Rules

- Model Building Rules
  - Two Types of Components: Pipes and Junctions
  - Connections have to go from a Junction to a Pipe (it is not possible to connect 2 pipes, neither 2 junctions)
  - Multiple connections are forbidden (a collector has to be use)
  - The elevations and the crossed areas are defined in the pipes

Model Building Rules

- **Model Building Advice**
  - It is advisable that all the ports are interconnected
  - To generate a default partition
  - To specify the working fluid in the body of the experiment
  - To chose a right number of nodes for each pipe
  - To specify a right communication interval
  - To change the value of the absolute error (ABS_ERROR) to a smaller value in the body of the experiment if it is going to work with very small mass flows.
  - It is considered direct flow from port f1 to port f2

Model Building Rules

- **Definition of the working fluid**
  - The working fluid is a variable for all the components
  - The current version of PIPELIQTRAN uses the same working fluid for a determinate circuit in the model because the type of fluid is a variable that is exchanged between the ports of the components.
  - It is necessary to define the working fluid in the experiment, if not the first element of the fluid list is going to be used
  - Working fluids can be changed in the experiments but this is not a recommended practice

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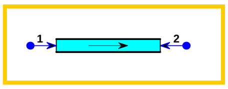
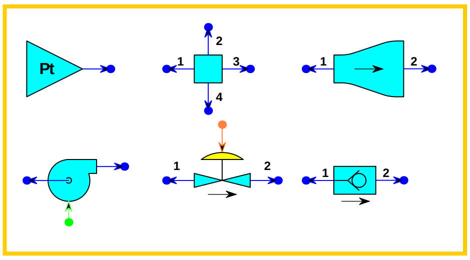
Components of the PIPELIQTRAN Library

Classification of Components by Port Direction

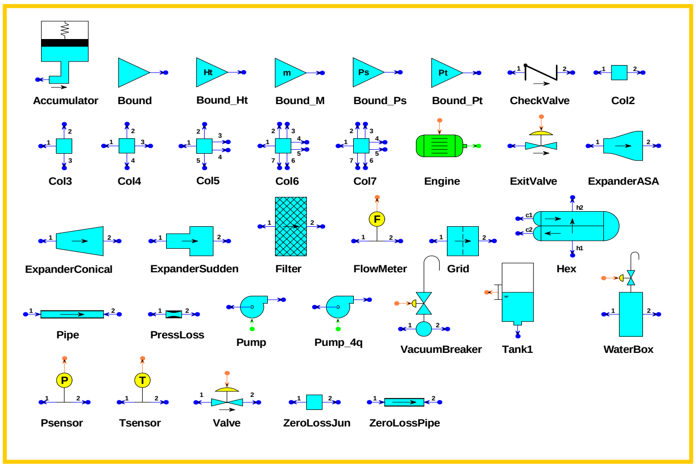
- **Pipe**: Two fluid inlet ports (f1 y f2).



- **Junctions**: For non-pipe components all the fluid ports are outlets

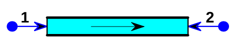


Components of the PIPELIQTRAN Library



Components of the PIPELIQTRAN Library

Component Pipe



- The pipe is the main component of the library
- It is the component used to interconnect components in the model

Components of the PIPELIQTRAN Library

Component Pipe

Phenomena modelled

- Number of variable nodes (Discretization)
- Waterhammer waves
- Equation of energy (optional: FALSE)
- Cavitation in inner points (optional: TRUE)
- Gas release (optional: FALSE)
- Sound speed modified by wall extensibility and by gas release
- Pressure losses calculated according to static friction factors
- The elevations of the pipe stretches
- Nominal diameters and Schedules
- Number of parallel tubes

Components of the PIPELIQTRAN Library

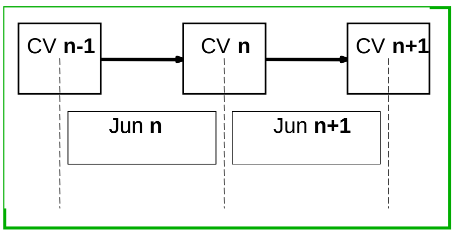
Component Pipe

Conservation of Mass & Energy

They are applied to control volumes

$$\frac{dP_j}{dt} = \frac{c^2}{V_j}(m_j - m_{j+1})$$

$$\frac{dT_j}{dt} = \frac{(m_j\, c_p\, T_j - m_{j+1}\, c_p\, T_{j+1})}{\rho V_j\, c_p}$$



Components of the PIPELIQTRAN Library

Component Pipe

Sound speed

- **Effect of the pipe-wall elasticity**

  Three support situations for a thin-walled pipeline are examined and the wave speed formulas modified:

a) pipe anchored with expansion joints throughout

b) pipe anchored at its upstream end only

c) pipe anchored throughout against axial movement

$$c' = \frac{c_o}{\sqrt{1 + \frac{K}{E} \cdot c_1}}$$

$$a) \quad c_1 = \frac{D_{in}}{e}$$

$$b) \quad c_1 = \frac{D_{in}}{e} \cdot \left(\frac{5}{4} - \mu \right)$$

$$c) \quad c_1 = \frac{D_{in}}{e} \cdot \left(1 - \mu^2\right)$$

Components of the PIPELIQTRAN Library

Component Pipe

Sound speed

– **Effects of Gas Release**

$$c = \frac{c'}{\sqrt{1 + \frac{\frac{m \cdot K \cdot (R/MM) \cdot T}{P^2}}{1 + (K/E) \cdot c_1}}}$$

Calculation of the rate of mass of gas release per unit of volume of liquid

$$If\left(P < P_s\right) \qquad \frac{dm}{dt} = C_k \cdot (P_s - P)$$

C_k is a coefficient that depends on the gas solubility
P_s is the gas saturation pressure.

Components of the PIPELIQTRAN Library

Component Pipe

Momentum balance

Conservation of momentum is applied to other CV between the middle points of the previous ones (staggered grid)

$$\left(\frac{L}{A}\right)_j \frac{dm_j}{dt} = P_{j-1} + av_{j-1} - P_j - av_j - K\frac{m_j^2}{\rho_j A_j^2}$$

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Components of the PIPELIQTRAN Library

Component Pipe

Artificial viscosity

It is a finite difference technique to model steep fronts of propagating shocks. Mainly it is used to reduce numerical dispersion at a moving shock wave front trading off shock steepness

The artificial viscosity (*av*) is introduced in the discretised momentum equations. The expression for *av* is given by:

$$av_j = -k_{damp} \cdot c \cdot \frac{(m_{j+1} - m_j)}{A}$$

where:

k_{damp} **= user-defined constant of order unity**

c **= sound speed**

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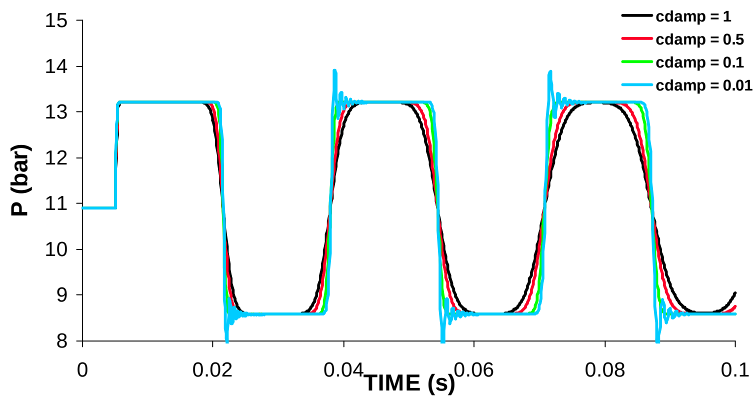
Components of the PIPELIQTRAN Library

Component Pipe

Influence of artificial viscosity in transitories



Components of the PIPELIQTRAN Library

Component Pipe

Pressure losses

$$P_{loss} = \frac{1}{2} f_p \cdot \frac{L}{D} \cdot \frac{\dot{m}}{\rho \cdot A^2} + \left[f_{turb} \cdot \left(\frac{L}{D}\right)_{fitt} + \left(f \cdot \frac{L}{D} \right) \right] \cdot \frac{\dot{m}}{\rho \cdot A^2} + P_{loss,ref} \cdot \frac{\dot{m}^n}{\dot{m}^n_{ref}} \cdot \frac{\rho_{ref}}{\rho}$$

where:

- f_p = pipe friction factor
- $(L/D)_{fitt}$ = total L/D of fittings (excludes pipe length)
- $(f\ L/D)$ = pressure losses defined as $f \cdot \frac{L}{D}$
- $P_{loss,\ ref}$ = reference pressure loss
- n = mass flow exponent in reference calculation of pressure loss

Components of the PIPELIQTRAN Library

Component Pipe

Cavitation

The calculation of the cavitation is optional. The mass balance with and without cavitation is the following:

- ***If(P>P$_{sat}$)***

$$\frac{dP_j}{dt} = \frac{c^2}{V_j}(m_j - m_{j+1})$$

V_b: Cavitation bubles

volume $\frac{dV_{b,j}}{dt} = 0$

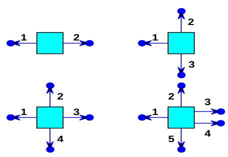
$$\frac{dV_{b,j}}{dt} = \frac{m_{j+1} - m_j}{\rho_j}$$

- ***If(P<=P$_{sat}$)*** **Cavitation**

$$\frac{dP_j}{dt} = 10^{-6} \cdot \frac{c^2}{V_j}(m_j - m_{j+1})$$

Components of the PIPELIQTRAN Library

Component Collector



- **The collector is the component that is used to join or to split the flow.**
- **There are several types of collectors depending on the number of connections they have**
- **The collector with the greatest number of connections is named Col10 and has 10 connections**

Components of the PIPELIQTRAN Library

Component Collector

Mass Balance

$$\frac{dP}{dt} = -\frac{\sum_{j=1}^{j=n} m_j}{V} \cdot c^2$$

Energy Balance

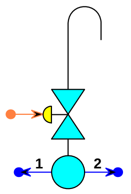
$$\rho \cdot c_p \cdot V \cdot \frac{dT}{dt} = -\sum_{j=1}^{j=n} m_j \cdot h_j$$

Momentum Balance

$$10^{-6} \cdot \frac{dm_j}{dt} = (P - P_j) - 0.5 \cdot \xi_j \cdot \frac{m_j}{\rho \cdot A_j^2}$$

Components of the PIPELIQTRAN Library

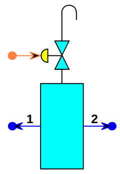
Component VacuumBreaker



- It inherits the model of the collector with two branches
- It has an air inlet and outlet
- Air flow conditions are considered isentropic
- It allows the simulations of empty circuits.

Components of the PIPELIQTRAN Library

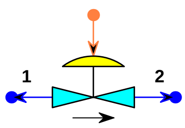
Component WaterBox



- It is similar to VacuumBreaker component, but in this case it is possible to define the total volume and the elevations of the top and the bottom of the water box
- It has been modelled to be able to simulate different types of condenser configurations

Components of the PIPELIQTRAN Library

Component Valve

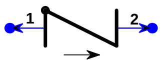


- It represents a control valve
- Closing law
- Time constant of the actuator (`tao`)
- Momentum balance

$$10^{-6} \cdot \frac{dm_j}{dt} = P_1 - P_2 - \frac{m^2}{\rho \ A_v^2}$$

Components of the PIPELIQTRAN Library

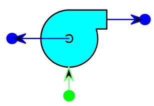
Component CheckValve



- It inherits the model of the abstract valve
- It is necessary to specify a pressure difference to keep the valve open or closed
- State machine has been defined
- Valve flow coefficient for forward (Avf) flow and for backward flow (Avb) need to be defined

Components of the PIPELIQTRAN Library

Component Pump_4q

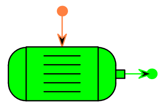


It represents a four quadrants pump, that includes the four pump operation zones.

- The characteristics curves of a pump are specified for three specific speeds (25, 147, 261)
- The user can include his own characteristics curves
- It can be connected to an engine component by means of a port called shaft

Components of the PIPELIQTRAN Library

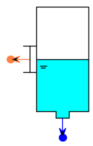
Component Engine



- This component simulates the behaviour of a engine
- It allows to simulate the start-up of a pump defining the relationship between the torque and the engine speed.
- It has the option to use a ratchet

Components of the PIPELIQTRAN Library

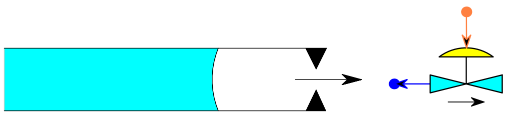
Component Tank



- There are several models of tank with different number of flow connections
- It is necessary to specify the relationship between the volume and the level
- Surface pressure
- Elevation of the liquid surface and the tank bottom
- Pressure loss coefficients in the outlets

Components of the PIPELIQTRAN Library

Component ExitValve



• Air enters and leaves the pipe through the valve under isentropic flow conditions

• The air mass within the pipe follows the isothermal law (gas mass is small)

• The air admitted to the pipe remains near the valve until it can be expelled

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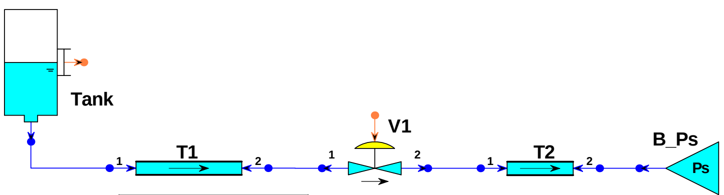
Examples

- Instantaneous closing of a valve
- Pump shutdown
- Naco case

Examples

Instantaneous closing of a valve

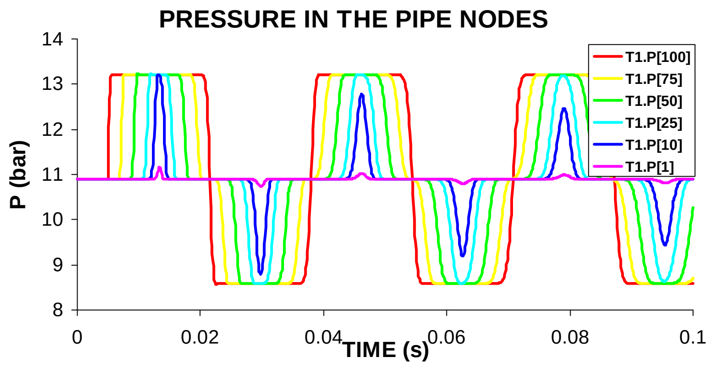
TANK	
P_{surf}	1 bar
z_{surf}	100 m



PIPE T1	
Node number	100
D_{out}	0.85 m^2
L	10 m
c_s	1219 m/s

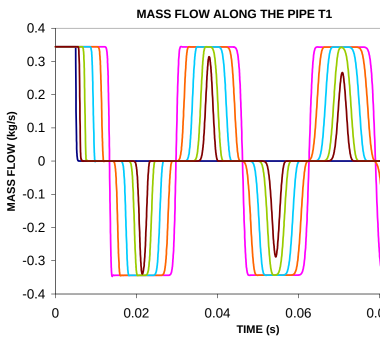
Examples

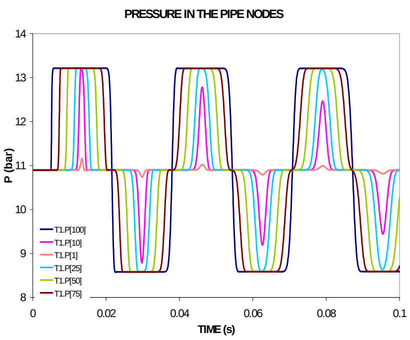
Instantaneous closing of a valve



Examples

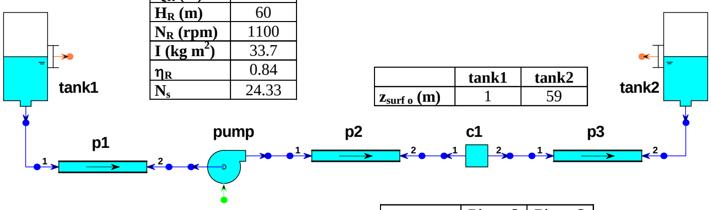
Instantaneous closing of a valve





Examples

Pump Shutdown



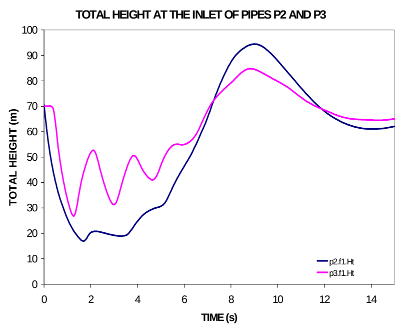
Pump	
Q_R (m)	0.5
H_R (m)	60
N_R (rpm)	1100
I (kg m^2)	33.7
η_R	0.84
N_s	24.33

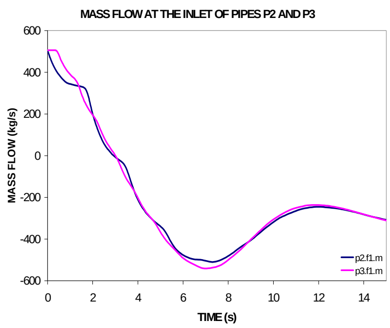
	tank1	tank2
$z_{surf\,o}$ (m)	1	59

	Pipe p2	Pipe p3
L (m)	450	550
D (m)	0.75	0.75
Q_o (m^3/s)	0.5	0.5

Examples

Pump Shutdown





Examples

NACO case

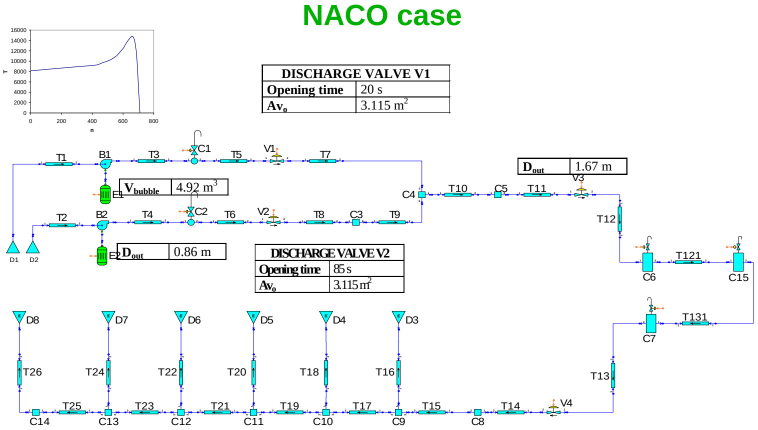
- Sequential start-up of the two pumps with the circuit full of water

- Comparison with the THICOM (Hydraulic Transients with Multiples Boundary Conditions) results

- The aim of this case is to check if the opening time of the discharge valves is adequate so that the pressures in the system do not exceed the tolerated limits

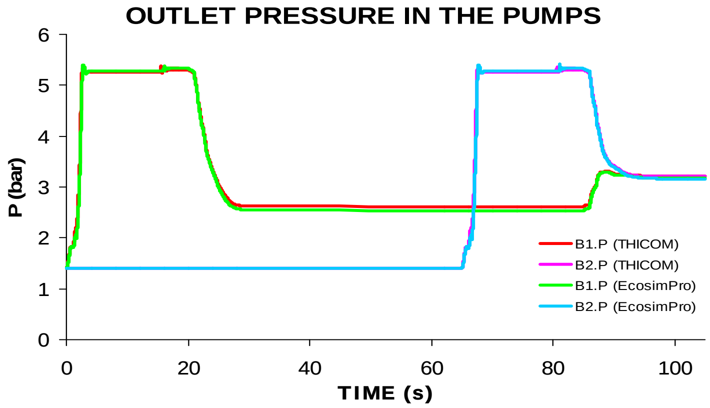
Examples

NACO case



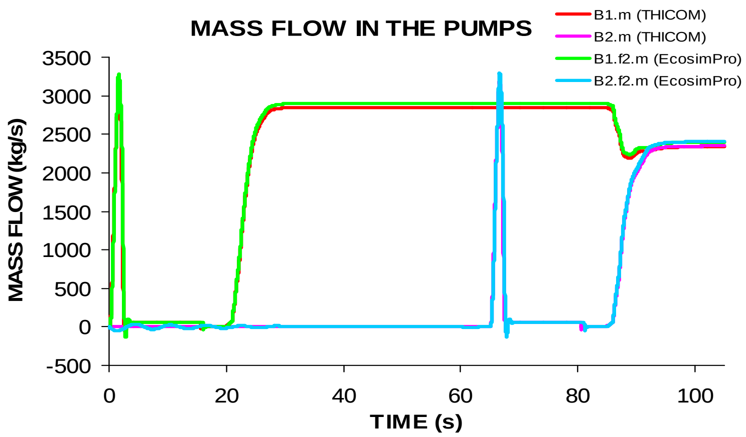
Examples

NACO case



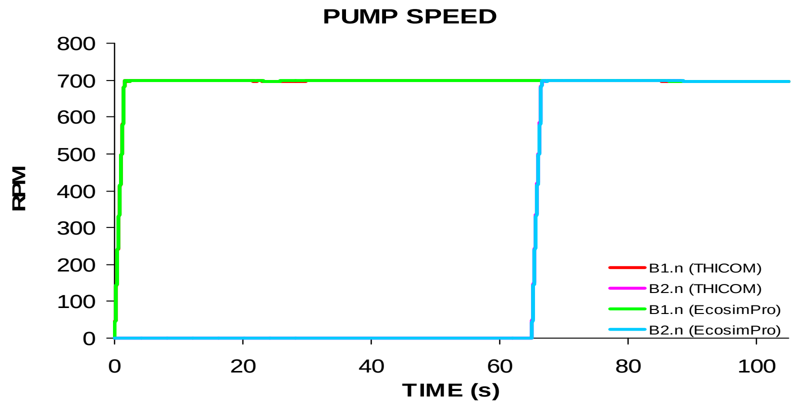
Examples

NACO case



Examples

NACO case



Index

- Overview of PIPELIQTRAN Library
- Model Building Rules
- Components of the PIPELIQTRAN Library
- Examples
- Conclusions

Conclusions

- This library allows to develop precise analysis of hydraulic transients. Although, the characteristic method is more precise and efficient for these kind of analysis

- Several cases of the same model can be analysed in a easy way, only modifying the experiment

- It allows to include new components in a easy and fast way

Heat Balance of a Thermo-electric Solar Power Plant

Empresarios Agrupados Internacional (EAI)

Alfonso Junquera
26th November 2009

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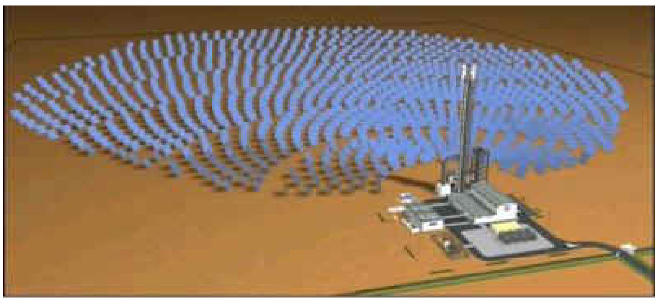
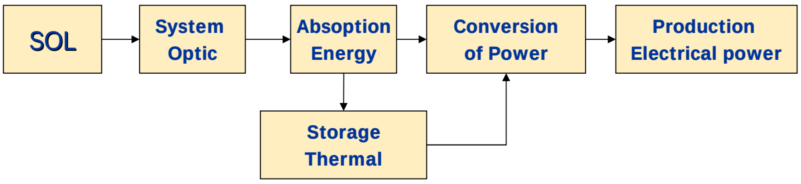
Thermo-electric Solar Plants

- Solar energy for the generation of electricity
  - Concentration systems.
  - Direct radiation
- Technology of the central receptor (solar tower)
  - Heliostat field

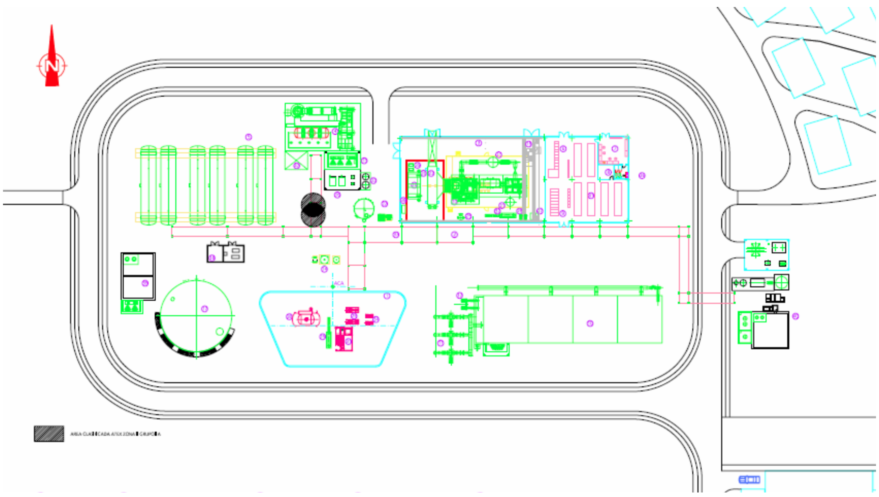


Heat storage systems

- Need for heat storage systems in thermo-solar power plants
  - Discontinuous solar radiation
    - Night hours and transients due to cloud passage
  - Planned operating modes: daily o continuous operation
- Heat storage systems currently in use
  1. Direct storage with water-steam of the cycle
  2. Storage in molten salt tanks



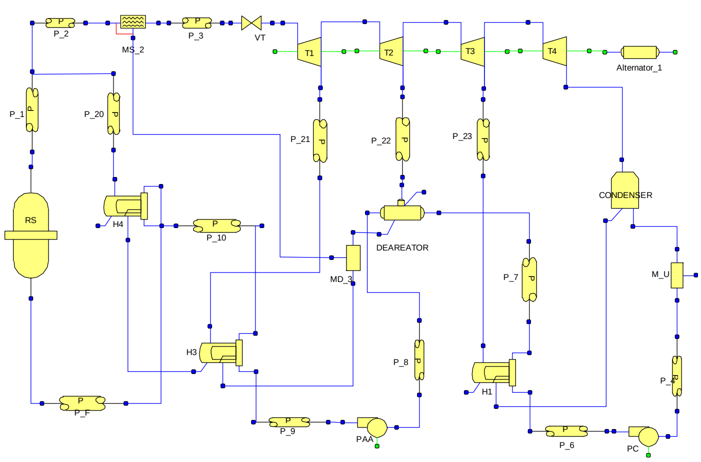
PS20 installation drawing



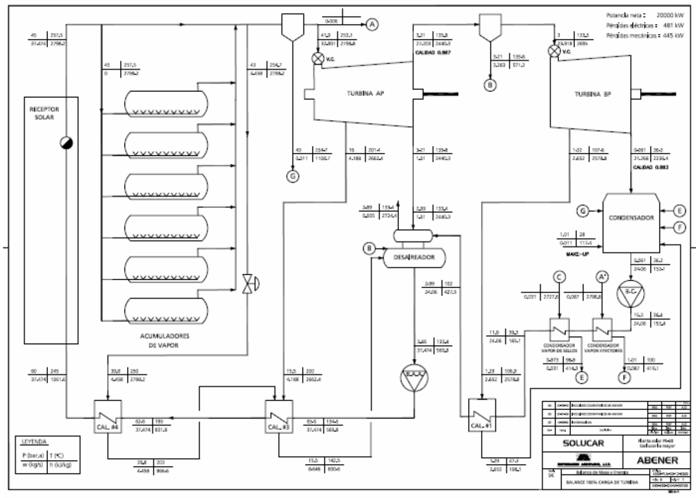
Goals of the EcosimPro simulation

- Heat balances at diferenet loads and with the accumulators in operation (charging and discharging)
- Checking of the sizing of the steam accumulators. Compliance with the criterion of keeping the plant in operation for 55 minutes at 50% load (cloud passage transients)
- Study strategies for charging/discharging the accumulators depending on the atmospheric conditions, to prevent plant trip
- Alternative charging control for accumulators

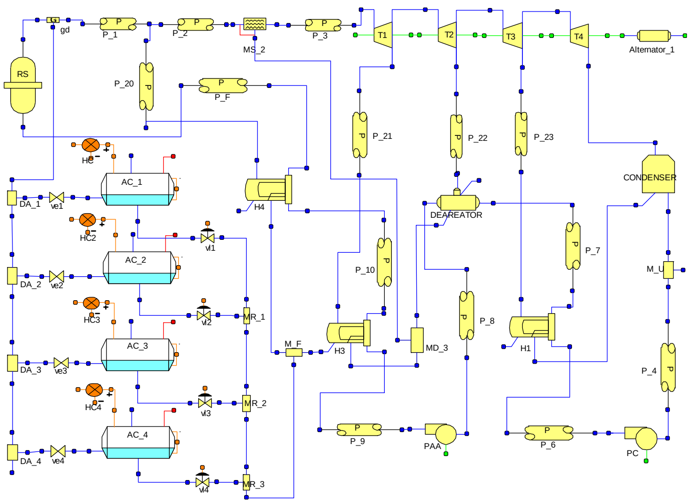
Model of the PS10 using EcosimPro Turbine cycle



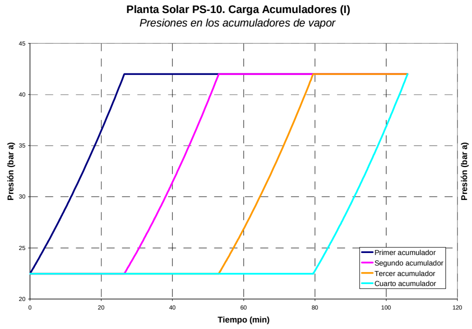
Heat balance of the PS10 cycle

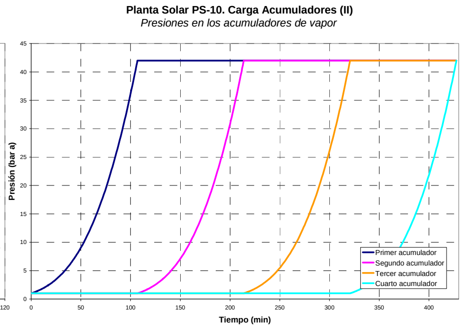


Model of the PS10 Charging the Accumulators

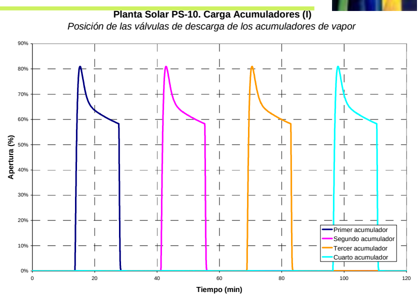


Hot and cold charging of the accumulators

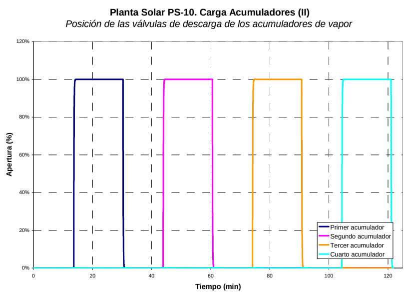


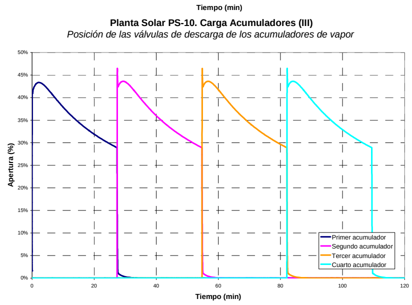


Charging the accumulators. Control alternatives

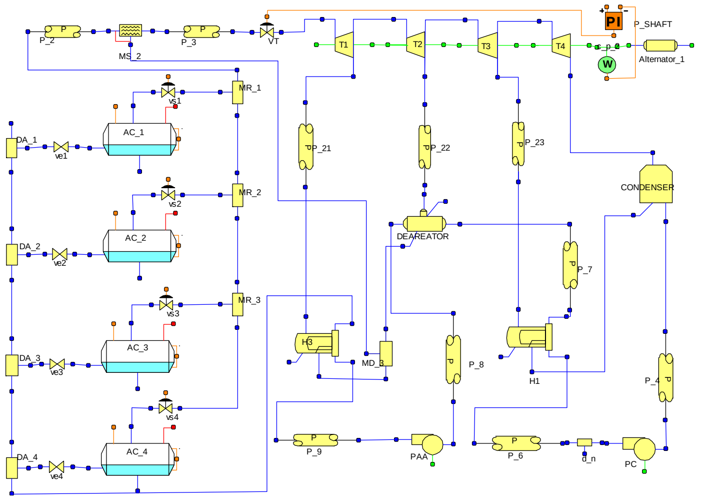


CONTROL ALTERNATIVES:

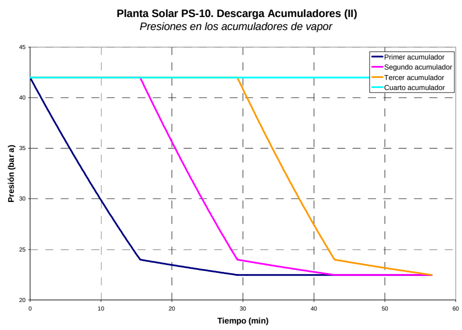


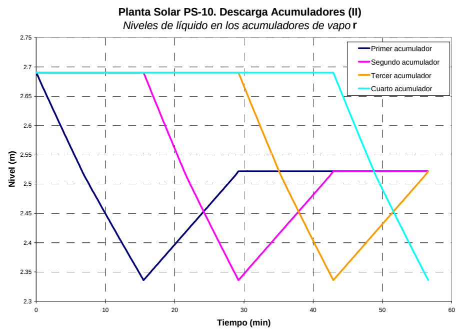


Model of the PS10 Discharging the accumulators

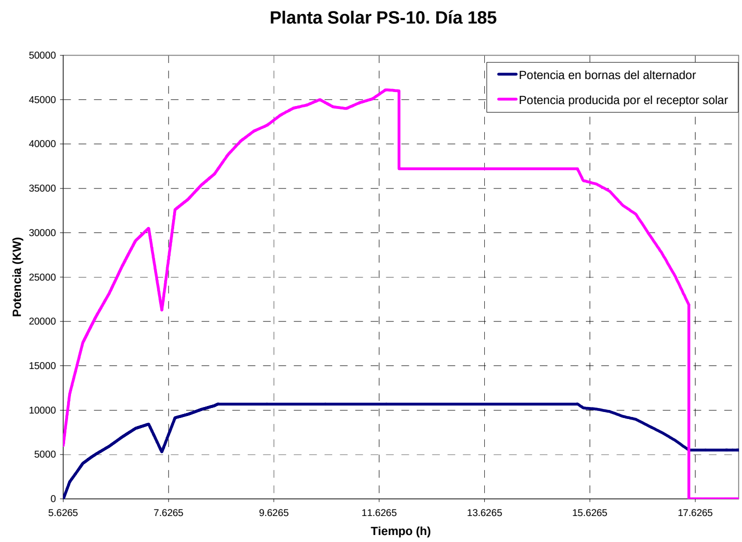


Discharging the accumulators

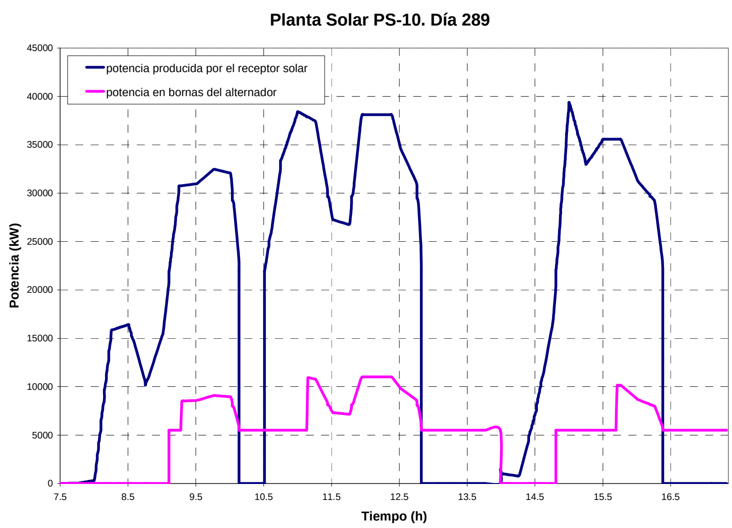




PS10 Solar Plant Simulation



PS10 Solar Plant Simulation



Conclusions

- FOR THE DESIGN
  1. The results of the case modelling the discharge of the storage system validate the geometric dimensions of the accumulators and initial level required to let the solar plant operate for 55 minutes, generating 5500 kW without any contribution from the solar receptor.
  2. The most convenient alternative control for the excess fluid in the accumulators is to regulate the floe of liquid discharged to Heater 3, so that it is the same as the flow of steam entering the accumulator.
  3. The operation during the six basic days seems to give satisfactory results on cloudless days but on cloudy days all cases led to the discharge of the accumulators before the end of the day.

Conclusions

- FOR OPERATION
  1. The long charging time means that the daily operation of the plant should start with the charging of the accumulators, if a completely cloudless day is not expected. On these days it would be convenient to charge the accumulators using the steam from the auxiliary boiler bedore the sun rises.
  2. On cloudy days an option would be to slow down the discharge of the accumulators by generating less than 5500 kW

Heat Sink Study

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26 November 2009

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Introduction (I)

The natural circulation heat sink for Almaraz Nuclear Power Plant (PWR, 2 x 980 MWe) is the Arrocampo reservoir. The heat removal capacity of this heat sink has direct repercussions on cycle performance and, subsequently, on the energy performance of the complete facility.

This artificial reservoir, built alongside the actual power plant, has a storage capacity of 35.5 hm3 and a surface area of 773 ha.

Introduction (II)

The ever more stringent environmental requirements demand very precise control of the thermal conditions of the makeup water taken from the River Tajo basin and the water discharged into it.

To combine both the legal and technical-economic aspects, using EcosimPro and the THERMAL-BALANCE and CONTROL libraries we have developed a transient calculation model which enables us to model the reservoir, the new additional cooling systems, and the makeup and discharge systems with all the fine details, as well as to analyse the behaviour taking into account the local climatology – hourly – over a given period.

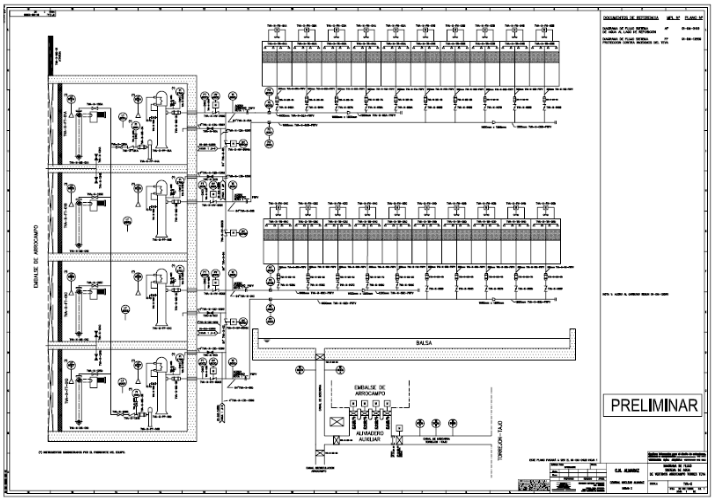
Introduction (III)

The following are the objectives sought:

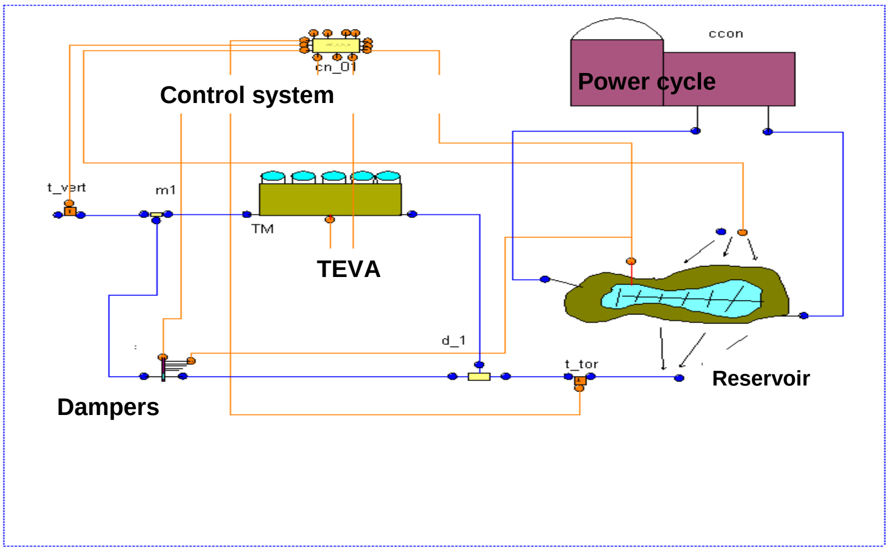
- **To define a control system which enables plant operation to be optimised from the technical-economic point of view (maximum net energy produced), maintaining the makeup flow and discharge flow & temperature values within the legally established limits**

- **To study different alternatives regarding possible different operating modes**

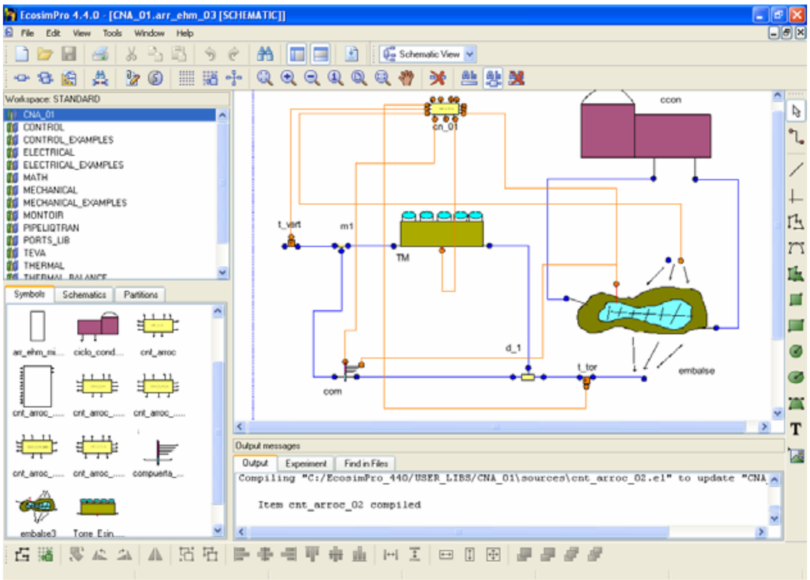
P&ID of the new system



The overall model



The overall model in EcosimPro



The cycle model

The cycle model is a simplified model.
From it we can obtain:

- **The heat rejected to the reservoir by the condensers of both units based on the circulating water flow & temperature and the Plant operating mode / time of year**
- **The net power**

It offers the possibility of reading – from external tables – the operation mode, which enables us to reproduce well known historic data.

The reservoir model (I)

➢ It is based on NUREG 0693 "Analysis of Ultimate Heat Sink Cooling Ponds"

➢ It is a reservoir model completely mixed on each node; ie, a uniform temperature is considered on each of the nodes where the user decides to divide the reservoir

➢ The ambient conditions (temperature, pressure, relative humidity, solar radiation and wind speed) are read from external files which, as in the case of the cycle model, enables us to reproduce well known situations and, consequently, validate the model

The reservoir model (II)

The following is taken into account at each node:

➢ Mass transfer mechanisms:

- ❖Makeup from the upstream node
- ❖Discharge towards the downstream node
- ❖Evaporation
- ❖Random external makeup
- ❖Random external bleed-off

➢ Energy transfer mechanisms: Overall energy balance, it time, between:

- ❖Inlet and outlet currents
- ❖Solar radiation
- ❖Atmospheric radiation
- ❖Heat exchanged by conduction and convection
- ❖Heat removed by evaporation
- ❖Energy stored on the node

Model of the tower

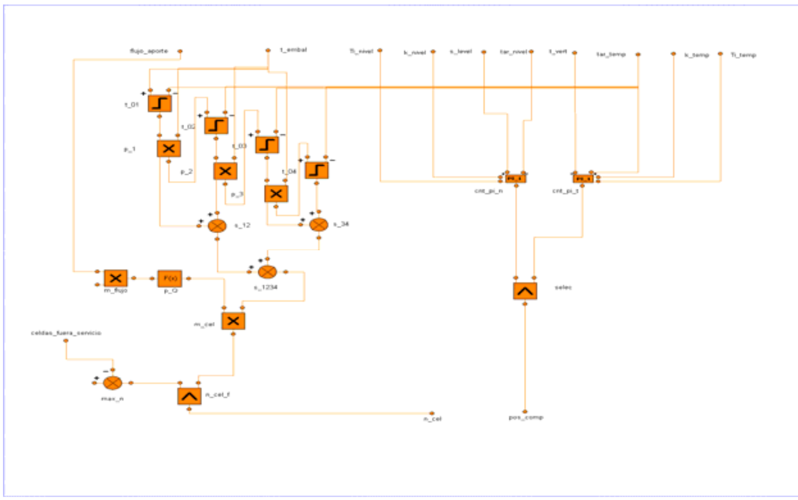
The new, mechanical draft, counterflow cooling tower comprises of a series of 20 cells, fed individually from the reservoir by water supply headers. It is simulated using the operating curves supplied by the manufacturer.

Discharge Damper Model

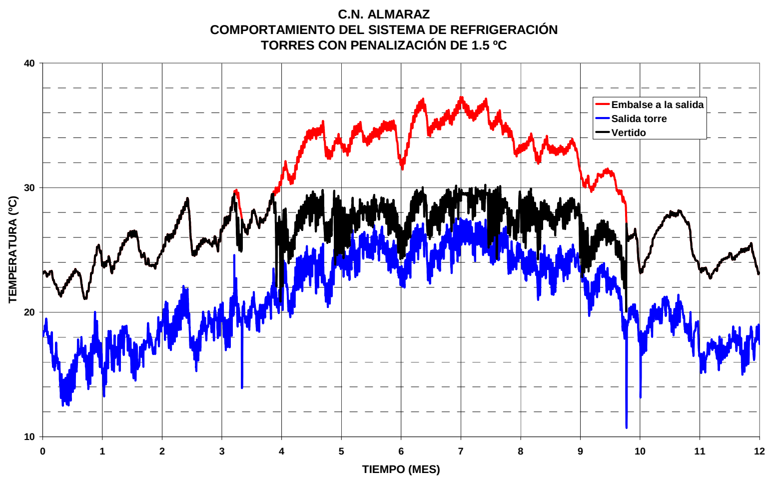
Based on:

Alfonso Ugarte's "FLAT DAMPER CALCULATION" (Hydraulics Course, Autumn 2004, University of Chile), assuming a quasi-stationary hydraulic behaviour, although the damper position is a dynamic variable.

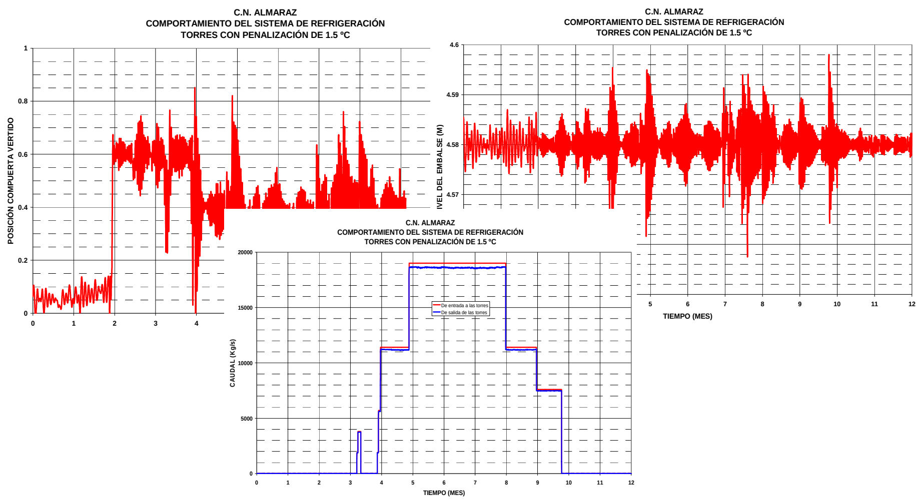
Control Model



Some results (I)



Some results (II)

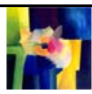


Conclusions

- We have a very fine-tuned, precise calculation model of the new cooling support system to be installed in Almaraz NPP, which reflects the behaviour of the complete system in adequate detail. With it, we can obtain sufficient operating parameters and criteria to attain the objectives cited at the beginning

- Changing the setpoint parameters –even the functions and configuration- of each of the composite elements is a task that can be carried out quickly and easily

Conclusions



➢ Its adaptation to models of varying complication from the thermohydraulics point of view is facilitated by some of EcosimPro's basic advantages:

- The possibility to encapsulate models
- Models are easy to re-use
- Its acausal methodology enables us to use the same components for different studies
- We can create physical models because each component corresponds to a real system component and each connection to a real system connection

ALMARAZ NPP STEAM GENERATOR LEVEL CONTROL STUDY

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Objectives

1. **For immediate application: Evaluate the effect that the new feedwater control system has on the SG makeup water following a main line break**

2. **For subsequent applications: Avail of a feedwater system calculation model which contemplates the new control system in minute detail, which is easy to modify, and which enables us to perform reliable behavioural analyses of the logic-hydraulic assembly in situations or manoeuvres of interest in reasonable times**

Additional Tasks

Validation of EcosimPro:

It has been necessary to validate the PIPELIQTRAN library used to develop concrete models for Almaraz NPP:

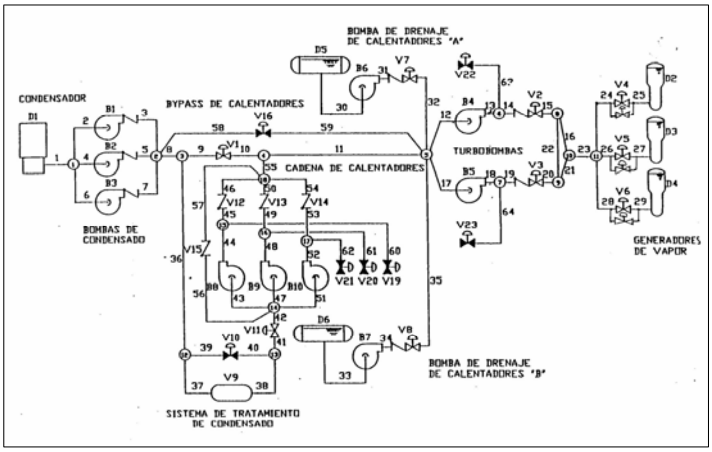
> **A double validation has been performed through the study of individual components (*separated effect problems*) and complex components (*integral test problems*)**

Models

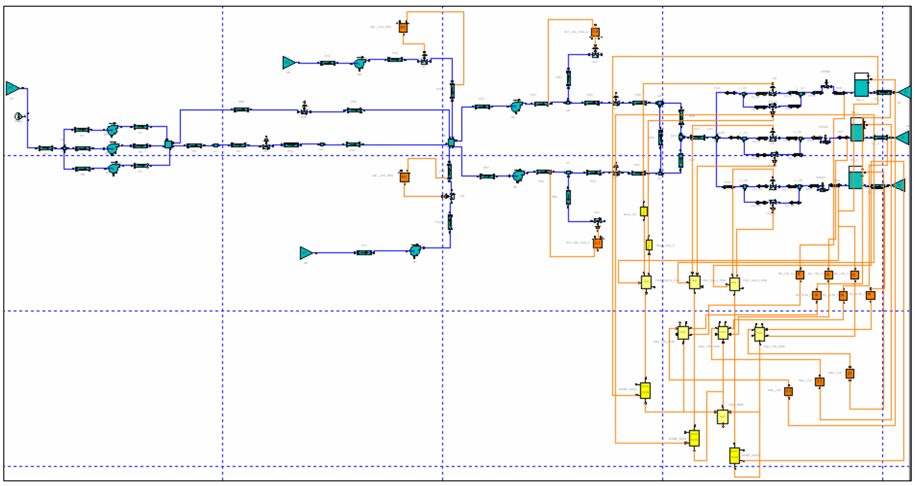
1. **Hydraulic**
2. **Control**

Hydraulic Model

Original THICOM Model:

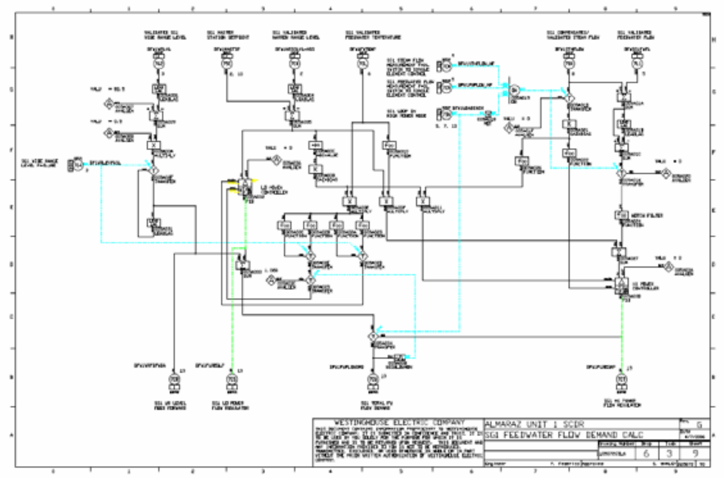


EcosimPro Model



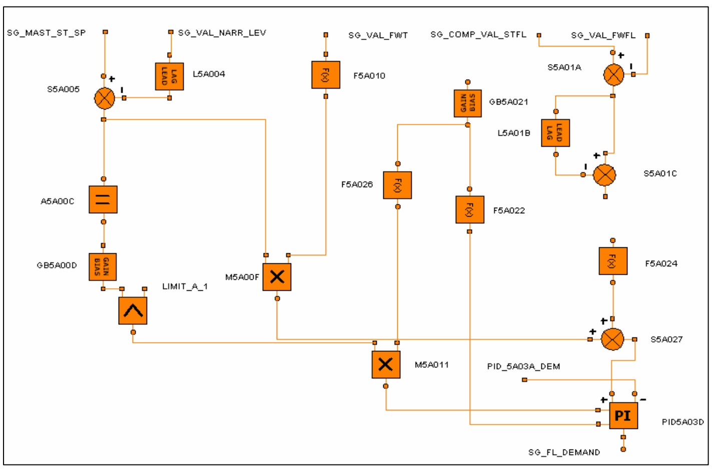
Control Components (I)

Westinghouse Diagram



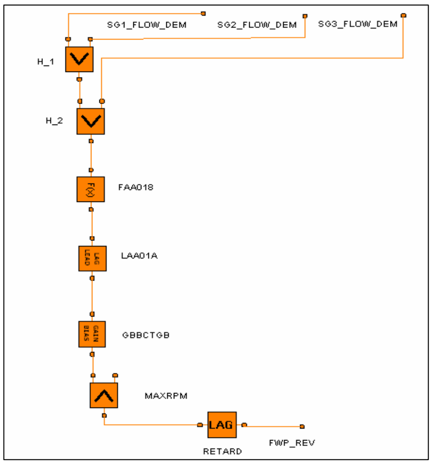
Control Components (I)

SG_FW_DEM



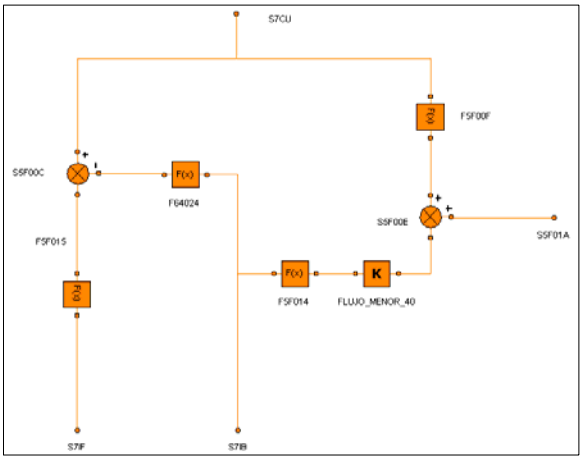
Control Components (II)

FW_RPM



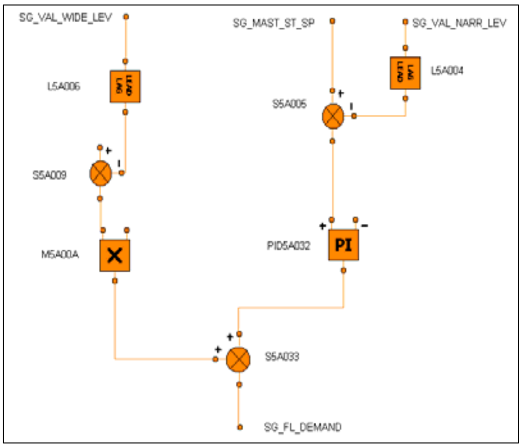
Control Components (III)

FW_VALV_POS



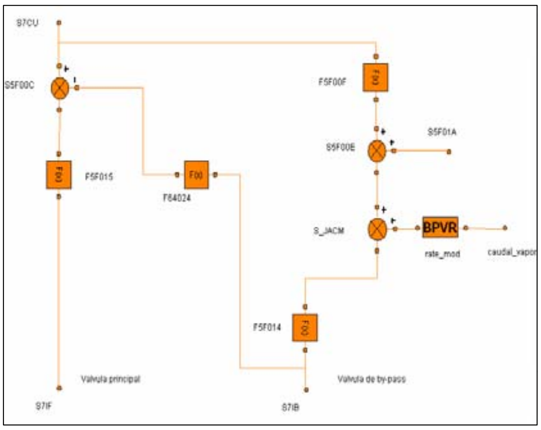
Control Components (IV)

SG_FW_DEM_LO

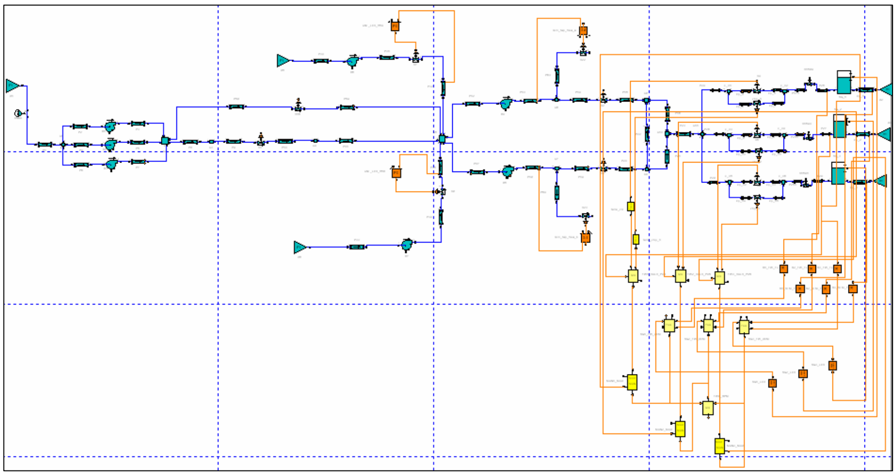


Control Components (V)

FW_VALV_POS_JACM

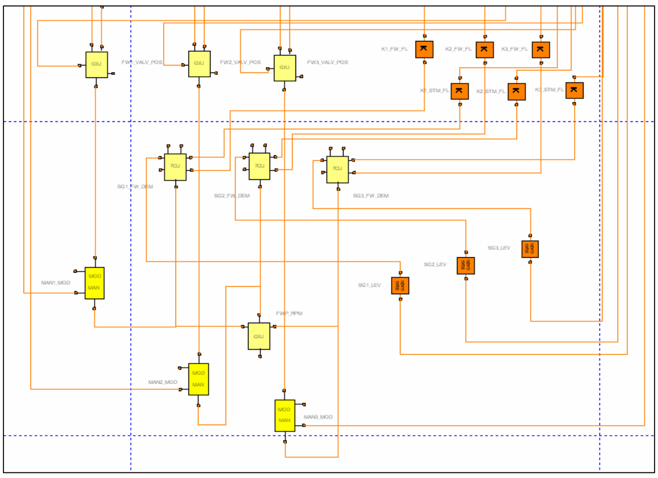


EcosimPro Model



EcosimPro Model

Control Detail



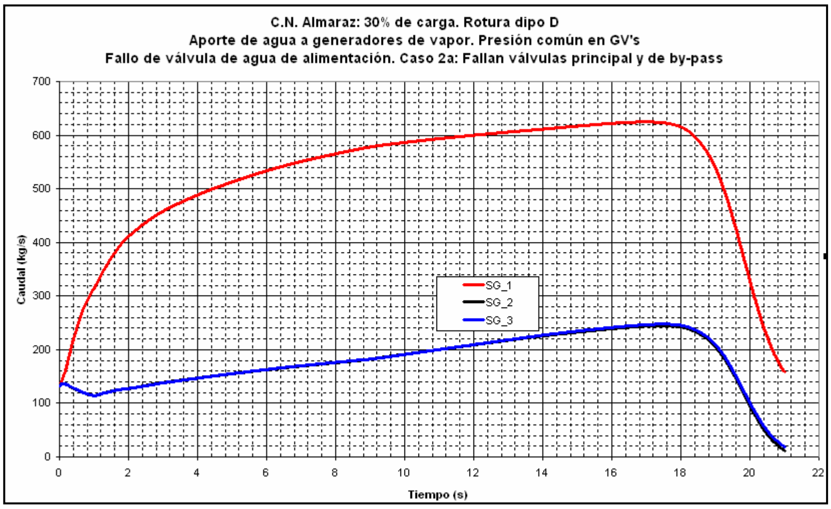
Configuration of Experiments and Method followed for the Analysis

- The general normal operating parameters (condensate pump suction pressure, heater drain temperatures and flows, steam generator pressure and main steam demand) are imposed as boundary conditions on an initial model in which all controls and equipment work correctly, in order to obtain a steady state continuous operation situation. The result of this analysis is saved in a file which will be used in the next step as a “restart” file.
- Depending on the load, the corresponding model is modified to “disconnect” the control that acts on the equipment whose failure we wish to study, imposing its operating mode on the “experiment” file.
- The signals that generate the main steam flow readings are “disconnected”; information is given manually to the elements that need it assuming that the flow gauges –in a broken state due to great pressure difference– must give a maximum steam flow signal which is false.
- The corresponding case is run using the aforementioned “restart” file as the initial conditions, imposing Westinghouse’s mass discharge values due to the break as a function of time and the rest of the established hypotheses.

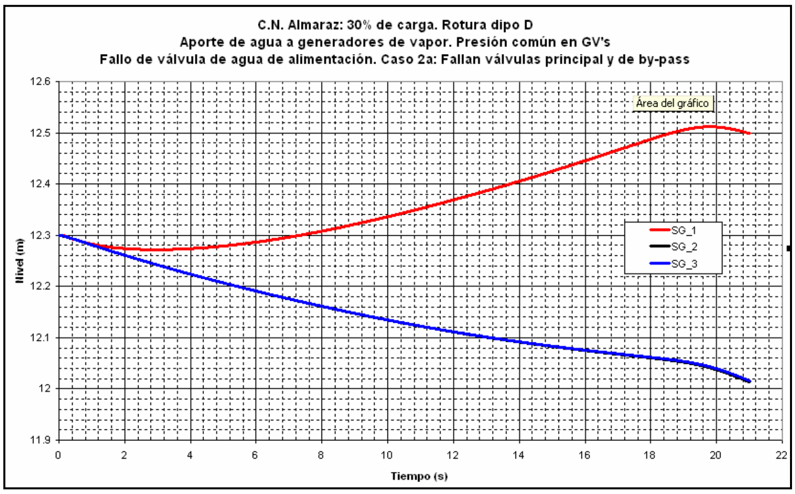
Some Analysed Cases

- Failure of one turbine pump at 0% and 30% power
- Failure of two turbine pumps at 30% power
- Bypass valve failure (initiated with the accident) at 0% and 30% power
- Bypass valve failure (prior to the accident) at 0% and 30% power
- Main valve failure (initiated with the accident) at 0% and 30% power
- Main valve failure (prior to the accident) at 0% and 30% power
- Main and bypass valve failure (initiated with the accident) at 0% and 30% power
- Main and bypass valve failure (prior to the accident) at 0% and 30% power

Results (I)



Results (II)



Conclusions

- We have EcosimPro libraries which have been validated
- We have a calculation model of the new control system installed in Almaraz NPP which is fine-tuned and reflects system behaviour in minute detail
- Changing the setpoint parameters –functions- of each of the constituent elements or their configuration is a task which can be carried out quickly and easily
- Adaptation to models of varying complexity from the thermohydraulics point of view is facilitated by some of EcosimPro's basic features: encapsulation and ease of reusing models
- Thanks to this, we have succeeded in building an operating model in record time
- It constitutes a great example of the importance it has so that end users have a detailed model –independent of the suppliers- with which they can perform a detailed analyses of the effect that different control strategies or different physical configurations have on key transients

Montoir de Bretagne CCGT 435 MW

Calculation of the Hydraulic Transients of the Circulating Water System

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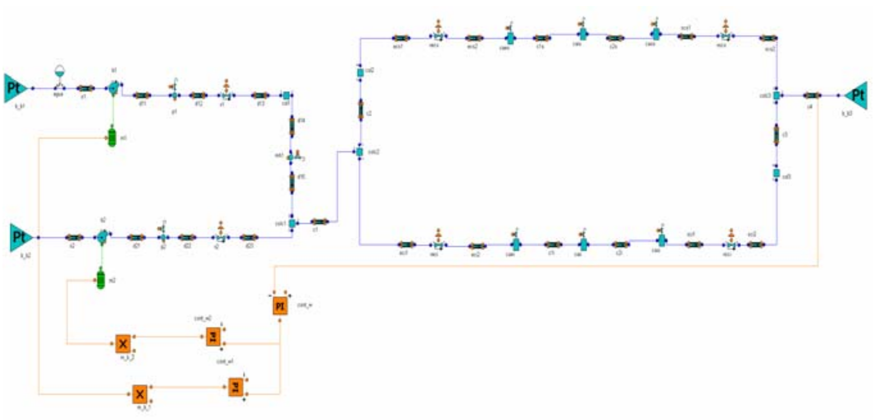
Purpose of the calculation:

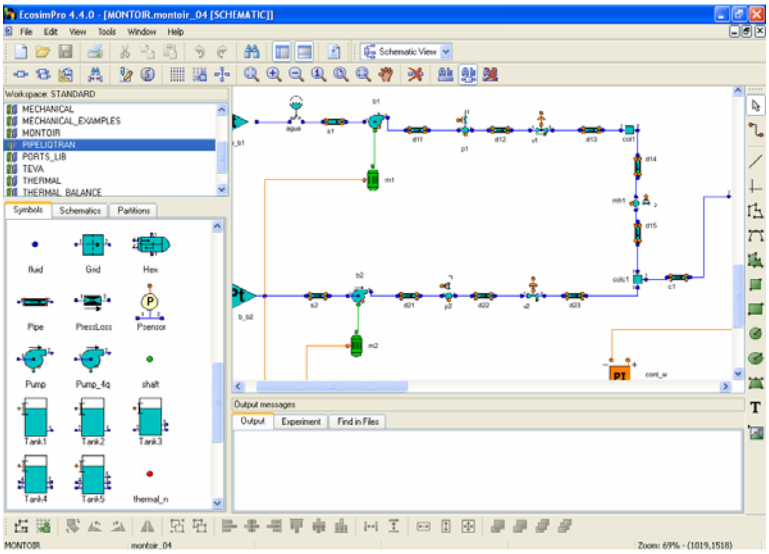
Analysis of the system transients on order to verify:

- The design pressure limits of same
- The actuation times of the circulating water pump isolation valves.
- Propose the layout of the system protection elements.

Model



EcosimPro graphic tool



Features of the model

- Large difference in the pump water suction level, depending on the tides (8 m approximately)
- Use of variable speed drives to vary the frequency of the pumps.
- Variable speed drives modelled by PID controllers on the motors.
- Two experiments per transient, depending on the two levels of suction.

Selection of the operation mode.

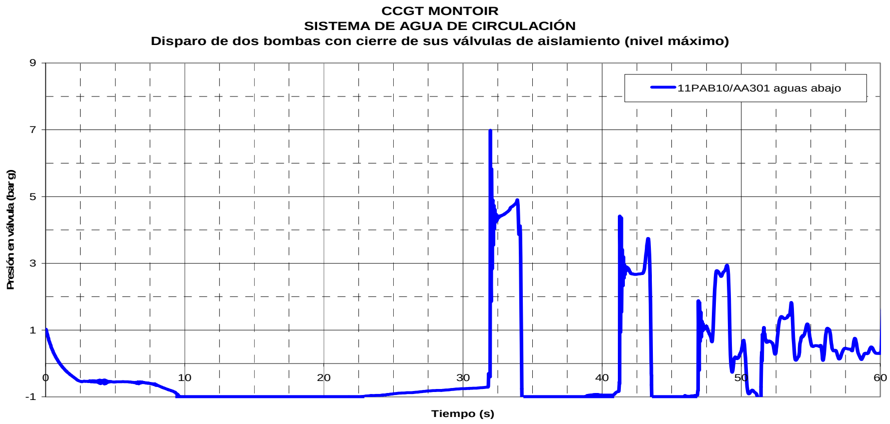
- Several preliminary analyses are carried out, corresponding to two operating modes:
  - Without allowing air to enter the system
  - Opening all the air inlets to the system
    - Purpose: to establish the most favourable operation mode, with regard to pressures

Transients analyzed

- Trip of two pumps with simultaneous closure of their isolation valves
- Trip of one pump and simultaneous closure of its isolation valve
- Trip of one pump while its isolation valve remains open
  - From this preliminary analysis, the following results were obtained:

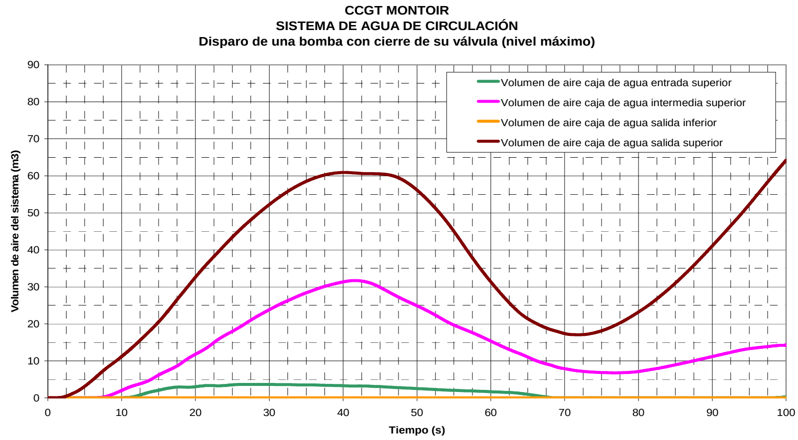
Preliminary experiments (I)

If air is not allowed to enter the system, the design pressures are exceeded



Preliminary experiments (II)

Using all the systenm air inlets, it is evident that the system is incapable of evacuating the air when only one pump is in operation



Conclusions reached from the preliminary experiments

- **The transients are carried out by allowing the opening of a vacuum breaker which must be located in the first collector.**
- **All the remaining air inlets and outlets without possibility of opening.**
- **Each transient will be studied for each level of suction depending on the tides.**

Some transients and goals of the syudy (I)

- **Trip of one pump and simultaneous closure of the isolation valve**
  - **In this case the following will be analyzed:**
  - **If the closure time of the isolation valve is appropriate for the pump for the tripped pump to be protected and the pressures do not exceed the limits.**

Some transients and goals of the syudy (II)

- **Trip of one pump while its isolation valve remains open**
  - **On this case, the following will be analyzed:**
    - **Behaviour of the tripped pump and the inverse rotation speed values reached, with no rachet.**
    - **The possibility of keeping the plant in operation if this happens shall be assessed.**

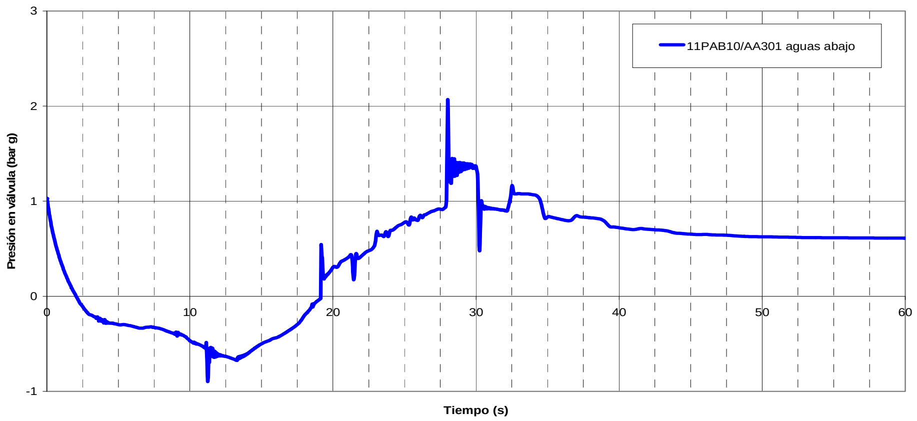
Most significant results

- **Case I: Trip of one pump and simultaneous closure of its isolation valve**

Most significant results: Case I

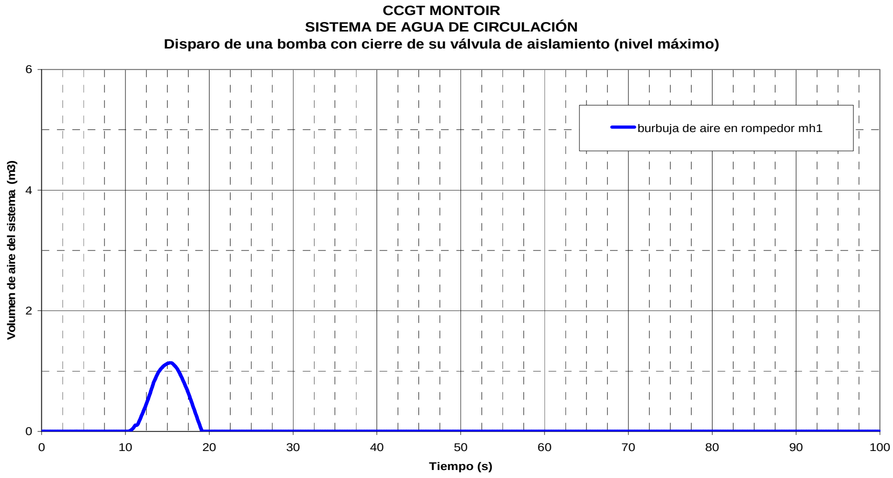
Maximum level

CCGT MONTOIR
SISTEMA DE AGUA DE CIRCULACIÓN
Disparo de una bomba con cierre de su válvula de aislamiento (nivel máximo)



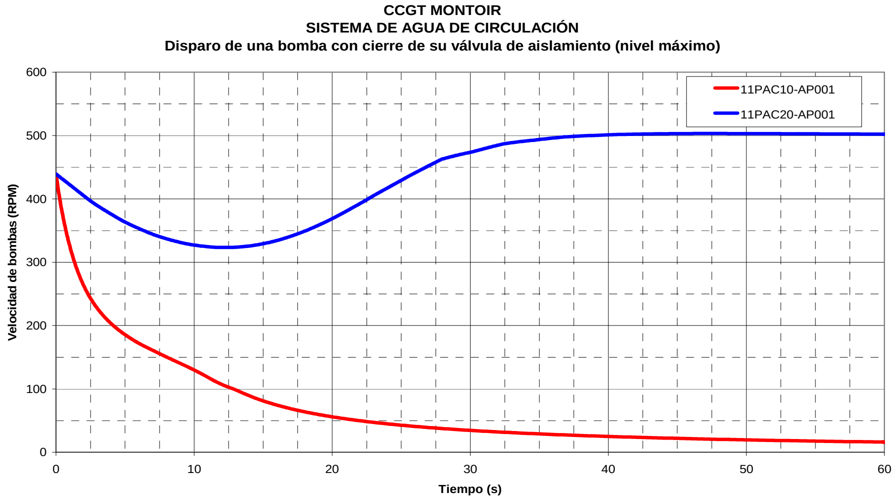
Most significant results: Case I

Maximum level



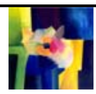
Most significant results: Case I

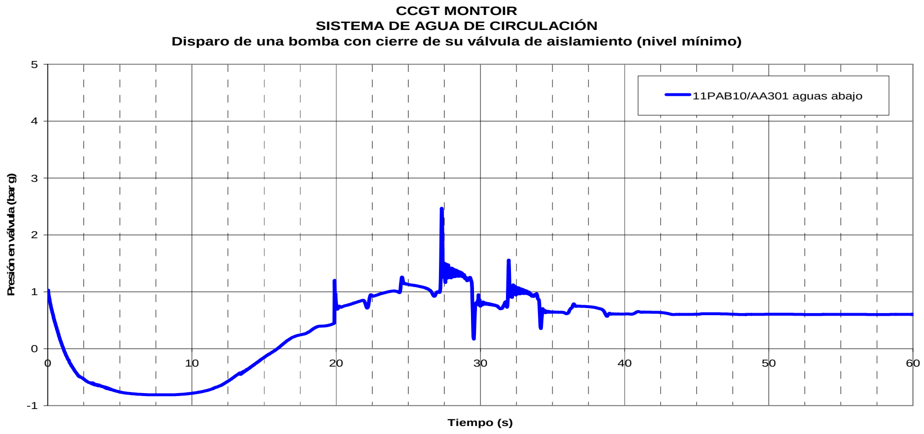
Maximum level



Most significant results: Case I

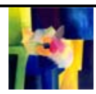
Minimum level

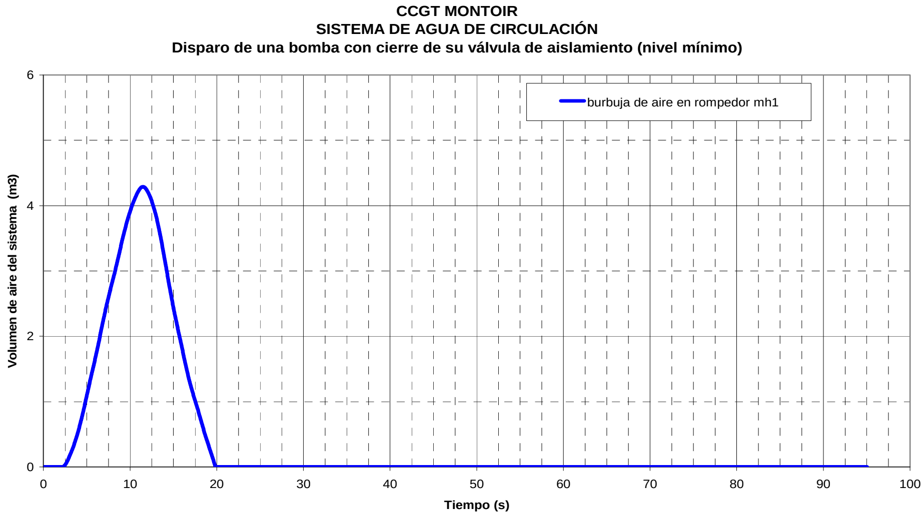




Most significant results: Case I

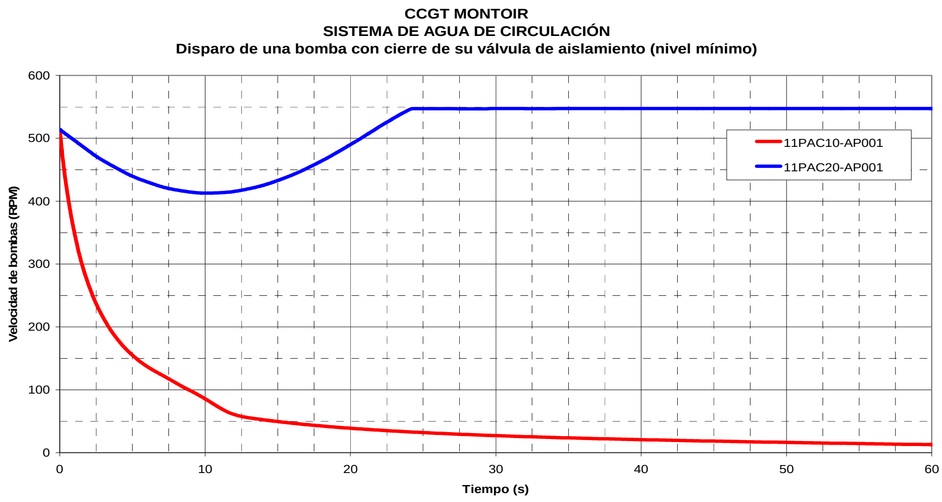
Minimum level





Most significant results: Case I

Minimum level



Trip of one pump with simultaneous valve closure. Conclusion:

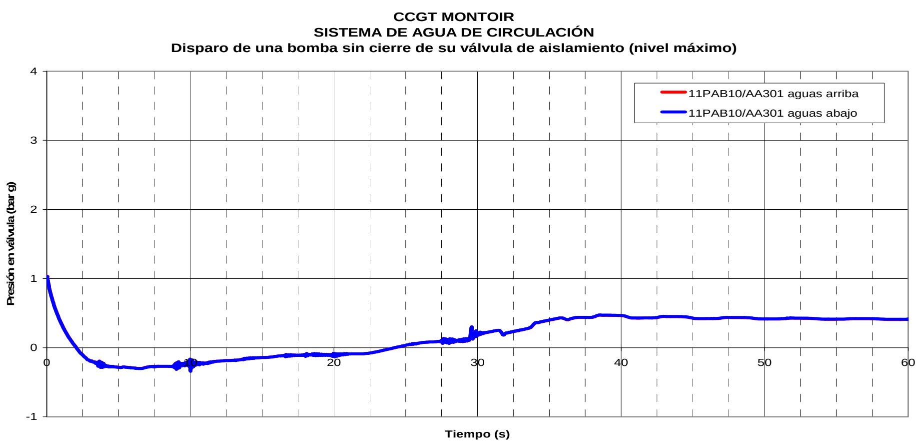
- During this event, the main complication appears while adjusting the variable speed drive control.
- Due to the very configuration of the system and the disposition of the flowmeter, there is time variation between the real flow marked by the flowmeter and the location of the pump trip, and in turn of the operating pump response during the incident.
- Regarding the pump rotating speed, please note that no countermeasure is necessary, since there are no negative rotations that could damage the tripped pump.

Most significant results

- **Case II: Trip of one pump without closure of its isolation valve.**

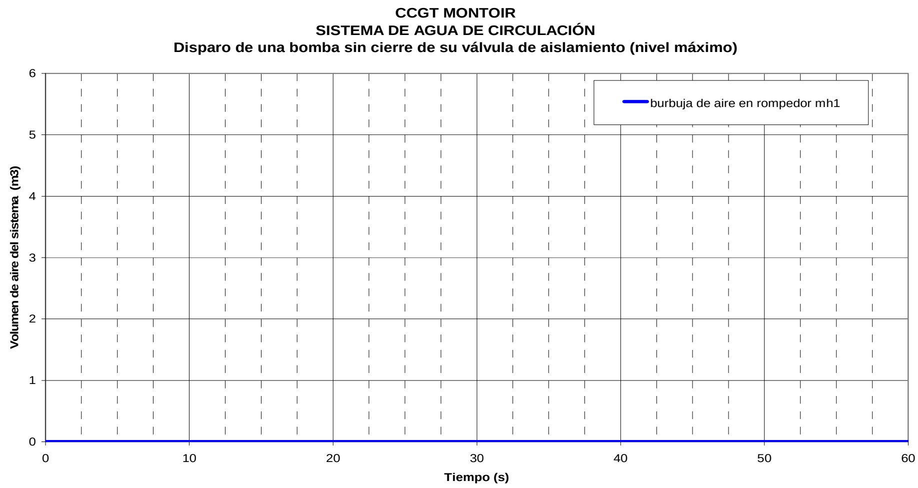
Most significant results: Case I

Maximum level



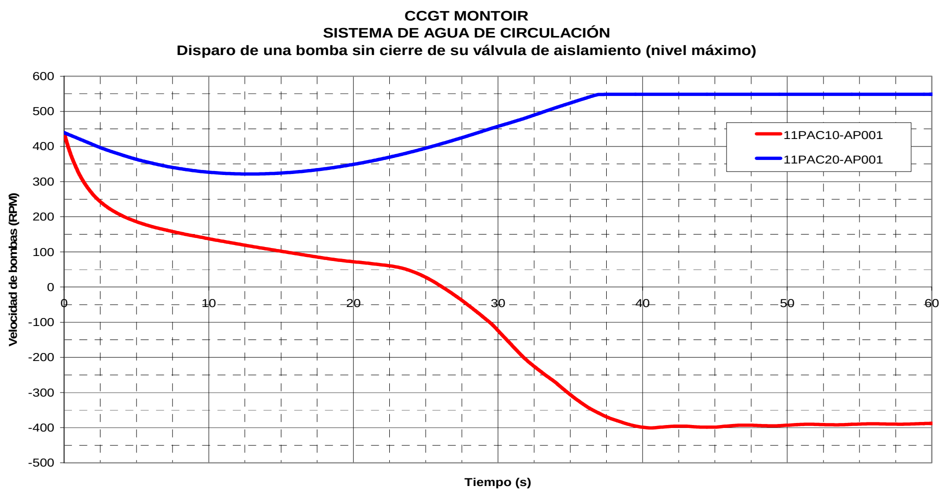
Most significant results: Case II

Maximum level



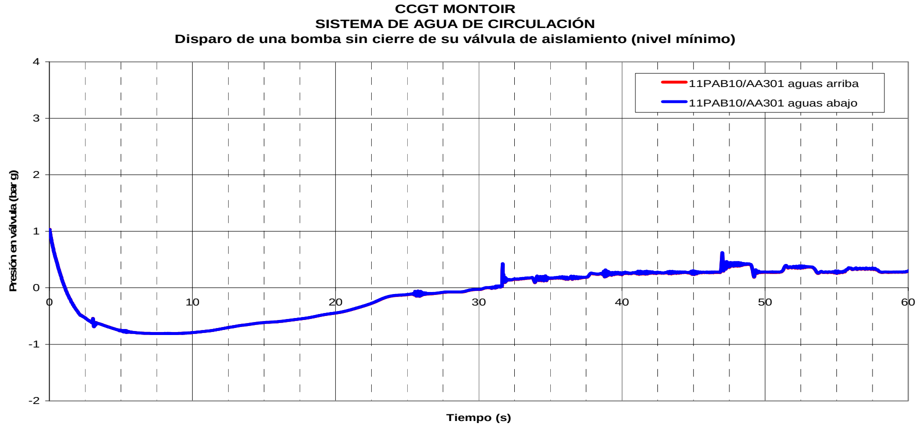
Most significant results: Case II

Maximum level



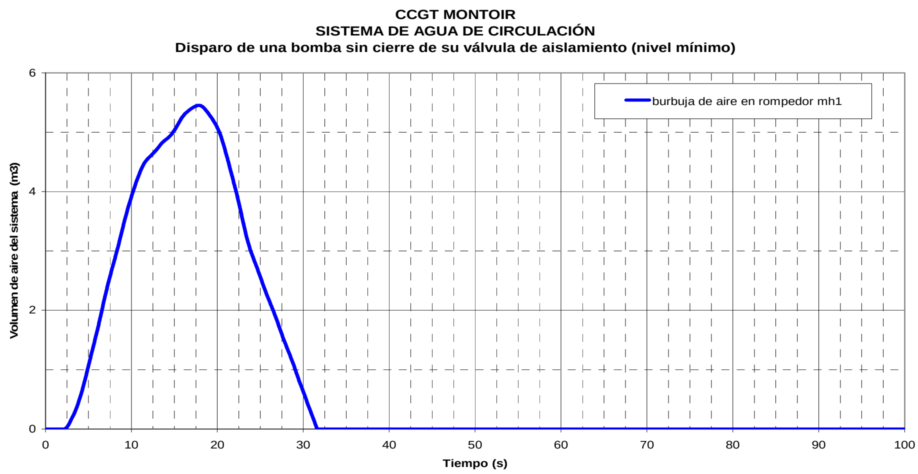
Most significant results: Case II

Minimum level



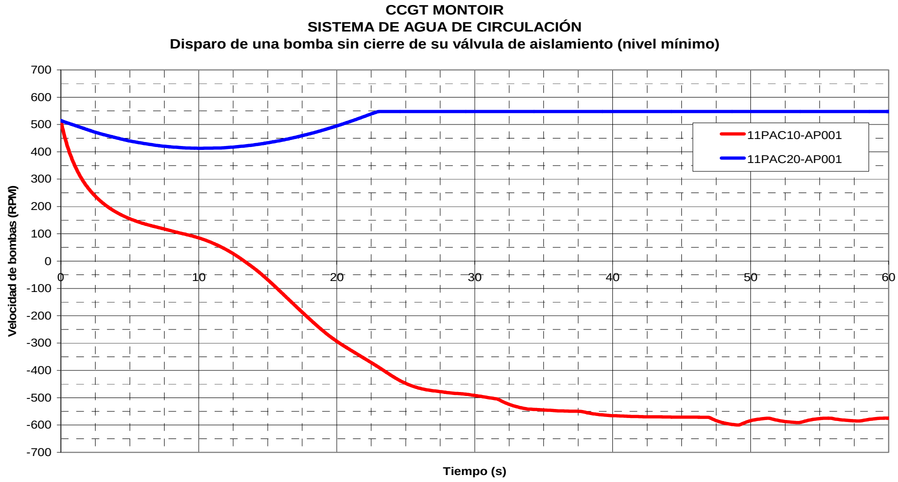
Most significant results: Case II

Minimum level



Most significant results: Case II

Minimum level



Trip of one pump without valve closure. Conclusion:

- After preparing this model, the risk of having pumps without ratchets that can rotate freely in the other direction is verified.
- For maximum level, the pump that trips reaches a maximum negative rotation speed of 400 rpm, (73% of the rated rotations).
- For minimum level, the pump that trips reaches a maximum negative rotation speed of -600 rpm, (110% of the rated rotations).

Final Conclusions:

- One vacuum breaker will be installed in manhole mh1. Its effective diameter will be 2" with a setflow pressure of 1.01325 bar (absolute pressure).
- It is necessary to establish the flow control parameters in order to give the required response to risky situations that could occur during operation.
- In no case will the pumps be greater than 150% of the rated regime of rotation in the transients studied in which they rotate in inversely.

Transients in the Combined Cycle Natural Gas Supply System

Empresarios Agrupados Internacional (EAI)

Alfonso Junquera
26th November 2009

Telephone: 34 – 91 448 85 98
http: www.ecosimpro.com

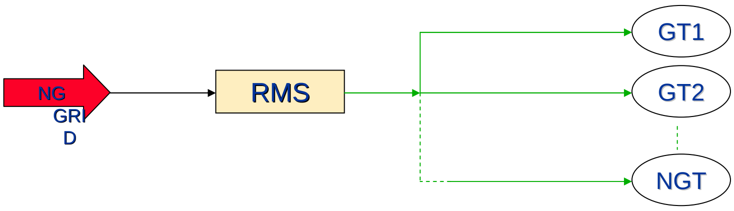
Setting out the problem (I)

PURPOSE OF THE STUDY:

- To study the transient behaviour of the pressure in the natural gas supply grid after a turbine trip or load rejection
- To verify compliance with the requirements indicated by the supplier of the gas turbine with regard to the pressure variations at the terminal point of supply
  1. Ramp criterion
  2. Step criterion
- To verify compliance with any additional requirements from the Owner For example, no trip of a safety interrupt valve after the shutdown of the gas turbine.

Setting out the problem (II)

GENERAL ISSUES in power plants that have **more than one gas turbine in parallel**

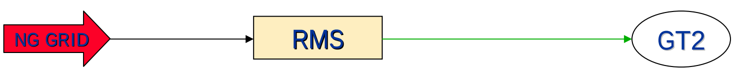


Trip of a GT:

- **Start of pressure transient in the system due to sudden reduction in gas flow in one of the lines**
- **The system (regulation valves + piping volume) is not capable of handling the transient, and another turbine could trip.**

Setting out the problem (III)

GENERAL ISSUES in power plants that have one **gas turbine**



GT trip:

- **If the system volume is not sufficient, over-pressure could result causing the RMS to trip**

Load rejection:

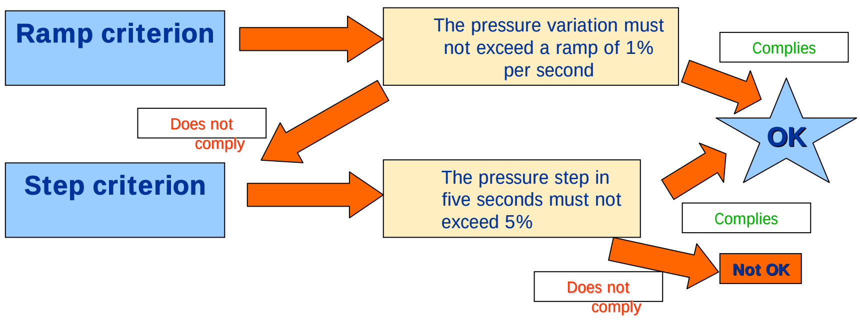
- **The sudden reduction of gas flow at the turbine inlet (from 100% to 25%) could cause a pressure transient, causing the turbine to trip.**

Setting out the problem (IV)

SUPPLIER'S CRITERIA

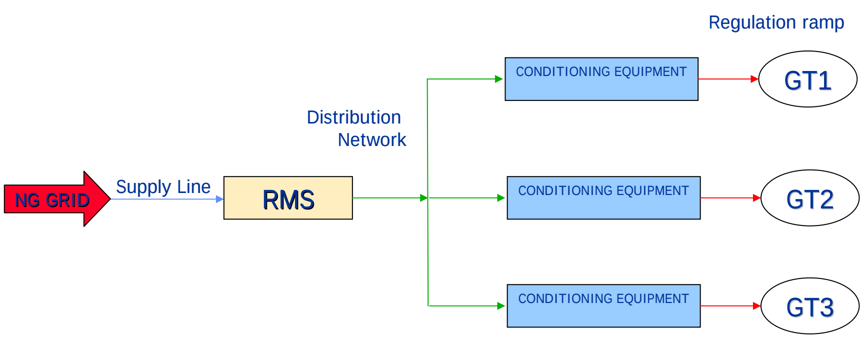
At all **times** the **gas pressure at the turbine** inlet **between maximum and minimum allowed**

During **transients**:



Regulating and Metering Station

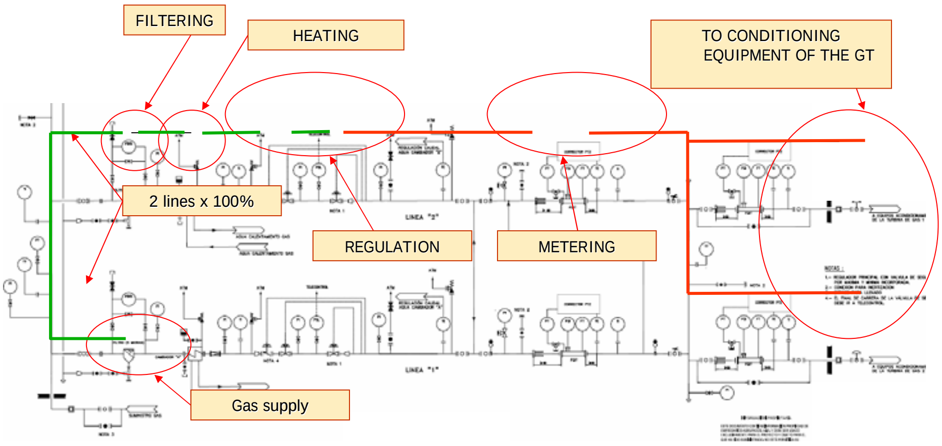
NATURAL GAS CONDITIONING EQUIPMENT (I)



NATURAL GAS SYSTEM

Regulating and Metering Station

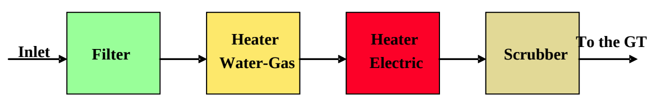
NATURAL GAS CONDITIONING EQUIPMENT (II)



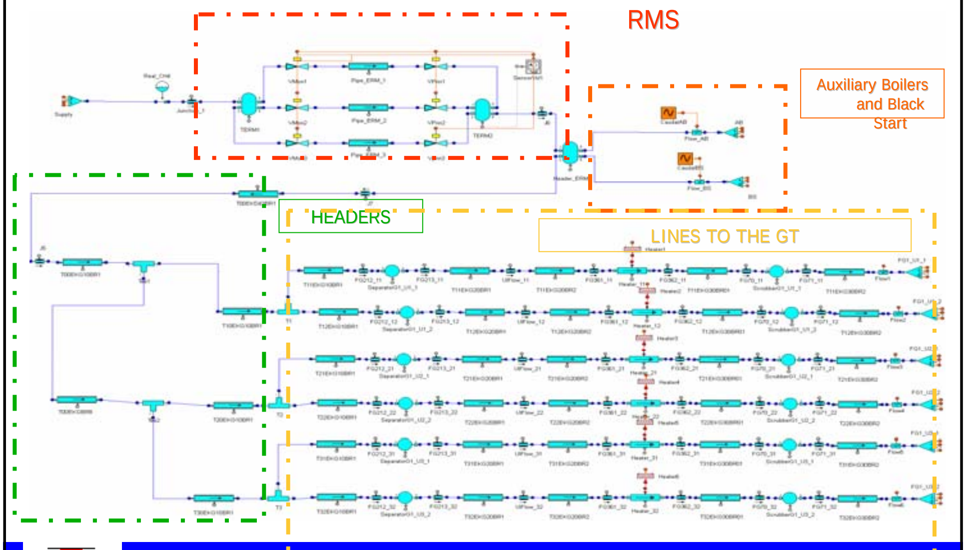
Regulating and Metering Station

NATURAL GAS CONDITIONING EQUIPMENT (III)

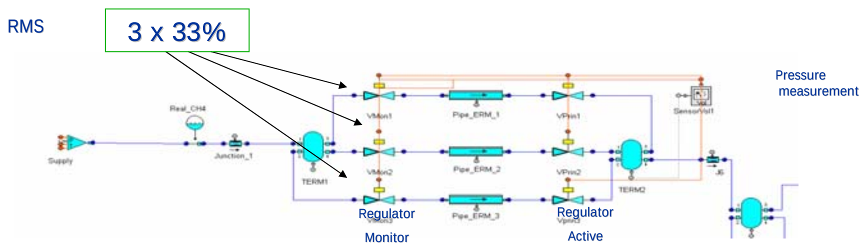
- **Gas filtering and heating before it enters the turbine**
- **Generally there are several modules:**
  - **Filter to eliminate liquids**
  - **Scrubber to filter out particles**
  - **Water-gas heater and electric heater**



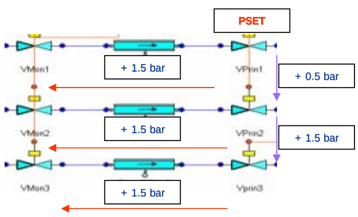
System model in EcosimPro (I)



System model in EcosimPro (II)

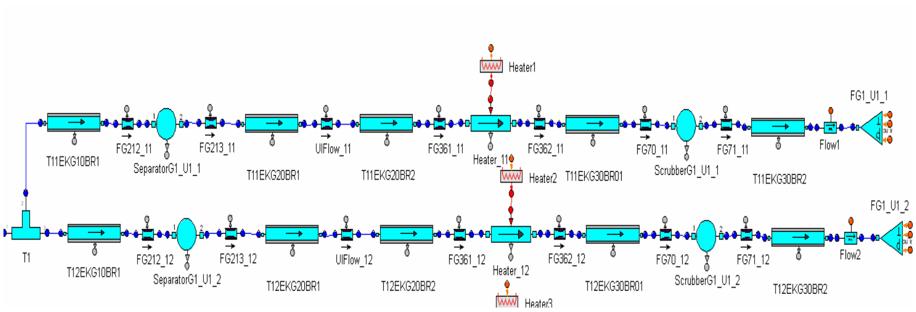


The pressure setting of the regulators is different on sequential opening



System model in EcosimPro (III)

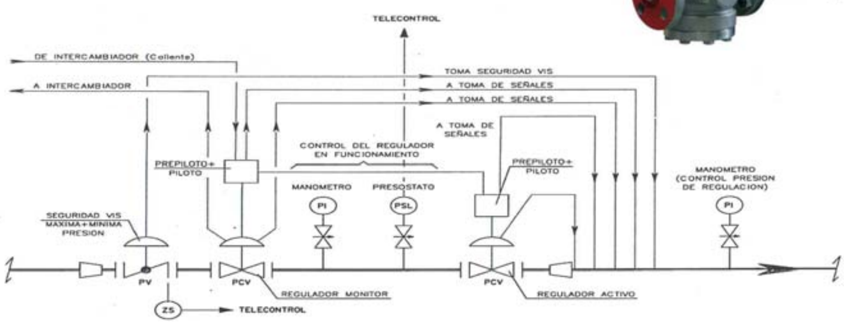
CONDITIONING EQUIPMENT AND GAS TURBINE



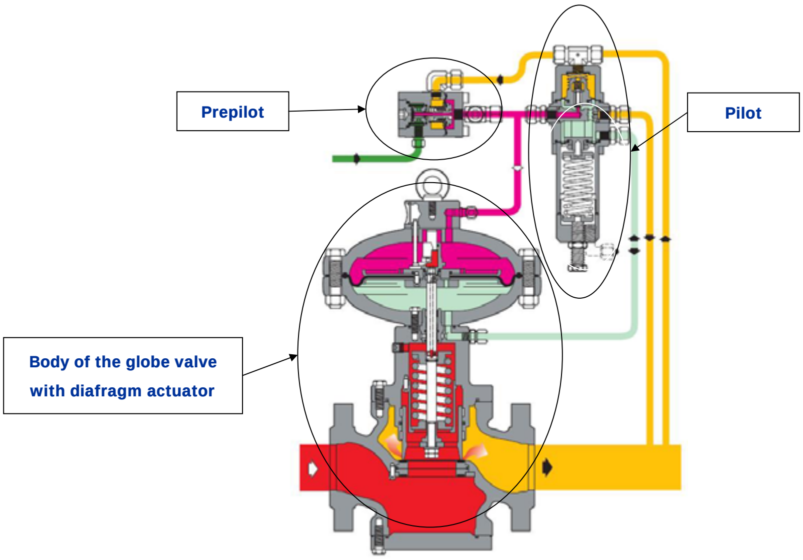
Pressure Regulating Valve (I)

The pressure regulation system comprises two regulators:

- Active regulator: Normally regulates
- Monitoring regulator Actuates in the event of failure of the active regulator

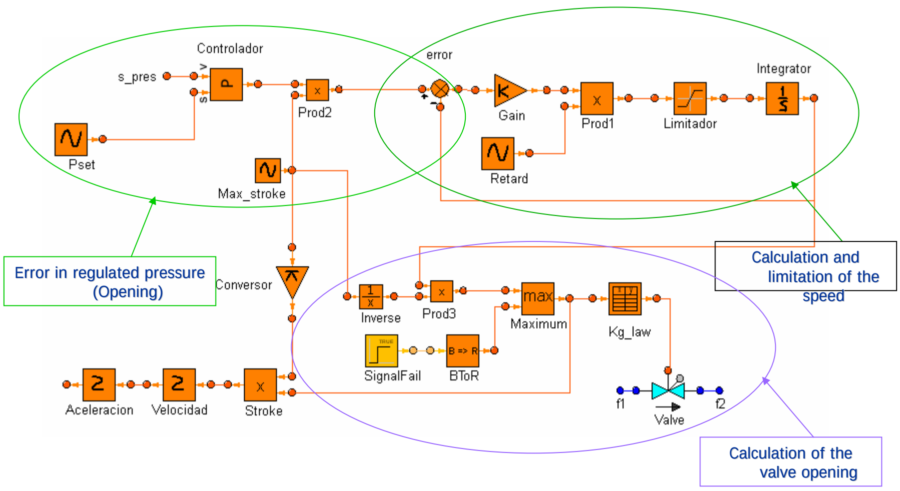


Pressure Regulating Valve (II)



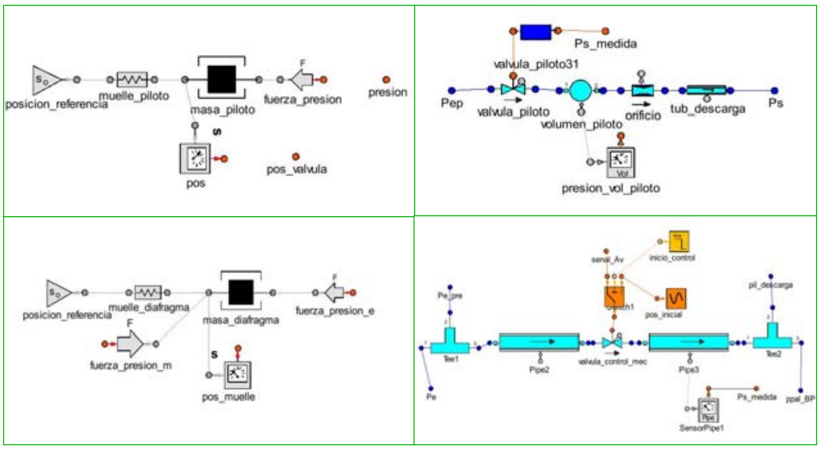
EcosimPro model of the Pressure regulating Valve (I)

SIMPLIFIED MODEL (CONTROL BLOCKS)



EcosimPro model of the Pressure regulating Valve (II)

FLUID-MECHANICAL MODEL



Simulation in EcosimPro

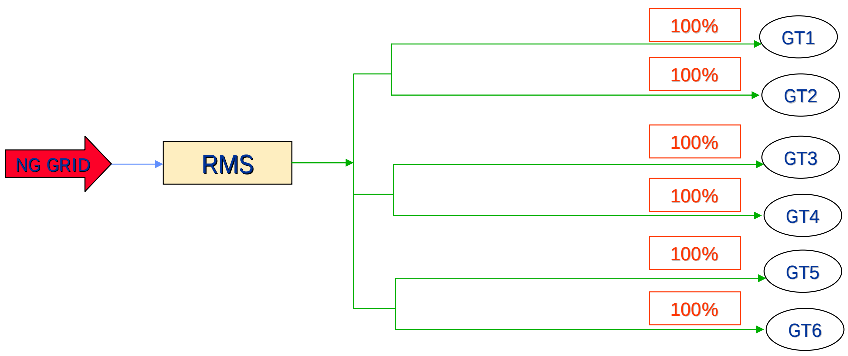
TRIP OF A GAS TURBINE (I)

Initial condition:

All 6 turbines are in operation at 100% load.

Start of the transient

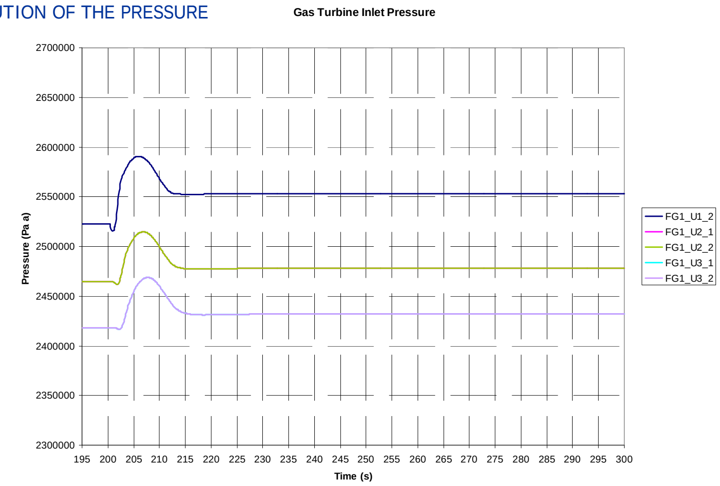
At instant t=200 s, one of the gas turbines trips, reducing the gas flow entering the turbine from 100% to 0% in 1 second.



Simulation in EcosimPro

TRIP OF A GAS TURBINE (II)

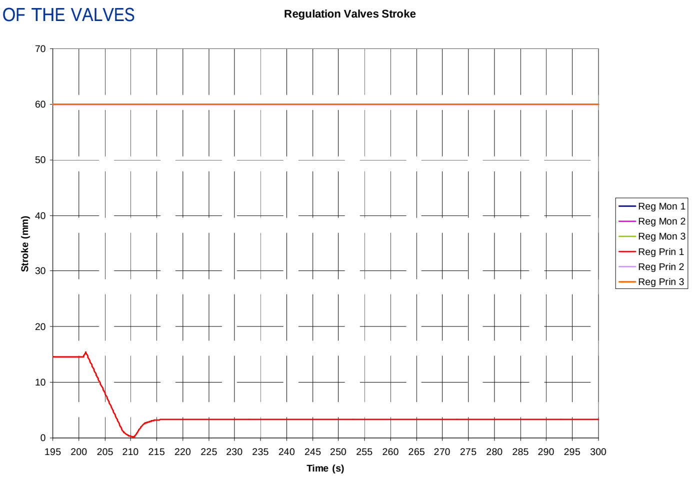
EVOLUTION OF THE PRESSURE



Simulation in EcosimPro

TRIP OF A GAS TURBINE (III)

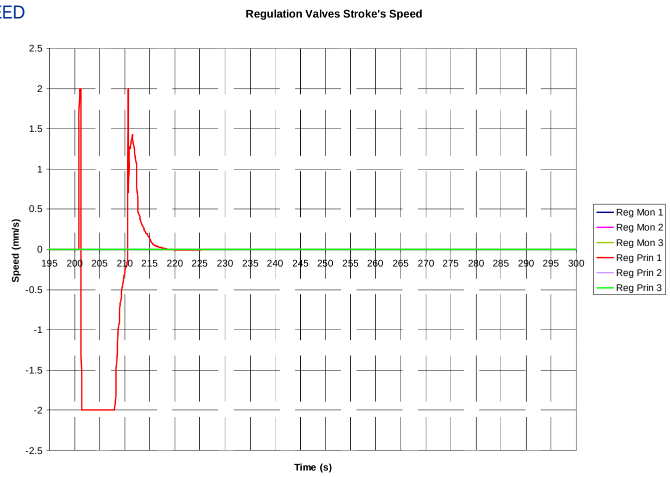
OPENING OF THE VALVES



Simulation in EcosimPro

TRIP OF A GAS TURBINE (IV)

VALVE SPEED



Conclusions

- **FOR THE DESIGN**
  1. **The results of the transients with EcosimPro allow validation of the specified valves in order to comply both with the requirements of the gas turbine supplier and of the owner.**
  2. **To study the alternatives to reduce the maximum pressure during the transient:**
     - **Additional volume required so as to comply with the requirements**
     - **Devices to accelerate the regulation valves**
  3. **In the event of not complying with the requirements of the turbine supplier the design of the RMS can be modified to incorporate control valves instead of self-regulating valves**

- **FOR OPERATION**
  1. **Using the model it is easy to adjust the set-points of the valves so as to assure their behaviour during transient and static situation.**

1st WORKSHOP ON ENERGY SIMULATION APPLICATIONS USING EcosimPro

Designing ITER Tritium Plants with EcosimPro

Laboratorio Nacional Fusión

TECNO fus

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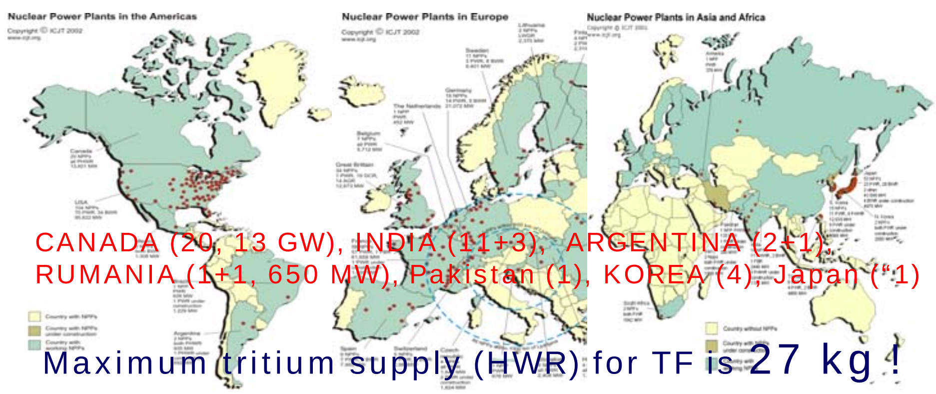
1. Need for a **TRITIUM CYCLE IN FUSION TECHNOLOGY**

Supply/demand analysis

- A fusion reactor D(T,α)n [17.62 MeV/at-T] consumes tritium at rates of **55.8 kg/GW$_t$-a of fusion energy**
- **Production in a** CANDU Is **1-2 Kg/GW$_t$**-year with specific α designed Li-Al targets
- Most optimistic APT extrapolations **~12 kg/GW$_t$-a** (spallation targets or Li/Al targets suitably designed)
- Tritium decays at rates of **4.57% per year**



CANADA (20, 13 GW), INDIA (11+3), ARGENTINA (2+1)
RUMANIA (1+1, 650 MW), Pakistan (1), KOREA (4), Japan (*1)

Maximum tritium supply (HWR) for TF is 27 kg !

Market Scenario (civil) for Tritium

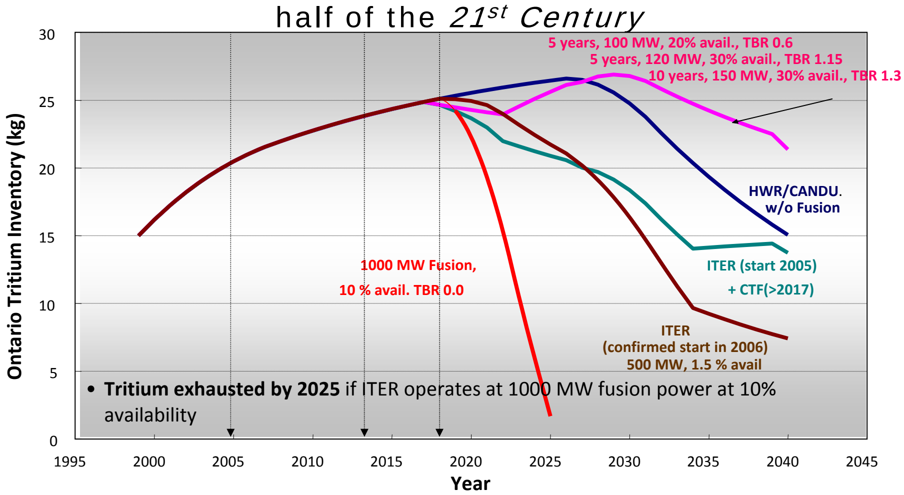
WHAT HAPPENED

- Tritium inventory in 1999: **15 kg**
- Recovery rates in **1999: 2.1 kg/a**, decreases to **1.7 kg/a in 2005**, inst till 2025
- In 2025, the reactors reach the end of their lifetime and tritium production rates fall
- Ontario Power Generation (OPG) have 13 of their 20 CANDU reactors operating
- Reactors with operating licence **x 40 years**
- OPG sell 0.1 kg/a to users external to ITER/VNS (price € 70-120 million per kg)
- Tritium decays at 4.57 % / year

WHAT IS NOT HAPPENING:

- Scenarios of D-D/TBR startup with tritium production
- CANDU lifetime extension to 60 years
- Restart of CANDU reactors
- Construction of new CANDU
- Tritium from military programmes entering the civil market
- Irradiation of Li targets in commercial reactors (including CANDU)
- Early shutdown of CANDU reactors

Projections for Tritium Availability for TNF in the first half of the *21st Century*



- In TNF (exp. + Plants) we must generate our own Tritium!
- Tritium going to condition strategy to DEMO ! (init. 5-10 kg) [IFMIF included]

- EXPERIM. DEVICES (ITER): **OPERATING FLEXIBILITY/ROBUSTNESS**
- POWER PLANTS: **ROBUST TBR & CONTROL** TECHNOLOGIES

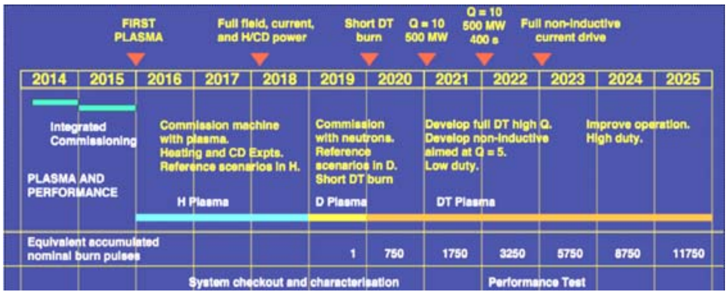
2. Operating PHASES and OPRATING MODES of ITER (1)

ITER Needs

"Technical Basis for the ITER FDR– part 6.2.5".

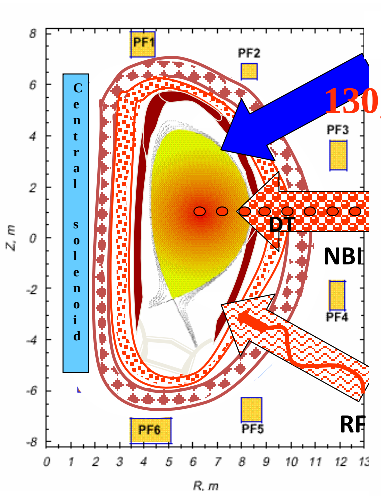
- Construction in 2005 and duration 8 years, + 4 yr op without tritium
- Operation 6 + (10?) years burning DT of tritium

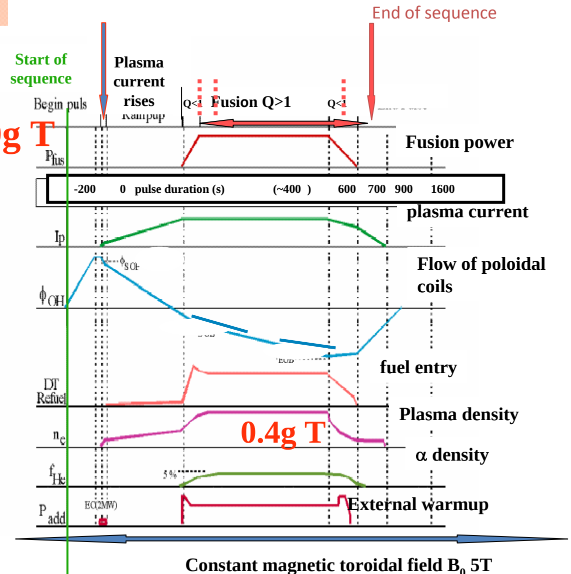
$$\frac{1\,\text{atom of T}}{17.59\,\text{MeV} \times 1.60 \times 10^{-19}} \times 500\,\text{MWth} \times 440\,\frac{\text{s}}{\text{pulse}} \times \frac{3\,\text{gr of T}}{6.022 \times 10^{23}\,\text{atoms of T}} = 0.389\,\text{gr T (per pulse)}$$



- There will be no additional unforeseen needs for SS
- No habrá regeneración (TBR = 0)
- **1.5 % real operating availability: 11751 pulses** **4.57 kg**
- 10 a of operation, 3000 pulses/yr (PP ~ 0.3 MWa m^{-2} < 3dpa): **11.67 kg**

2. Need for a TRITIUM PLANT (PdT) iN ITER (1)





0.4 g of T per discharge (0.3% of thel T circulating through the vacuum chamber)

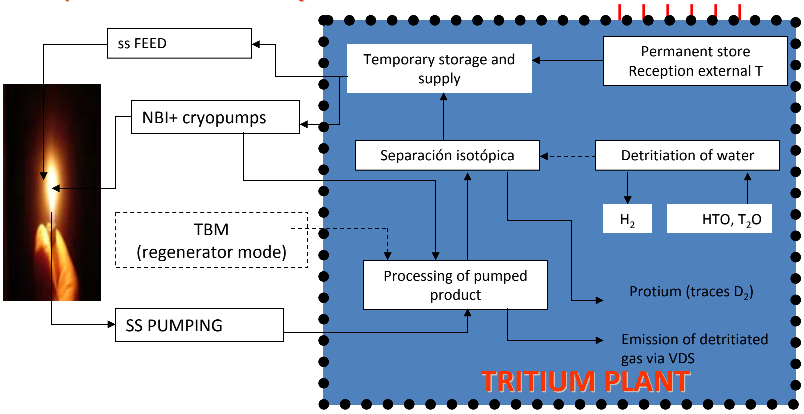
- **Short pulse** DT (450 s fusion, 1350 s dwell)
- **Long pulse** DT (3000 s fusion, 9000 s dwell)

a 200 Pa m^3 s^{-1} (50 depth + 150 peripheral: 100/DT + 44.5/ D_2 + 5.5/ T_2)

2. Need for a TRITIUM PLANT (PdT) IN ITER (1)

→ Low burn rate in ITER (**max 1 % burn per pulse at peak feed 200 Pa $m^3 s^{-1}$**) close to long confinement pulsed (short pulses **450 s**, long pulses **3000 s**)

Necesidad de procesado de enormes flujos de efluente tritiado



→ ITER: **also am experiment in the integrated operation of the PdT** (system availability operating reality): process demands: feed, pumping, detritiation

→ To date, only the JET (UK) and TFTR (USA) have handled tritium for fusion

→ **ITER DT operating scenarios (5th -10th yr) means processing ~1400 kg (!) of tritium a leap of 4 orders of magnitude !!!!**

3. Need for a TRITIUM PLANT (PdT) IN ITER (1)

FUNCTIONS OF THE PdT

- **process tritiated gaseous flows** to produce flows to refuel flows and established isotopic compositions

- confine tritium x **multiple barriers** :
  - → primary components
  - → boundaries
  - → secondary components ("Glove Boxes") and rooms

- **detritiation of residual flows**, aqueous/gaseous flows and purification of atmospheres in normal/incidental/accidental op prior to emission to atmosphere

PdT-ITER conception, design and operating bases are based on robust technology* developed and tested for more than 2 decades, with realistic and demonstrable capabilities to control the overall dynamic inventory of T

3. Need for a TRITIUM PLANT (PdT) IN ITER (1)

MAIN PdT DESIGN CRITERIA

→ **OPERATING SAFETY** in terms of **containment/control of tritium**

- Tritium: radioisotope which converts "everything it touches" into radioactive material
- Containment barriers and techniques
- Counting techniques (dynamic tracking) and control strategies in operation

The French Nuclear Safety Authority:

→ **obligated dynamic control of T (> 2g)**
→ **foresee inputs/outputs from the facility**
→ **obligation to detect and inform about balance control anomalies**
→ **need to know tritium in one ss in accident event**

→ **MINIMISE tritium inventories(*) in units and systems**

- Inventory limits (administrative for licensing)
- For different types of tritium inventories: **trapped/movable**, **inside/outside** the CV

→ **< 1000 gr in PFC, : < 330 movable tritium**
→ **< 120 gr in cryopumps foresee inputs/outputs from the facility**
→ **< 700 gr circulating in cycle: < 100 gr in each subsystem**
→ **250 gr T in hot cells and storage areas**
→ **0.7 through cooling loop**

→ **HIGH DETRITIATION** of effluents **MINIMUM ACCIDENTAL AND CHRONIC emissions**

- Economic handling of tritium (recovery **ABSOLUTELY NECESSARY**)
- Environmental impact of ITER (substantial part)

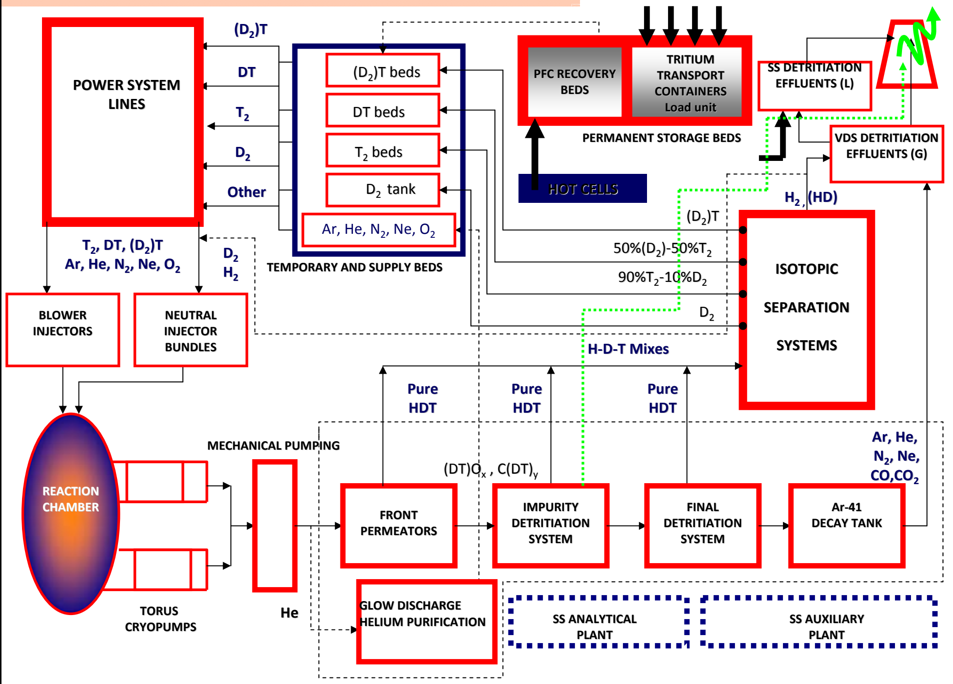
→ **MINIMUM PRODUCTION OF TRITIATED WASTES (particularly solids)**

- Environmental impact of ITER (substantial part related with tritiated wastes)

→ **Costs**

- *Complexity of system design* (at safety levels given) vs *tritium costs*

4. BASIC FUNCTIONS "of plant", GENERAL OUTLINE and MAIN UNITS (1)



5. Simulation of the **TRITIUM PLANT (PdT) IN ITER** (1)

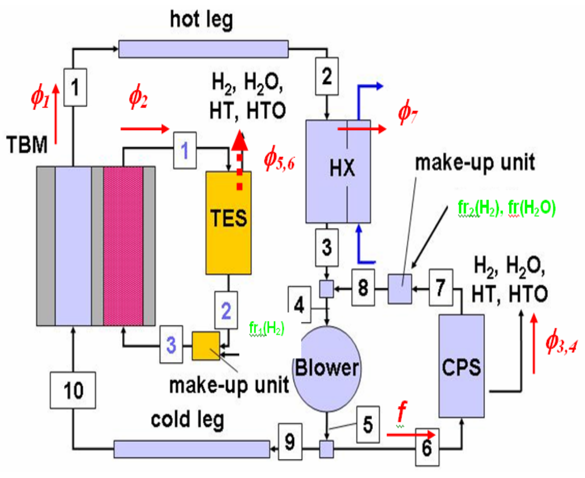
OUTLINE

- Modular structure
- Material modules: transport (permeation, diffusion) and surface (recombination-disassociation) processes
- Enclosure type modules: chemical and adsorption processes, flow between enclosures
- Current reference TMAP7. QA ITER. Reference in the tritium transport calculation

VERY IMPORTANT! TO SUCCEED IN COUPLING THE PHYSICS OF ALL THE PROCESSES TO CAPTURE THE TRANSIENT PHENOMENA

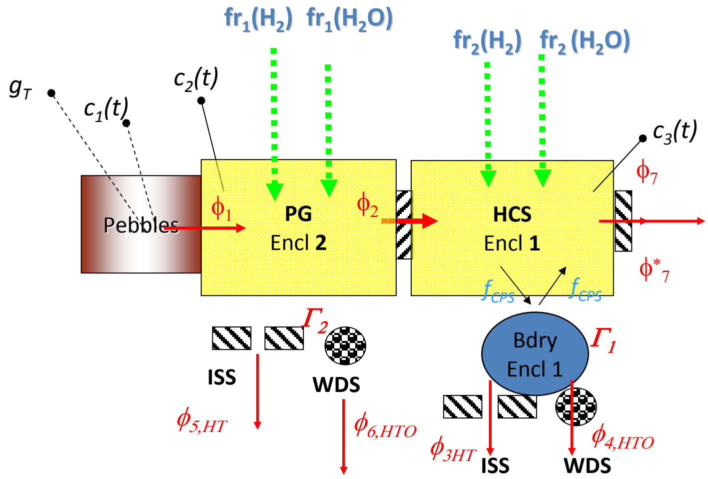
5. Simulation of the **TRITIUM PLANT (PdT) IN ITER** (1)

EXAMPLE OF MODULAR DIAGRAM



5. Simulation of the **TRITIUM PLANT (PdT) IN ITER** (1)

EXAMPLE OF MODULAR DIAGRAM



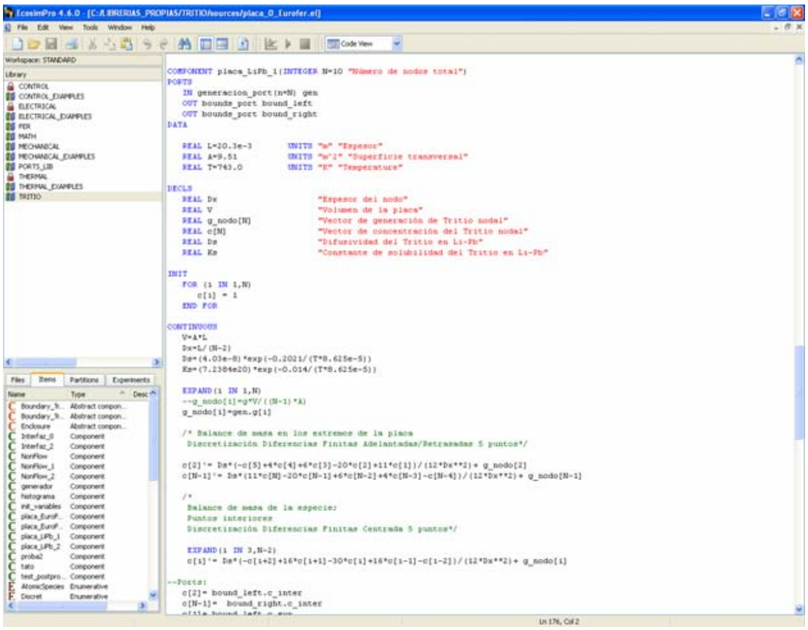
5. Simulation of the **TRITIUM PLANT (PdT) IN ITER** (1)

CURRENT SITUATION

```
ands.inp - Bloc de notas
Archivo  Edición  Formato  Ver  Ayuda
$
$ (7) Solubility of H in LiPb (m-3 Pa-1/2) [RomaTalk]
y=7.2384e20*exp(-0.014/8.625e-5/temp),end
$
$ (8) Solubility of H in EUROFER (m-3 Pa-1/2) [G.A. esteban
$et al. Journal of Nuclear Materials (2007) in press.]
y=1.355e22*exp(-0.157/8.625e-5/temp),end
$
$ (9) Recombination of H+H in EUROFER (m4 s-1)[Baskes Formula]   Left
y=(0.1*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))
+10000000000.0-0.1)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-1000.0)/10000000000.0))
+0.00001*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0)/10000000000.0)-INT((((conce(7)+conce(8)+conce(11))/
(conce(9)+conce(10)))+10000000000.0-0.1)/10000000000.0))+
INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0-1000.0)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-10000000000.0)/10000000000.0))
*10.115e-26*sqrt(temp)*exp(-0.554/8.625e-5/temp),end
$
$ (10) Recombination of T+T in EUROFER (m4 s-1)[Baskes Formula]  Left
y=(0.1*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))
+10000000000.0-0.1)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-1000.0)/10000000000.0))
+0.00001*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0)/10000000000.0)-INT((((conce(7)+conce(8)+conce(11))/
(conce(9)+conce(10)))+10000000000.0-0.1)/10000000000.0))+
INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0-1000.0)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-10000000000.0)/10000000000.0))
*5.845e-26*sqrt(temp)*exp(-0.554/8.625e-5/temp),end
$
$ (11) Recombination of H+T in EUROFER (m4 s-1)[Baskes Formula]   Left
y=(0.1*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))
+10000000000.0-0.1)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-1000.0)/10000000000.0))
+0.00001*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0)/10000000000.0)-INT((((conce(7)+conce(8)+conce(11))/
(conce(9)+conce(10)))+10000000000.0-0.1)/10000000000.0))+
INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0-1000.0)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-10000000000.0)/10000000000.0))
*7.157e-26*sqrt(temp)*exp(-0.554/8.625e-5/temp),end
$
$ (12) Generation and Extraction T
y=1.0*(INT((time+1770)/1800)-INT((time+1370)/1800)
+(time-1800*INT(time/1800))*(INT((time+1800)/1800)
-INT((time+1770)/1800))/30+(490-time+1800*INT(time/1800))
*(INT((time+1370)/1800)-INT((time+1310)/1800))/60),end
$
$ (13) False Diffusivity
y=4.36e-16,end
$
$ (14) Dissociation of H2 in EUROFER (m4 s-1)[Baskes Formula]    Left
y=(0.1*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))
+10000000000.0-0.1)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-1000.0)/10000000000.0))
+0.00001*(INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0)/10000000000.0)-INT((((conce(7)+conce(8)+conce(11))/
(conce(9)+conce(10)))+10000000000.0-0.1)/10000000000.0))+
INT((((conce(7)+conce(8)+conce(11))/(conce(9)+conce(10)))+
10000000000.0-1000.0)/10000000000.0)-INT((((conce(7)+conce(8)+
conce(11))/(conce(9)+conce(10)))+10000000000.0-10000000000.0)/10000000000.0))
```

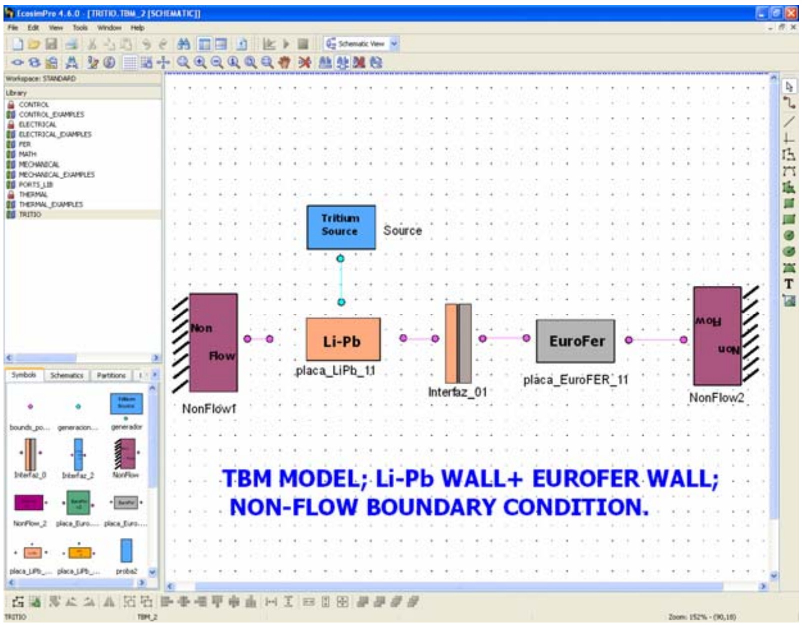
5. Simulation of the TRITIUM PLANT (PdT) IN ITER (1)

EcosimPro



5. Simulation of the TRITIUM PLANT (PdT) IN ITER (1)

EcosimPro



5. Simulation of the **TRITIUM PLANT (PdT) IN ITER** (1)

EcosimPro

5. Simulation of the **TRITIUM PLANT (PdT) IN ITER** (1)

ADVANTAGES of EcosimPro

- **Modular structure. Object-oriented, acausal language (EL)**
- **Library of modules common to all problems of interest**
- **CIEMAT: reference on tritium transport simulation in the TBM-European Consortium**
- **Need for a tritium transport code in ITER:**
  - For designing systems in the previous phase
  - To extrapolate results in the different ITER stages for the next experiments
  - To utilise results for future devices

PLACE A SPANISH CODE AS REFERENCE FOR A FUSION REACTOR!

THANK YOU VERY MUCH!